Out of the Darkroom and into the Dark:

The Experiences of Medical Imaging Technologists Regarding the Introduction and Ongoing Use of New Technology.

Joanna Thorogood

2021

A thesis submitted to Auckland University of Technology
in partial fulfilment of the requirements for the degree of

Doctor of Health Science

School of Clinical Sciences

Faculty of Health and Environmental Sciences

Abstract

Medical imaging is undergoing constant change, which has accelerated with the advent of digital imaging technology. Commonly cited benefits of digital systems include: reduced repeat examinations, image manipulation, and image transmission to multiple locations. However, there are concerns that Medical Imaging Technologists' (MITs) knowledge of this technology is questionable and that MITs are becoming deskilled, due to over reliance on the equipment. Despite this, there seems to be limited research on the impact the introduction of digital technology has had on MITs.

This study used a sequential exploratory mixed methods research design to consider how the introduction and ongoing use of digital imaging technology has affected MITs in Aotearoa NZ. Phase One drew on Interpretive Description and used semi-structured interviews to explore MITs' personal experiences of the introduction and ongoing use of digital technology, and its perceived impact on practice. The interview findings were used in the development of a survey for Phase Two. Phase Two used a cross-sectional survey to describe and identify factors influencing MITs' knowledge and understanding of digital imaging and its application, as well as their perceived competence in using digital technology.

The overarching finding was that the introduction of digital imaging had created a major shift in MIT clinical practice, principally due to the significance of the transition being underestimated, which influenced the educative processes adopted. In turn, this led to a theory-practice gap. Despite the cited benefits of digital imaging technology, some of the underlying complexities and tensions that exist within medical imaging practice, were exacerbated through its introduction. For example: decision making around repeat imaging and whether an increased patient dose outweighs any potential risk to the patient; the limited time MITs have to build rapport with patients; and high occupational stress in MITs. Ultimately these appeared to contribute to a potentially negative impact on quality care provision.

Contents

Abstract ... i
List of Figures ... vi
List of Tables ... vii
List of Appendices ... viii
List of Abbreviations ... ix
Attestation of Authorship ... x
Acknowledgements ... xi
Ethics Approval ... xiii
Chapter 1 Introduction ... 1
1.1 Introduction ... 1
1.2 Background to the study ... 1
1.3 NZ legislative and regulatory requirements ... 4
1.4 My position within the research ... 6
1.5 Research aim, questions, and methodological approach ... 8
1.6 Thesis structure ... 11
1.7 Summary ... 12
Chapter 2 Literature Review ... 13
2.1 Introduction ... 13
2.2 Search process ... 13
2.3 Medical imaging as a profession ... 14
2.3.1 Historical influences ... 14
2.3.2 Medical imaging education ... 18
2.3.3 Evidence-based practice ... 20
2.3.4 Medical imaging culture ... 23
2.4 Medical imaging clinical practice ... 26
2.4.1 Image quality and radiation dose ... 26
2.5 The impact of digital technology ... 33
2.5.1 Change theory ... 37
2.6 Budgetary constraints ... 39
2.7 Summary ... 41
Chapter 3 Research Methodology ... 43
3.1 Introduction ... 43
3.2 Research paradigms ... 43
3.2.1 Pragmatism ... 44
3.3 My worldview ... 47
3.4 Determining the research paradigm and methodology ... 50
3.5 Mixed methods research ... 52

3.6 Interpretive Description 56
3.7 The link between Interpretive Description and pragmatism 58
3.8 Cross-Sectional surveys and pragmatism 60
3.9 Summary 61
Chapter 4 Method 62
4.1 Introduction 62
4.1.1 Research questions for each phase 62
4.2 Participants 63
4.2.1 Phase One 63
4.2.2 Phase Two 64
4.2.3 Sampling 64
4.2.4 Recruitment 67
4.3 Phase One: Data collection 68
4.4 Phase One: Data analysis 70
4.5 Trustworthiness in qualitative research 74
4.5.1 Epistemological integrity 74
4.5.2 Representative credibility 75
4.5.3 Analytic logic 75
4.5.4 Interpretive authority 75
4.6 Phase Two: Data collection 76
4.6.1 Self-perceived competency 76
4.6.2 Knowledge and understanding 78
4.7 Survey development 78
4.8 Data checks 85
4.8.1 Logic checks 85
4.8.2 Assumptions of normality 86
4.8.3 Validity 89
4.8.4 Correlation 90
4.9 Regression modelling 90
4.10 Phase Two: Data analysis 92
4.11 Reliability and validity in quantitative research 93
4.12 Rigour and validity in mixed methods research designs 94
4.13 Ethical considerations 96
4.14 Summary 97
Chapter 5 Phase One Interview Findings 98
5.1 Introduction 98
5.2 A shift in practice 98
5.2.1 Speed of introduction 99
5.2.2 Task driven training 103
5.2.3 Lost In translation 108
5.2.4 Changes to support and autonomy 110

5.3 Unintended consequences 114
5.3.1 The effects of increased imaging speed 115
5.3.2 A safer, cleaner process 122
5.3.3 Balancing radiation dose 125
5.4 Summary 136
Chapter 6 Phase One Discussion 138
6.1 Introduction 138
6.1.1 The transition was underestimated 138
6.1.2 The shift in MI practice 146
6.1.3 The health and safety balancing act 149
6.2 Summary 155
Chapter 7 Phase Two Quantitative findings. 156
7.1 Introduction 156
7.2 Sample characteristics 156
7.2.1 Demographics 156
7.2.2 Education 156
7.2.3 Work context 156
7.2.4 Training 163
7.3 Bivariate and multivariate analyses 165
7.3.1 Multiple-choice questions: Knowledge and understanding 165
7.3.2 Perceived competencies 171
7.4 Linear regression modelling 178
7.4.1 Total MCQ 178
7.4.2 Total competency 181
7.5 Summary 185
Chapter 8 Phase Two Discussion 187
8.1 Introduction 187
8.2 Research Question 1: What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application? 189
8.2.1 In relation to clinical practice: Do MITs understand how digital systems respond to different levels of radiation exposure? 192
8.2.2 In relation to clinical practice: Do MITs understand how different functionalities of the equipment influence best practice? 194
8.2.3 In relation to clinical practice: Do MITs understand whether their practice is meeting the ALARA principle? 196
8.3 Research Question 2: What factors are related to MITs' knowledge of and perceived competence in the use of digital technology? 200
8.3.1 What factors are related to MITs' knowledge and understanding of the practical application of digital technology? 200
8.3.2 What factors are related NZ MITs' perceived competence using digital technology? 203
8.4 Summary 207

Chapter 9 Synthesised Discussion and Conclusion 210
9.1 Introduction 210
9.2 Patient centred care 211
9.3 Quality care 213
9.3.1 The theory-practice gap 214
9.3.2 Increased radiation dose 221
9.3.3 Communication 223
9.4 Professional identity 226
9.5 Strengths and limitations of the study 228
9.5.1 Limitations 228
9.5.2 Strengths 232
9.5.3 Implications for clinical practice 233
9.5.4 Implications for education 234
9.5.5 Implications for research 234
9.6 Conclusion 235
References 237
Glossary 287
Appendices 288

List of Figures

Figure 1 Comparison of different image capture techniques.. 7

Figure 2 Flowchart of mixed methods exploratory sequential design 55

Figure 3 Mind map illustrating potential candidate themes and subthemes 72

Figure 4 Outline of the key stages of the survey development..................................... 79

Figure 5 Flowchart demonstrating the basic stages of image production for F-S, CR and FPDR systems 117

Figure 6 Frequency of weekly activities... 160

Figure 7 Causes of excess radiation exposure 163

Figure 8 Training received for CR and FPDR 164

Figure 9 Responses to EI error MCQ F6 167

Figure 10 Scores received for MCQs.. 167

List of Tables

Table 1 Competency subdomains and related competency statements 77

Table 2 Survey questions relating to MIT knowledge, understanding and perceived competency of digital imaging technology 83

Table 3 Key variables collected in the survey 84

Table 4 Data distribution 88

Table 5 Cronbach Alpha score 89

Table 6 Regression model dependent variables 91

Table 7 GRAMMS criteria for assessing rigour in mixed methods research 95

Table 8 Validity threats in Sequential Exploratory Designs 96

Table 9 Sample characteristics 158

Table 10 Proportion of time per week on QC activities at work station monitor 161

Table 11 Types of education and training 164

Table 12 Number of training hours 165

Table 13 MCQ and number (%) of correct answers by MITs 166

Table 14 Mean MCQ scores achieved: Comparison between groups with different: years since qualification; employer; and age 169

Table 15 Mean MCQ scores MITs achieved: Comparison between groups with different education experiences and employment status 170

Table 16 The level of MIT competencies: Comparison between groups with different age ranges 174

Table 17 The level of MIT competencies: Comparison between genders 175

Table 18 The level of MIT competencies: Comparison between groups with different number of FPDR training hours 176

Table 19 The level of MIT competencies: Comparison between groups with different AED use per week 177

Table 20 Results of linear regression analysis for detecting independent determinants of knowledge score of MITs 180

Table 21 Results of linear regression analysis for detecting independent determinants of MITs self-ranked competencies 183

List of Appendices

Appendix A: Phase One flyer and information sheet....288
Appendix B: Phase Two flyer....293
Appendix C: Phase One consent form....294
Appendix D: Phase One indicative interview questions....296
Appendix E: Phase One transcriptionist confidentiality agreement....297
Appendix F: Interview memo excerpt: Potential candidate themes....298
Appendix G: Initial interview coding excerpt....302
Appendix H: Final interview themes....305
Appendix I: Survey feedback rubric....306
Appendix J: Phase Two survey....308
Appendix K: Dependent and independent variables used in Linear Regression model....322
Appendix L: Ethics approval Phases One and Two....329
Appendix M: Phase One counselling support....331
Appendix N: Phase Two supplementary results tables....332

List of Abbreviations

AED	Automatic Exposure Device
ALARA	As Low As Reasonably Achievable
APC	Annual Practising Certificate
APR	Anatomical Programmed Radiography
CNR	Contrast to Noise Ratio
CPD	Continuing Professional Development
CR	Computed Radiography
CT	Computerised Tomography
DHB	District Health Board
DI	Deviation Index
DQE	Detective Quantum Efficiency
DR	Digital Radiography
EBP	Evidence-Based Practice
EI	Exposure Index/Indicator
EIT	Target Exposure Index/Indicator
FPDR	Flat Panel Digital Radiography
F-S	Film-Screen
HPCAA	Health Practitioners Competence Assurance Act (2003)
IAEA	International Atomic Energy Agency
ICRP	International Commission for Radiation Protection
IT	Information Technology
kV	Kilovoltage
mAs	Milliamperes per second
MIT	Medical Imaging Technologist
MoH	Ministry of Health
MRI	Magnetic Resonance Imaging
NZ	New Zealand
NZIMRT	New Zealand Institute of Medical Radiation Technologists
NZMRTB	New Zealand Medical Radiation Technologists Board
PACS	Picture Archiving and Communication Systems
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

J. Thorogood
Signature

2nd December 2021
Date

Acknowledgements

As many researchers have identified previously, the doctoral journey is one that frequently starts as a solo journey, but it is one that cannot be achieved or completed without the support of many individuals. I would like to acknowledge and thank everyone who has walked alongside me, held my hand, or held me up, as I have walked this path.

To my supervisory team – Associate Professor Deborah Payne, Professor Nicola Kayes and Dr Priya Parmar, thank you for your insight, sage advice, words of wisdom, encouragement, and humour. Your unwavering support guided me from the very start of this process. I feel very privileged to have had you as my mentors.

Thank you to all my participants who gave up their time, either to participate in my interviews or to complete my survey. Your honesty and openness shone through in our conversations and in your survey responses. Your experiences supported the need for this study and revealed the impact digital imaging has had on MIT clinical practice. This study would not have been possible without you.

I would like to thank all my friends and colleagues who so patiently listened to me attempting to articulate my thoughts at various stages of this process. You questioned and challenged me, and in so doing helped me consolidate and refine my ideas.

To my family – thank you for believing in me when I did not. Your encouragement and support sustained me in more ways than you can imagine.

Editing and proofreading:

I acknowledge and thank S. & A. Knox who proofread and formatted my thesis. Neither of them have any academic or professional experience related to my research topic.

Their review process checked:

- for the presence of grammatical and typographical errors
- any punctuation mistakes i.e. missed or misplaced full stops, semicolons, or commas
- the formatting of tables, figures, and cross-references.

This thesis is dedicated to my children, Sarah and Adam:

"Education is the movement from darkness to light" (Allan Bloom).

Ethics Approval

Ethical approval was obtained from:

- Auckland University of Technology Ethics Committee – 3rd May 2016, 16/102 (Phase One)
- Auckland University of Technology Ethics Committee – 28th November 2018, 16/102 (Phase Two)

Chapter 1 Introduction

1.1 Introduction

This thesis presents an exploratory sequential mixed methods study exploring how the introduction of digital technology and its ongoing use in planar radiography[1], has impacted on Medical Imaging Technologists (MITs) and their clinical practice. An MIT is responsible for producing high-quality diagnostic images with the minimum radiation dose to the patient (The New Zealand Medical Radiation Technologists Board, 2018). These images are used to assist in the diagnosis of injury or disease. Radiographic images are essentially a series of differing intensity values governed by physical tissue characteristics, which can be affected by physiological or pathological changes (Toennies, 2017). While there has been research on digital imaging technology, this has primarily focused on its benefits and drawbacks. Benefits identified have included increased speed, efficiency, and reduced patient radiation dose due to reduced repeat imaging (Mettler et al., 2003; Moore, 2016; Wani et al., 2019). Cited disadvantages have included the risk of increased patient radiation dose which may be associated with a lack of MIT knowledge (A. K. Jones, Heintz, et al., 2015). To date, there do not seem to have been any studies exploring how MITs experienced the introduction of this technology. Furthermore, no studies have investigated the introduction of digital technology within the New Zealand (NZ) MIT population. It is envisaged that the findings from this study may have the potential to influence how future technological innovations are introduced within the medical imaging environment.

This chapter will outline: the background to the study; the legislative and regulatory requirements for MITs working in New Zealand; and the research focus. My position within the context of the research will also be discussed.

1.2 Background to the study

The use of diagnostic imaging procedures has risen rapidly since the 1970s and is partially attributed to the introduction of Computerised Tomography (CT) and digital imaging modalities. In 2008, it was estimated that 3.6 billion diagnostic x-ray

[1] Planar (or plain film imaging) utilises x-rays to pass through a patient onto to a detector, to produce a 2-dimensional representation of the patient's anatomy.

examinations were undertaken annually across the globe, reflecting an increase of approximately 50% since 1996 (The United Nations Scientific Committee on the Effects of Atomic Radiation, 2010). The medical use of radiation is now the second largest contributor to the total population radiation dose globally (The United Nations Scientific Committee on the Effects of Atomic Radiation). While much of this may be due to increased use of high dose techniques such as CT, all radiation exposure from medical imaging needs to be controlled, monitored and regularly reviewed due to its potentially harmful effects (Uniyal et al., 2017).

Medical imaging has undergone consistent change following Roentgen's initial discovery of x-rays in 1895. These changes have accelerated with the advent of CT, magnetic resonance imaging (MRI), interventional radiology and dual modality (hybrid) scanning such as positron emission tomography (PET) with CT. This has had a significant impact on the way disease is diagnosed (Margulis & Sunshine, 2000) not only through specialised imaging modalities but also with the introduction of digital imaging in general or planar (two-dimensional) imaging. Planar digital imaging began in the 1980's and was a major change, given that for the previous one hundred years, images had been produced using the interaction of x-ray photons emitted from a patient onto a photographic plate or film-screen (F-S) cassette (Fridell, 2011). Although plate technology had changed in the interim from handmade glass plates to factory made cassettes (Haus & Cullinan, 1989; Schaetzing, 2005), the creation of the final image still relied on a piece of film being developed through a photographic process to visualise the latent (invisible) image. Namely, the film underwent a three-staged cycle of development, fixing and drying. At the end of this process, the films' appearance enabled MITs to determine whether the correct exposure factors had been selected (Campbell et al., 2019). In digital imaging, the latent image is created as a set of digital data and processed for viewing through the use of computer algorithms (Fauber, 2016). In 2007, Vano described the introduction of digital imaging as potentially representing "the greatest technological advance in medical imaging over the last decade" (Vano, 2007, p. 4216).

Current digital imaging systems include direct/indirect flat panel digital radiography (FPDR) and computed radiography (CR). CR systems were frequently the first systems to be deployed in medical imaging departments, predominantly due to cost considerations and the minimal changes required to existing F-S systems (Rivetti et al., 2010). For example, an FPDR installation process may require an imaging room to be out of operation for two weeks and can cost anything from US $200,000 -$450,000 (Loria, 2017). Nevertheless, as equipment is being scheduled for replacement, CR systems are being phased out in preference for FPDR systems. Major considerations for the replacement process are that FPDR systems are more efficient, faster and require less radiation dose to the patient than CR systems (Loria, 2017). Commonly cited benefits of digital systems include: the wide exposure latitude[2] (limiting the need for repeat examinations from inaccurate exposure choices), time savings, image manipulation and image transmission to multiple locations via Picture Archiving and Communication Systems (PACS)[3] (Andria et al., 2016).

Nevertheless, apart from the cost implications, significant drawbacks have been highlighted. In 2007, these were documented to include concerns about a lack of knowledge and understanding of electronic soft copy displays of radiographic images for both MITs and radiologists (Vano, 2007). The "lack of consistent feedback to technologists concerning the use of optimal acquisition techniques" plus the wider exposure latitude, may lead to an increase in patient radiation dose (Williams et al., 2007, p.374). The risk of patient overexposure was also highlighted by Vano (2007):

> While digital techniques have the potential to reduce patient doses, they also have the potential to significantly increase them. Experience has shown that as many radiology departments have transitioned to digital equipment, patient doses have not reduced but have increased measurably. If careful attention is not paid to the radiation protection issues of digital radiology, patient doses will increase significantly and without concurrent benefit (p. 4216).

While it could be argued that 14 years on, this should no longer be a cause for concern, issues highlighted in 2007 remain problematic (Alsleem et al., 2019; Seeram et al., 2015). The issue of "exposure creep", defined as unintended over exposure of the patient to radiation (Mothiram et al., 2014) has been well documented in the literature. More recent studies have highlighted that exposure creep continues to be a

[2] The exposure latitude is the measure of the range of exposures that may be recorded as a series of usefully distinguishable densities on a receptor. The wider the latitude, the greater the range of object densities visualised.
[3] Defined as a computer system designed for digital imaging that can receive, store, distribute and display digital images.

concern associated with digital imaging practice (Dalah, 2020; Hayre, 2016; S. Lewis et al., 2019a; McFadden et al., 2018). “Collimation creep”, due to MITs irradiating larger areas of patient tissue than necessary, has also been identified as a concern following the introduction of FPDR (Alsleem et al., 2019; Eaton, 2018). Despite the number of studies which highlight and discuss the benefits and drawbacks of digital imaging systems, the impact of this technology on medical imaging practice from the MIT perspective does not seem to have been explored.

1.3 NZ legislative and regulatory requirements

In New Zealand, the use of radiological equipment is governed by The Radiation Safety Act (2016), which replaced The Radiation Protection Act 1965 and the Radiation Protection Regulations 1982 (Radiation Safety Act 2016). The Act applies to any irradiating equipment and clearly defines the need to comply with “fundamental requirements”, which include protecting people from the adverse effects of radiation (Radiation Safety Act 2016, s. 1). According to the Ministry of Health (2018) an MIT is a “health practitioner with specialist education and training in medical radiation technology who is competent to perform radiological procedures on delegation from a radiation practitioner” (p. 2). Competency includes ensuring patient radiation dose is “as low as reasonably achievable, taking into account economic, social and environmental factors” (Radiation Safety Act 2016, s. 1). This is known as the ALARA principle and falls within the radiation protection tenet of optimisation, an internationally adopted concept (International Commission on Radiological Protection, 2007). Optimisation is defined by the International Atomic Energy Agency (IAEA) as the production of a diagnostic patient outcome, using the lowest radiation dose possible (International Atomic Energy Agency, 2015). Aspects of clinical practice which influence radiation dose relate to equipment design and the protocols adopted within the imaging department (Seeram et al., 2013). The use of an appropriate quality assurance process is one way in which equipment functionality and department protocols may be evaluated, maintained or improved (Valentin, 2004). The employer is responsible for the introduction and ongoing audit of quality assurance processes (Ministry of Health, 2018), while the operator influences patient dose when selecting the projection and its associated technical parameters (Valentin, 2004). As such, optimisation is governed by equipment manufacturers, the employer, and the equipment operator.

MITs are also expected to adhere to the two other key principles of radiation protection i.e. justification and dose limitation. Justification incorporates the ethical principle of beneficence, in that irradiating an individual is only justifiable if there is a benefit to that individual, through diagnosis or treatment planning, or there are significant benefits to the population through health screening, or for research purposes (International Atomic Energy Agency, 2009). Justification requires MITs to determine whether the benefits of a radiation exposure outweigh any potential risks to the patient. This is achieved through evaluating the information on the imaging request form and the patients' clinical indications, prior to exposure (Vom & Williams, 2017). Dose limits are used in relation to the public or the occupational exposure of workers, not patients (Streffer, 2007) and therefore will not be considered further within my thesis, as I am not exploring how digital technology has influenced radiation exposure to these two groups. In summary, patient radiation protection is encapsulated through justification - the benefit should outweigh the risk in every exposure; and optimisation - the exposure must be as low as reasonably achievable while maintaining image quality (Seeram et al., 2013).

Overall, MITs are expected to have high levels of knowledge related to justification, optimisation, and the practical aspects of minimising patient dose, including awareness of typical doses from diagnostic imaging procedures (Ministry of Health, 2018). A high level of knowledge is defined as "detailed knowledge and understanding sufficient to be able to educate others" (Ministry of Health, 2018, p. 33). Education and competence standards for NZ MITs are set by the New Zealand Medical Radiation Technologists Board (NZMRTB). The MIT regulatory body was established under the Health Practitioners Competence Assurance Act 2003. Under the Act, the NZMRTB has a duty to protect the public by ensuring MITs are competent and fit to practise, and is supported through the setting of competence standards (New Zealand Medical Radiation Technologists Board, 2018). The competence standards outline the minimum level of knowledge, skills and professional qualities required to practise in NZ. They are designed to be used by multiple users, including the public; education and continuing professional development (CPD) providers; and practitioners (in preparation for registration or practising certificate renewal). MIT practitioners are expected to utilise the standards, and self-reflection, to determine individual learning needs to maintain the required competencies for their scope of practice (New Zealand Medical Radiation Technologists Board). Moreover, the NZMRTB stipulates the practitioner is required to keep a verifiable record which logs their CPD hours, activities and learnings (The New Zealand Medical Radiation Technologists Board, n.d.-a). In each year, 20% of practitioner CPD records are audited by the Board (The New Zealand Medical Radiation Technologists Board, n.d.-b).

It is therefore clear that there are both legislative and regulatory requirements for MITs to ensure their knowledge is up to date and that they have the necessary knowledge and skills to practise safely.

1.4 My position within the research

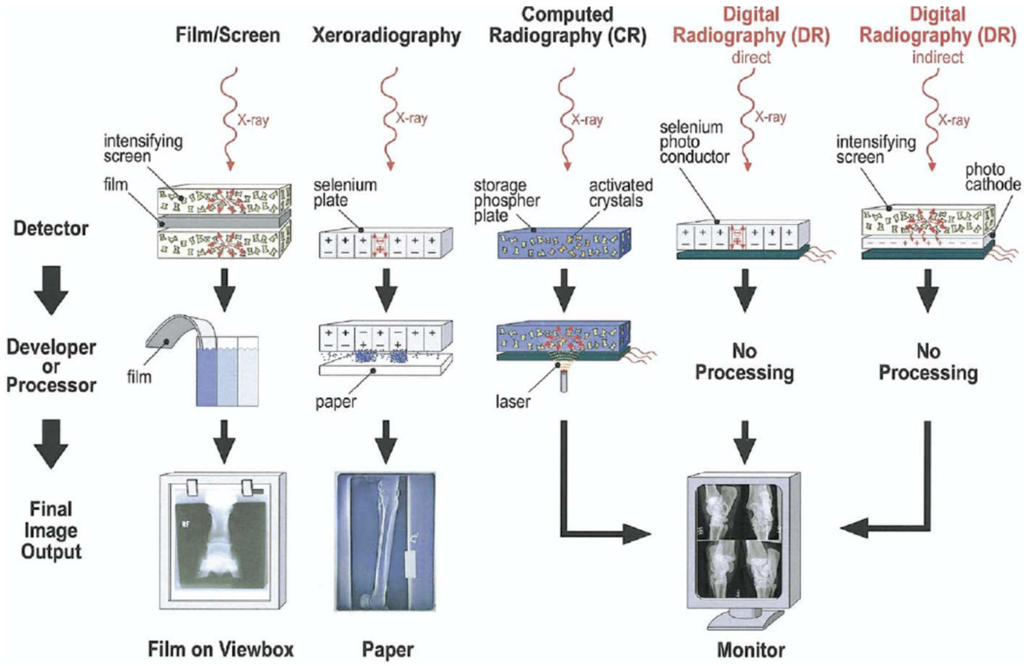
I qualified as a medical imaging practitioner in the United Kingdom (UK). I have many years of clinical experience and for the last 18 years my work has been in medical imaging education. This has given me professional disciplinary knowledge and insight which I have been able to bring to this study. I have also personally experienced the introduction of digital technology. During my clinical practice, change was experienced and evident through the evolution of the technology. For example, in my early career, MRI was a concept rather than a reality. Initially it had been predicted that MRI would only be useful for imaging the brain and the spinal cord. There was no suggestion in the early 1980's MRI would prove useful for soft tissue imaging. But today it is used to diagnose disease or injury in a number of areas such as the cardiac, breast, abdominal and musculoskeletal systems (Rao et al., 2015).

In terms of image production, I have experienced a move from wet developing[4] in the late 1970s to the introduction of FPDR in 2007. My experiences of different image capture techniques are exemplified in Figure 1 below. This illustrates the number of changes I have experienced within one area of medical imaging practice i.e. planar radiography.

[4] A manual process requiring the operator to submerge the film into chemical baths. Taking approximately 1 hour to produce a dry image ready for review (Bushong, 2017).

Figure 1

Comparison of different image capture techniques



(McKnight, 2004, p. 353)

As a clinical practitioner, the level of education I received when transitioning from F-S (or analogue imaging) to CR was minimal. While fewer repeat images were required (due to incorrect exposure factor choice) initially I was repeating images, as were my colleagues, due to key content missed in the training sessions. I also found I was using increased milliampere-seconds (mAs) levels, compared to F-S systems, to produce diagnostic images, potentially resulting in increased patient radiation dose. I voiced my concerns to the senior staff. The response was yes, higher mAs values were now necessary, but as doses were lower than national recommended dose reference levels[5] (DRLs) I should not be concerned. I had trained as a Radiation Protection Supervisor in a previous workplace and had lectured on radiation protection and quality assurance. I therefore found the response to my concerns to be both unsatisfactory and disconcerting. Shortly afterwards I started work as a medical imaging lecturer. Studying theories of learning and teaching made me aware that the training I received when

[5]The establishment of diagnostic reference levels are used as a tool for optimising the radiation dose delivered to patients during diagnostic and/or therapeutic procedures. The Medical Exposure Directive (1999) defines DRLs as: *"dose levels in medical radiodiagnostic practices or, in the case of radio-pharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied*."
Retrieved 1st April 2019, from: https://ec.europa.eu/energy/sites/ener/files/documents/109_en.pdf

transitioning to digital imaging did not reflect these. I was subsequently offered a senior lecturer role in New Zealand and emigrated.

Over time, as more research was published related to the use of digital technology and in particular, concerns about the way MITs were using it, I wondered why this might be. Furthermore, while issues had been brought to the fore, there seemed to be little discussion about potential causes and solutions. I was concerned about the potential impact the introduction of digital technology had on the quality of patient care. Additionally, it seemed to me the MIT voices and their experiences and perspectives were missing from the literature. It was from these ideas that my research design evolved.

While I recognised my experiences in the UK were subjective and socially constructed and therefore may not reflect the NZ context of medical imaging practice, I was aware there was a risk my personal views would have undue influence in the study. Therefore, it was vital for me to focus on the experiences of my participants and the information they provided during the research process. To aid me, I used a reflective journal throughout to illuminate my preconceptions and consider how my professional, background and personal assumptions might influence each stage. Discussion with colleagues and presentation of my initial findings at an Auckland MIT study day also supported my reflexivity and aligns with Gough's recommendations in demonstrating personal reflexivity (Gough, 2003).

1.5 Research aim, questions, and methodological approach

As indicated above, I wanted to uncover how NZ MITs had experienced the transition to digital imaging technology. Moreover, I was interested in exploring their knowledge of the digital imaging systems they used.

The overall aim of this thesis was to answer the following research question: **"How has the introduction and ongoing use of digital imaging technology affected MITs in Aotearoa NZ?"** To gain an in-depth understanding of this topic, the aim was subdivided, to:

1. Explore MITs' personal experiences of the introduction and ongoing use of digital technology, and its perceived impact on practice.

2. Describe and identify factors relating to MITs' knowledge and understanding of digital imaging and its application, as well as their perceived competence in using digital technology.

A mixed methods approach was selected to allow me to explore MITs' perceptions, and investigate factors influencing their clinical practice. A single research approach would not have provided sufficient opportunity to explore both areas. The research objectives were met through different research questions and determined the use of a sequential exploratory mixed methods design (described and justified in detail in Chapter 3). For the first, qualitative phase of this study, the guiding research question was:

"What are the experiences and perceptions of MITs regarding the introduction and ongoing use of digital imaging technology?"

This was facilitated through interviewing ten MITs using a semi-structured interview approach. The following indicative questions were used, with additional prompts to further explore the responses:

1. Could you tell me about the first time you worked with digital imaging equipment?
2. Can you tell me about your experience of ongoing use of this technology in your practice?
3. How do you think your practice has changed as a result of using this technology?
4. From your perspective, what are the benefits/challenges of utilising this equipment?
5. From your experience, what knowledge/professional development opportunities are needed to ensure safe and effective use of digital technology in your practice environment?
6. How do you currently manage your continuing professional development in this area of practice?

Interpretive Description was used to analyse the data and create themes and subthemes. These supported the creation of a survey for the second quantitative phase of the study. In this phase, forty nine MITs were surveyed to answer the following research questions:

1. **"What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application?"**
2. **"What factors are related MITs' knowledge of and perceived competence in the use of digital technology?"**

To address these research questions, they were broken down into more specific objectives as follows:

1. In relation to clinical practice, do MITs understand:

    a) how digital systems respond to different levels of radiation exposure?
    b) how different functionalities of the equipment influence best practice?
    c) whether their practice is meeting the ALARA principle?

2. What factors are related to MITs' knowledge and understanding of the practical application of digital technology? It was hypothesised that:

    a) MITs who learnt about FPDR or CR in their undergraduate programme would demonstrate higher levels of digital technology knowledge
    b) MITs who had received training in FPDR or CR technologies would demonstrate higher levels of digital technology knowledge
    c) MITs who spend more time using FPDR or CR equipment on a weekly basis would demonstrate higher levels of digital technology knowledge.

3. What factors are related NZ MITs' perceived competence using digital technology? The aim was to describe MITs' self-perceived competencies in the use of digital technology, and identify whether sociodemographic characteristics or context specific factors were associated with feelings of competency.

This was assessed using a self-ranked competency scale relating to MIT clinical practice and utilisation of digital technology. A competency scale was selected as it reflects an individual's self-rated feelings of ability and is linked to feelings of self-confidence (Takase et al., 2015).

1.6 Thesis structure

The thesis is comprised of nine chapters. This chapter has introduced the thesis, and has outlined its background and the research question. My personal context within the research has been disclosed.

Chapter 2 presents a review of the current research on the introduction and use of digital technology in medical imaging practice. Current gaps in the literature which support the aims of this study are identified.

Chapter 3 introduces the research methodology used to answer my research question. The mixed methods approach is outlined and a rationale provided for the choices made, based on the research aims and the stance of the researcher.

Chapter 4 covers the methods undertaken in both phases of the research. It includes: participant sampling and recruitment; survey design; data collection and analysis procedures; how rigour, credibility and trustworthiness were maintained; and the ethical considerations employed.

Chapter 5 introduces the findings from Phase One of the study, namely the themes and subthemes identified through Interpretive Description of the interview data.

Chapter 6 discusses the main findings from Phase One with reference back to existing literature and the research questions.

Chapter 7 presents the findings from Phase Two of the survey. The results from the statistical analysis of the survey data, include sample characteristics; bivariate and multivariate analyses; and regression modelling.

Chapter 8 considers the main findings from the descriptive and inferential statistical analyses undertaken in Phase Two, discussed in the context of published literature.

Chapter 9 merges findings from both phases, identifies key overarching findings and discusses the key contribution to knowledge. Recommendations for clinical practice, education and future research based on the research findings are discussed, as well the strengths and limitations of each component.

1.7 Summary

This chapter has provided the background to my research. It has introduced the overarching research aim, questions and methodology used. I have shared my position and starting point for this research. Finally, an outline of the thesis structure has been provided.

In the following chapter, I expand on the background to the study through a critical literature review.

Chapter 2 Literature Review

2.1 Introduction

In this chapter, I provide a review of the published literature relating to the introduction and use of digital technology in medical imaging practice. I also briefly introduce key historical turning points in the emergence of the profession, and discuss key technical aspects pertinent to the medical imaging practice.

Several objectives were achieved through undertaking a critical literature review. It enabled me to appraise the existing literature, deepening my understanding of the topic. This helped me to identify existing themes plus potential gaps in the research and supported the development of my research question, aims and objectives.

2.2 Search process

Prior to undertaking the literature search, I used the SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type) search tool to highlight the key elements of my research question and help support an effective and efficient search process. The SPIDER tool has been developed from the PICO (Population, Intervention, Comparison, Outcome) tool, and is considered a beneficial search strategy tool for qualitative and mixed-methods studies (Cooke et al., 2012).

My initial literature search used databases located in the Medical Imaging Subject Guide on the Unitec library website. These were EBSCOhost; Informit; ProQuest; ScienceDirect; and Scopus. I searched the databases using key words or phrases which included but were not limited to: ‘competence’; ‘computed radiography’; ‘diagnostic radiography’; ‘digital technology’; ‘dose creep’; ‘education’; ‘evidence-based practice’; ‘exposure creep’; ‘flat panel digital radiography’; ‘healthcare’; ‘image quality’; ‘knowledge’; ‘medical imaging’; ‘patient safety’; ‘quality assurance’; ‘radiation protection’; ‘technology’; ‘training’. Abbreviated terms such as ‘radiograph*’ and ‘radiol*’ were used to produce articles related to radiographers, radiography, radiology, and radiologists.

The terms were searched for in the articles’ title, abstract or keywords. The sensitivity and specificity of my search process was enhanced using Boolean operators such as

‘AND’, ‘OR’, and ‘NOT’, as they allowed me to broaden or narrow the search as required (Bettany-Saltikov, 2016).

Papers were included if they were full text peer-reviewed journal articles, published from 1995 and written in English. A large number of articles which met these inclusion criteria were produced, and reading these enabled me to establish and filter out those not directly related to my research question. As part of the critical review process, papers relevant to my research question were analysed from different perspectives (Bolderston, 2008). Factors I considered included: the methodologies employed; the aim and objectives of the article and whether these were met; congruency between the methods, results, and discussion sections; key findings, strengths, and limitations; plus, any evidence of contentious issues. These were mapped out in a review matrix, enabling me to organise the literature into common themes while providing additional insight into this area of research.

The literature search process was supported and strengthened through review of the in-text citations, references, and citation lists. Results were reviewed and organised through using key headings such as “challenges” and “introduction” and “healthcare”. As my study progressed, I updated my search terms to encompass new knowledge of the subject matter. These included: ‘collimation creep’; ‘information technology’; ‘automation’; I also established an auto alert process to capture new literature as became available.

The critical literature review indicated several factors which may be influential during the transition to and ongoing use of digital technology. These were: medical imaging as a profession; medical imaging practice; the impact of digital technology; and budgetary constraints.

2.3 Medical imaging as a profession

2.3.1 Historical influences

Decker & Iphofen (2005) commented that in the United Kingdom, knowledge associated with the development of radiography as a profession has been dominated by evidence from other professions, such as physics and radiology, rather than its own. This may be due to it not being a specialist area in its own right initially. For example, historically there were various groups who took an interest in x-rays, such as doctors, photographers, pharmacists, and electrical engineers. Decker & Iphofen asserted the patriarchal dominance of the medical profession and the reductionism of radiography to a "technical skill contributed to the 'master–servant' relationship of radiology and radiography" (p. 264). This was evident in 1896, when the "science of radiology" separated from the physical processes required to produce images, thereby distinguishing the role of the medical profession from the technicians who were responsible for image production. Furthermore, the focus on technology (rather than the patient) within medical imaging has been attributed to: a) the hierarchical nature of radiography and b) the power differential between radiologists and MITs (Ferris, 2005)

It could be suggested the subordination of radiography in Britain was inevitable following the passing of the Medical Act 1858, thirty-seven years prior to the discovery of x-rays (as cited by Larkin, 1978). The Medical Act, designed to regulate qualifications of medical and surgical practitioners, allowed the medical profession to effectively "monitor and inhibit the development of autonomous and private practice and was able to ensure that advances in medical knowledge and technique did not create further para-medical occupations, which… could challenge an existing role and authority structure" (Larkin, 1978, p. 846).

In the 1920's the technicians sought legal status by applying to the Board of Trade. Their application was sent to other interested parties including the General Medical Council (GMC). Concerns were raised by the GMC in relation to the reporting of images. Their arguments supporting the division of labour between technicians and radiologists, predominantly centred on patient welfare, despite the fact that "medical professional knowledge of the specialism was questionable" (Larkin, 1978, p.851).The technicians producing radiographic images were generally recognised as being more knowledgeable about imaging than the medical profession. This was because radiology was a new field of expertise, and postgraduate medical training had only been recently introduced. Nevertheless, the Board of Trade acquiesced to the GMC and approved the technicians' application, subject to the following proviso: that technicians could only accept patients for radiographic examination under the direction and supervision of a qualified medical practitioner. Furthermore, any additional amendments to the radiography application were to be reviewed by the GMC. The role division and the sociological recognition that medicine was a discipline[6] over and above the technical skills and abilities associated with radiography, culminated in a resolution issued at the behest of the GMC in 1924. The resolution released by the recently formed Society of Radiographers in the UK, decreed:

> "… no non-medical member shall accept patients for radiography, radioscopic or therapeutic work except under the direction and supervision of a qualified medical practitioner. Neither shall any such member make any report or diagnosis on any radiographic or screen examination" (Jordan, 1995 as cited in Sarah Lewis et al., 2008, p.91).

When the declaration was subsequently adopted by several other counties, including Australia and New Zealand, it ensured continuing dominance of the medical profession over radiography internationally. However, it should also be noted the right and authority of the medical profession to diagnose and treat patients has ensured continued dominance over multiple health-related professions, not just radiography (Freidson, 1974).

Professional recognition of radiography in the UK was finally achieved in the early 1960's with state registration, creation of a code of conduct and "the development of its own body of knowledge base, previously influenced by medicine, physics and nursing" (Decker & Iphofen, 2005, p. 264). However, the controlling influence of medicine over radiography was not confined to the UK and remains evident within current clinical practice. S. J. Lewis et al. (2008) in their grounded theory study determined the power of the medical profession continues to be demonstrated through "…economic, political, sociological and intellectual channels…" (p. 91). Furthermore, dominance in the workplace is maintained by controlling and restricting allied health professionals' autonomy via the division of labour; thereby ensuring and maintaining medicine's central position as the "paradigm profession" (p. 91). The authors added that continued domination is achieved by "subordination, limitation and exclusion" (p. 91), with subordination the principal form of domination within the health professions. Subordinate professions are those who have their work regulated and supervised by doctors, for example, radiography and nursing.

---

[6] A specialised branch of knowledge usually studied in higher education.

The effects of subordination were highlighted by MITs feeling inferior to medical practitioners, including radiologists. This in turn resulted in reduced morale, and emphasised the lack of professional autonomy (S. J. Lewis et al., 2008). Although this study was undertaken within Australia, there are very clear links to radiography practice within New Zealand, not only in terms of the public and private health systems but also because radiography practice in both NZ and Australia is influenced by the Royal Australian and New Zealand College of Radiologists (RANZCR) who is responsible for issuing practice standards and guidelines in relation to the safety and quality of radiology services.

RANZCR's stance on the roles of radiologists and MITs was reiterated in 2018, when they confirmed radiologists are team leaders who provide guidance to MITs to ensure the correct imaging procedures are undertaken, appearing to reflect a belief MITs continue to be subservient to radiologists. This was further indicated by statements indicating MIT role extension to include commenting or reporting on radiographic images, is not supported (RANZCR, 2018, p. 4-5), despite MITs undertaking these duties in countries such as the UK with the endorsement of the College of Radiographers (The College of Radiographers, 2013) and the Royal College of Radiologists (The Royal College of Radiologists, 2011). In the UK, reporting MITs have been shown to benefit the imaging department through increased efficiency (Price, 2001; Woznitza, 2014) and have supported radiologists by freeing them to focus on complex imaging procedures (Culpan et al., 2019).

RANZCR's 2018 position has been highlighted as creating a clinical barrier to Australian MITs extending their practice due to a lack of radiologist support, which is exacerbated due to a lack of post-graduate educational and Continuous Professional Development (CPD) opportunities (A. Murphy et al., 2019). As indicated by RANZCR, radiologists consider themselves to be at the top of the medical imaging department hierarchy. Within private practice, radiologist dominance is further evidenced through practice ownership and therefore resource allocation and budgetary decisions (Jain, 2014; Rosenkrantz et al., 2017).

It is possible that the historical medical dominance of the medical imaging profession is ensuring a continued focus on technology within medical imaging practice.

Furthermore, it could be argued that medical dominance continues to affect current decisions relating to resource allocation, especially in relation to MIT in-service and post-graduate training, as well as other professional development opportunities.

2.3.2 Medical imaging education

The Society of Radiographers in the UK was founded in 1920 by two radiologists, highlighting again the link to the medical profession and its dominance of the allied professions. Membership was open to anyone who could demonstrate a minimum level of ten years continuous employment in an x-ray or electro-therapeutic[7] department of an approved hospital. In 1921, a syllabus was developed and membership became subject to successful completion of an examination and the award of a diploma. In 1923 several hospitals were inspected and became recognised training schools. In 1937, the Board of Medical Auxiliaries was established for professional registration. The Cope Report, published in 1951, recommended the creation of a statutory council to maintain a register of all medical auxiliaries who were qualified to work in the NHS. This was implemented via The Professions Supplementary to Medicine Act, 1960, and became compulsory for radiographers in 1962. In the 1970s the extension of the Diploma training for MITs from two to three years was enacted (Society And College of Radiographers, n.d.).

The first radiography degree programme in the UK, was validated in 1989. However, this did not occur without initial protests from within the medical imaging community. Members argued that degree education was not required and would not reflect the practical and technical skills required by MITs. Some factions within the Department of Health, including the Chief Scientific Officer, also supported the argument against degree education for MITs. The scientific officers wanted radiography to be undertaken by "imaging technicians" (Price, 2009 p.70). The reasons for this are not made explicit by Price, although it is perhaps not unreasonable to suggest this could be associated with concerns over crossing professional boundaries and perceived threats

[7] Initially electrotherapy was used as a means to treat "nervous ailments' such as epilepsy and also to provide rejuvenation to the body. Ueyama, T. (1997) Capital, profession and medical technology: The electro-therapeutic institutes and the Royal College of Physicians, 1888-1922. *Medical History,* 41, 150-181.
The connection to radiography is demonstrated by research in 1921, related to the theory of ionisation and the production of x-ray tubes for radiotherapy. Price, R. (2010) A focus on history: Ninety years of age and still going strong. *Radiography,* 16 (1), 1-2.

to the status quo. Although the changes discussed relate to radiography within the UK, these were also reflected in other countries such as Aotearoa New Zealand and Australia. In addition, the changes in radiography education provision followed a path very similar to that experienced in other healthcare professions. Namely, in the early part of the 20th century, students underwent an apprenticeship, learning from experts. This was followed by a professional qualification delivered outside of the higher education system. This in turn, was followed by the incorporation of training into higher education with recognised academic awards. For example, in the UK, following initial degree validation in 1989 "radiography became a graduate profession by 1993" (Price, 2009a, e.67).

Learning has been defined as not just the acquisition of knowledge, but also the application of knowledge through a change in behaviour (Cameron & Green, 2004). Therefore, one would expect effective training to allow the recipient to gain understanding of theoretical and practical concepts, and subsequently apply them in practice. This would apply equally to undergraduate (UG) and postgraduate (PG) degrees as well as continuing professional development. Sein et al. (2001) highlighted that a set or series of skills are not enough, specifying a hierarchy of knowledge is required to develop an effective training process which allows participants to develop as responsible and autonomous learners.

Johnston et al. (2010) specified that UG education is sufficient to produce MITs who can use medical imaging equipment safely. Detailed in-service education is then required periodically to maintain skills and prevent lax attitudes and behaviours from developing. Johnson et al. also indicated that the provision of specific and comprehensive training is essential when new technology is introduced into the imaging department.

Anecdotally, MIT training tends draw on a cascade process, in which an application specialist spends time with key staff explaining the functionality and operating systems. These staff members are then responsible for training the rest of the department. While this approach may be cost-effective and allows for an informal approach to be adopted (Bax, 2002), there is the potential for misinformation or critical gaps to occur (Suzuki, 2008). Furthermore, this type of training does not consider learning styles, relevant pedagogical theories, or require post-training evaluation, thereby limiting its effectiveness (Bragg et al., 2005; A. Brown, 2004; Eraut et al., 2004).

It has been recognised that within health education in particular, tacit knowledge created by experience and "action-learning" is more likely to lead to critical thinking and innovation. Training needs to be flexible, highly adaptable, practice-based and person-centred to utilise and transform tacit knowledge into explicit knowledge (Bevan & Fairman, 2014). To produce professionals who are able to resolve complex situations, and be reflexive and responsive, health education models are needed to meet their needs and those of the communities they serve (Feo, 2008). As such it has been argued that training should consider the individual learning needs of the learners (Holloway et al., 2018). It is not clear whether a cascade training approach would be able to meet these requirements. Additional concerns around cascade training include: the potential for surface learning; skills and knowledge are prioritised over values and attitudes; a potential lack of standardisation; dependence on the knowledge of the application specialist; training time is not protected (Davis & Lovegrove, 2016; Eraut, 2004; Hayes, 2000; Kennedy, 2005).

MIT education has moved from an "apprenticeship" based model of training focused on acquiring practical and technical skills, to a degree based model designed to support theoretical, experiential, and reflective learning. There seems to be limited research around the focus of cascade and applications training during the transition to digital technology and whether this influenced the knowledge, understanding and perceived competencies MITs have in relation to this technology.

2.3.3 Evidence-based practice

MITs are expected to utilise evidence-based research to support their clinical practice, and in many countries (including New Zealand, Australia, UK and America) mandatory CPD is needed to maintain a practising certificate and registration with the regulatory body (The New Zealand Medical Radiation Technologists Board, 2018). Nonetheless, there have been several concerns cited in relation to the mandating of CPD, which are considered to negatively affect its usefulness. Barriers to learning include external commitments, competing priorities and a lack of support from employers (Henwood &

Flinton, 2012). In addition, Henwood and Flinton noted that MITs do not perceive any personal gain from undertaking CPD, which is reinforced when CPD is mandated, suggesting MITs could be demonstrating an apathetic approach towards CPD.

Sim & Radloff (2009) claimed that apathy within the radiography profession, could be due to a relatively low public profile and radiography still emerging as a profession. Furthermore, apathy has led to MITs undertaking CPD purely to maintain clinical competence and meet the requirements of their regulatory bodies. The authors argue this has resulted in MITs who are protocol led and lacking in critical thinking, which in turn, has adversely affected motivation and the desire and ability to learn, thereby creating a concatenation of events.

The notion of apathy is supported by Yielder & Davis (2009) who stated the issue is compounded when combined with a lack of functional autonomy. This may be related to underlying low self-esteem, apathy, and resistance to change evident in the culture of the radiography profession. Yielder & Davis contend that the control and subsequent effects of subordination continue to influence the attitudes of MITs i.e. they feel subservient and inferior to radiologists. Nursing and radiography students have been “socialised to value obedience, respect for authority and loyalty to the team” (Yielder & Davis, 2009, p.248) and their ability to be accepted into and remain part of the healthcare team, is dependent on them recognising this level of subordination. Palmer & Short (2000) claim this has been compounded by women dominating the allied health professions. It is evident that current issues within the profession continue to be inextricably linked to its historical influences.

Sim & Radloff (2009) asserted that a workplace culture which promulgates conformity and does not encourage staff to question and explore clinical practice, frequently results in staff who are demotivated particularly in relation to lifelong learning. It has been argued, that although employers may provide in-house training for staff to keep up to date with equipment changes, it is unable to produce behavioural change and therefore the impact on clinical practice is minimal (Di Michele et al., 2020).

The difficulty in changing medical imaging clinical practice, was also discussed by Joyce & O’Leary (2014). They examined why research demonstrating an increased Source to

Image Receptor Distance (SID)[8] reduces patient dose had not been widely implemented. An area of research which would seem to be highly relevant for MIT practise. The authors determined that introducing new ways of working in a clinical environment requires an evidence-based practice approach to working. However, this is currently not the case within radiography.

Integration of evidence-based practice within medical imaging has been problematic (Di Michele et al., 2020), although issues such as being nonresponsive to new theory are not restricted to medical imaging (Nilsen et al., 2017). Research awareness through an appreciation of research methodologies; the ability to critically evaluate research outputs; combined with an understanding of their significance have been suggested as precursors for the successful integration of evidence-based practice in medical imaging (Ahonen & Liikanen, 2010).

In 2001, Nixon highlighted the issues associated with radiography being considered to be "semi-professional as much of its knowledge base was built on research undertaken by medical practitioners and physicists, rather than by MITs" (p. 31). He contended that to be considered professionals, MITs needed to develop research skills. Hafslund et al. (2008) specified that MITs need to take responsibility for determining whether to utilise new techniques in their practice, continuing that being more research aware would support this.

Mandating research, as well as CPD, was another suggestion to produce a profession which uses an evidence-based approach to healthcare (Reeves, 2008). This argument does not consider the negative implications of a mandatory approach as previously discussed. Reeves' suggestion to mandate research could be construed as somewhat ideologically flawed, given the findings of Joyce & O'Leary (2014) and Henwood & Flinton (2012) and the impact of medical dominance, apathy, and workplace culture on the radiography profession.

Combining adaptive learning and developmental learning has been identified as an alternative approach to support the integration of evidence-based practice (Nilsen et

[8] Definition of SID: the distance between the focal spot on the target of an x-ray tube and the image receptor as measured along the beam. Retrieved, 7th June 2015: http://medical-dictionary.thefreedictionary.com/source-to-image-receptor+distance.

al., 2017). In this scenario, adaptive learning creates a situation where the use of evidence-based practice is habituated, so that the accessing, critique, and utilisation of research becomes a normal part of clinical practice. Developmental learning predominantly utilises reflection to identify subconscious assumptions and patterns of behaviour. In combination, the individual is able to acquire and utilise evidence-based practice skills while identifying and discarding previously learnt beliefs or behaviours which may impede the implementation of new research based knowledge (Nilsen et al.). It is therefore essential for trainers to consider how pre-existing knowledge and attitudes may hamper the adoption of new learning. Furthermore, successful implementation of evidence-based practice, is dependent on sufficient training, resources, and time allocation (Nilsen et al.). Unfortunately, cited barriers to medical imaging research and evidence-based practice continue to include time pressures, workload demands, a lack of resources, and workplace culture (Brettle, 2020).

It does not seem unreasonable to propose the issues highlighted in relation to apathy within the medical imaging profession, and difficulties in embedding evidence-based practice (EBP), may have influenced the transition to and ongoing use of digital technology within medical imaging.

2.3.4 Medical imaging culture

The concept of culture is complex and subject to numerous definitions, although it has the power to significantly influence change processes and whether they are successful. The concept of culture can be broken down into three elements i.e. organisation, individual and practice perspectives (Watling et al., 2020). The organisational component illustrates the values of the organisation and its employees. In this way, the culture of an organisation exhibits multiplicity, in that it is made up of several subcultures which influence its function. For example, within the District Health Board (DHB) environment different professional cultures exist in both clinical and nonclinical areas. Professional cultures have a direct influence on the practice perspective. The practice perspective reflects the potential for change, for example through research or new technology. It also encapsulates the way content, the environment, and timing influence outcomes (Watling et al.). Within professional cultures, there will be employees with individual cultural values, made up of many different components and experiences. These will govern the attitudes and behaviours displayed by the individual

(Karahanna et al., 2005). It has been postulated that international influences (such as ethnicity or religion) and national cultural concepts, affect people's values whereas practice is more likely to be affected by organisational and professional cultures (Karahanna et al.). The level of influence of these three different elements is contingent on the type of behaviour being evaluated. For example, in behaviours which are task-focused or linked to competencies, the dominating components are likely to be from organisational or professional cultures (Karahanna et al.). Organisational and professional cultures are therefore likely to have influenced the way in which digital technology has been introduced and utilised within the medical imaging environment. Organisational culture strongly influences the attitudes, behaviour and beliefs of its employees (Karahanna et al.). Therefore, it has a recognisable effect on learning and development, with a culture of collaboration and support required at a team and management level, as pre-requisites in supporting learning and change (Tynjälä, 2008). More specifically, organisational culture has been shown to play an important role in the way educational strategies are introduced and whether they are successful (Watling et al.), thus supporting the claim that organisational values and existing workplace practices, significantly influence whether new technology is successfully adopted (Ingebrigtsen et al., 2014; Karahanna et al., 2005).

Hayre et al. (2017) highlighted there is a risk that poor practice may become a culturally accepted behaviour, especially if MITs do not feel they have sufficient FPDR knowledge and therefore are more reliant on the technology. Reliance on technology in a protocol driven environment, reduces opportunities for critical thinking and reflection (Sim & Radloff, 2009) and creates a focus on conformity (Vom & Williams, 2017). While there are some benefits to conforming e.g. radiation protection best practice standards, there are drawbacks. This is particularly evident when challenging previously accepted practices or introducing change through innovation or EBP for example (Strudwick, 2011; Vom & Williams, 2017).

The need to conform is prevalent within medical imaging and has been influenced by professional and historical influences (Sim & Radloff, 2009). Conformity therefore forms a part of medical imaging professional or occupational culture. Occupational culture has been defined as being created through individuals closely identifying with their occupation (Pilz, 2009). Conformity and a resistance to change in MITs was also identified by Strudwick (2011), particularly in an environment where the underlying culture was one of blame. The need to conform also had the potential to influence attitudes towards learning, CPD and research, as Strudwick identified MITs demonstrated the accepted cultural norm of ambivalence towards these activities. However, another dimension to medical imaging occupational culture, is that MITs view their images as cultural artefacts, taking personal ownership of the images they create (Strudwick, 2014). The author identified that MITs were aware of the quality of their work. However, they could be defensive when they felt their work was under scrutiny and considered a negative reflection of their performance. Strudwick (2014) continued that MITs are unusual, in that there are very few health professions where a tangible artefact is created following the interaction with a patient. A feeling of ownership was produced as MITs saw themselves as image creators and the production of the image was their main focus. Strudwick added this might lead to a perceived emphasis on the technical aspects of the role.

It could be proposed that if Strudwick's (2014) assumption about the technical aspects of medical imaging is accurate, the need to understand the functionality of imaging equipment should be a leading driver in medical imaging CPD. Furthermore, the use of excess exposure would seem to be contradictory, as it could reduce the aesthetic appeal of the resultant image. However, it could be argued that if MITs are aware that insufficient exposure will lead to a substandard image, the decision to select higher exposure factors could be happening at a subconscious level in an attempt to produce the ideal image. This suggestion supports the findings of Warren-Forward et al. (2007), who found that both radiologists and MITs preferred the image quality of over-exposed images when they are automatically rescaled[9], which subsequently may translate into habitual unnecessary overexposure of patients.

It is clear that medical imaging occupational culture is complex and that the successful deployment and utilisation of digital technology is likely to be influenced by this

[9] Automatic rescaling is the process by which the computer ensures consistent image brightness is achieved, despite overexposure or underexposure of the image receptor.

culture. For example, medical imaging culture can result in numerous barriers to learning, ultimately affecting decision-making, and shaping clinical practice.

2.4 Medical imaging clinical practice

2.4.1 Image quality and radiation dose

Within medical imaging there is no single overarching definition of image quality (Shet et al., 2011). This is partly because image quality is determined by both objective and subjective means. Subjectivity in radiology is created due to the personal interpretation of the resultant image predominantly by the MIT and the radiologist. This interpretation may be affected by factors such as individual and social cognition; representative and availability heuristics; confirmation bias; plus, inattentional blindness (Buckle et al., 2013; Christensen, 2005b, 2005a; Drew et al., 2013). In an attempt to encapsulate the term “image quality”, Seeram (2019, p.188), states “at its broadest sense, a quality image is one that which makes accurate diagnosis possible” and is clearly linked to the image’s diagnostic quality. It is important to recognise image quality may be influenced at any stage within the entire imaging chain, as loss of electronic information at any point will result in image degradation (Butt et al., 2012). Fundamentally, digital image quality is determined by the relationship between noise and contrast.

Noise

Noise may be either electronic or quantum noise. Electronic noise is inherent within the imaging system and is not influenced by the MIT. Quantum noise or quantum mottle[10] is influenced by the number of x-ray photons[11] that exit the patient and subsequently interact with the detector. The higher the number of photons the patient is exposed to, the greater the radiation dose received by the patient. This is principally determined by the mAs setting. Therefore, the mAs selected by the MIT will determine the level of quantum noise present on the image. A low exposure (mAs) technique will produce a low signal to noise ratio (i.e. more noise) than a high exposure technique which results in more photons reaching the detector and a higher signal to noise ratio.

[10] Defined as variations in optical density on a radiographic image.
[11] Small discrete bundles of energy also known as quanta with no mass or electric charge.

The latter scenario will produce a better image than the first, but with an increased radiation dose to the patient (Seeram, 2019).

Optimisation of patient radiation exposure while maintaining image quality, continues to be explored following the introduction of digital technology. The risk of increased patient dose is because a high dose of radiation reaching the image receptor will not detract from image quality and may improve it; whereas, a lower dose may create an image with reduced quality due to increased noise levels. Therefore, MITs may select higher exposure factors than required, as there would be no adverse effect on image quality (Honey & Hogg, 2012). Although Automatic Exposure Devices (AEDs)[12] may be available, there remains an expectation that MITs are capable of determining the correct exposure factors for their patients (Balogun, 2021; The New Zealand Medical Radiation Technologists Board, 2018)

Contrast and Contrast Resolution

The contrast on a digital radiographic image, i.e. the ability to differentiate between different anatomical structures, is influenced by the region of interest; the quality of the x-ray beam; the image receptor characteristics; and the computer processing system. The contrast resolution refers to the ability to distinguish between two objects with similar subject contrast, for example differentiation between the abdominal organs.

The visibility of anatomical structures/detail, i.e. the contrast (or difference) in a signal, is governed by the amount of noise within the image. A large amount of noise may obscure key diagnostic information (Decoster et al., 2015). Therefore, factors which influence whether an image is deemed to be diagnostic include: noise; contrast resolution; detective quantum efficiency (DQE)[13]; spatial resolution[14]; and artefacts.

---

[12] The purpose of the AED is to deliver consistent, reproducible exposures across a wide range of patient habitus, diseases and tube potentials.

[13] Defined as the ratio of the squared image signal-to-noise ratio to the number of incident x-ray photons, the DQE describes how efficiently a system translates incident x-ray photons into useful signal (relative to noise) within an image. Ranger, N.T., Samei, E., Dobbins, J.T., & Ravin, C.E. (2007) Assessment of Detective Quantum Efficiency: Intercomparison of a Recently Introduced International Standard with Prior Methods. *Radiology*. 243(3) pp. 785–795

[14] The spatial resolution relates to the smallest object that can be detected on an image

The levels of noise, the contrast to noise ratio (CNR), and to some extent, the DQE are influenced by the exposure selections made by the MIT for example:

- the tube voltage predominantly affects the x-ray beam quality (kilovoltage [kV]);
- the tube current, the quantity of x-ray photons produced (milliamperes); and
- the exposure time is related to the time during which x-ray photons are emitted (seconds).

As the CNR is related to the contrast from the area of interest and the image background (A. K. Jones, Ansell, et al., 2015), it is a significant factor when evaluating image quality, because it governs the ability to visualise anatomical structures as well as subtle variations in contrast (Hampel & Pascoal, 2018). Since noise is influenced by mAs selection, and kV choice determines the contrast detectability on the image, the contrast to noise ratio is clearly affected by the exposure choices made by the MIT. The DQE of digital systems is kV dependent and many have higher dose efficiency capabilities at lower kV ranges. Consequently, a lower kV selection by the MIT should produce a higher signal to noise ratio and therefore a better quality image (Uffmann & Schaefer-Prokop, 2009).

Determining correct exposure factor selection

A central tenet for all radiography is the ALARA principle (International Atomic Energy Agency, 2011). Namely, every radiation exposure carries a risk, which increases with dose. Therefore, it is imperative the lowest amount of radiation required to produce a high-quality diagnostic image should always be utilised.

The effective dose a patient receives is predominantly governed through the exposure factors each MIT selects. A small single centre quantitative study in Ireland, evaluated MIT exposure choice selection for virtual patients with differing body mass indices (Darcy et al., 2015). The authors reviewed two key criteria MITs consider prior to irradiating a patient: the anatomical area to be exposed; plus, the thickness of the patient. Darcy et al. concluded there were significant differences in exposure choice selection for three of the radiographic examinations evaluated, which correlated with the age and/or the experience of the MIT.

Older MITs and those with more experience selected higher mAs values for one shoulder projection, but lower mAs values for the two lumbar spine projections. The authors were unable to suggest why these differences occurred but advised further research was warranted. Consideration that the lumbar spine would constitute a radiosensitive area of the body was not discussed in the article and could be one possible explanation. Nevertheless, Darcy et al. (2015) found inconsistencies in the MITs exposure choices resulted in variable doses being received by patients of an equivalent size, which was concerning. Variation in exposure choice selection was thought to be linked to MIT visualisation of the patient (Darcy et al.) but has also been linked to other variables including patient obesity (Kasprzyk et al., 2020). Difficulties in accurately assessing exposure choice to suit patient body habitus is an issue MITs have long faced and one predominantly overcome following the introduction of digital imaging due to its wide exposure latitude.

The difficulties associated with exposure choice selection are compounded when one considers that common practical decision-making tools used by MITs in clinical practice, such as the 15% rule[15], are based on F-S technology, which operates in a completely different way to digital systems. As such these tools may no longer be accurate or relevant in a clinical environment where digital imaging systems are the norm (Ching et al., 2014). For example, F-S systems require a fixed dose to be received by the cassette. However digital systems do not, due to their ability to manipulate the image through post exposure processing algorithms (A. K. Jones, Ansell, et al., 2015).

In their study on paediatric extremity imaging, A.K. Jones, Ansell et al. (2015) determined previously published guidelines on the use of high tube potentials (≥ 60kV) coupled with additional copper tube filtration to reduce paediatric dose, may no longer be appropriate. This was partially due to the CNR being affected by kV selection and in this case, the low inherent contrast in paediatric bony anatomy. Image quality in paediatric imaging could therefore be improved through a reduced tube potential of 40kV and the removal of additional copper filtration (A. K. Jones, Ansell, et al.). This recommendation may produce a dilemma for MITs, as it seems to contradict

[15] The 15% rule describes the relationship between kV and mAs i.e. increasing or decreasing the kV by 15% has the same effect as doubling or halving the mAs. It is predominantly used to support image quality in patients with pathologies in which manipulation of kV or mAs may be beneficial e.g. reducing kV by 15% for patients with osteoporosis, due to reduced bone density.

previously accepted good practice that a high tube potential and low mAs results in a lower radiation burden for the patient (Moey & Shazli, 2018).

Hampel & Pascoal (2018) identified the use of a higher tube potential (55kV) and the use of 0.1mm copper tube filtration, produces effective CNR values in paediatric imaging. They recommended individual departments should optimise each system to ensure image quality needs are met, while minimising patient dose. Interestingly, an American study seemed to expand on this by indicating it was the responsibility of the radiologist to determine the exposure choices made by the MIT to ensure image quality (Huda & Abrahams, 2015). It is clear there remains conflicting evidence regarding the approaches MITs should take in exposure choice selection to support image quality factors such as the CNR.

The ability of digital imaging to reduce patient radiation exposure is partly due to a wide exposure latitude, which is more accommodating of incorrect MIT exposure choices than traditional film-screen systems. This has reduced the need for MITs to appreciate how their exposure choices influence the resultant image (Walker et al., 2011). The increased DQE of digital technology, compared to F-S, also allows for a reduced patient radiation dose (Seeram, 2019). However, there is the potential to increase patient radiation exposure, with MITs sometimes unaware they have overexposed the patient (Uffmann & Schaefer-Prokop, 2009). Unlike F-S systems, where exposure errors are immediately apparent through the developed film appearing too dark or too light, digital images are automatically enhanced by the computer system.

Patient exposure can be evaluated in practice by reviewing the exposure indicator (EI) (Moore et al., 2012). The EI is displayed on the image and checked to see if it lies within the “acceptable range”, as designated by the manufacturer. The EI is generally calculated from the mean image signal and the main function is to allow ongoing comparison of operational functionality at one site. However, unless the MIT is knowledgeable and has confidence in the manufacturer’s EI value, there is a danger the MIT would be unaware the exposure choice had been incorrect (Erenstein et al., 2020; Seeram et al., 2015; Takaki et al., 2016). An over exposed radiograph may therefore appear to meet the acceptance criteria for that examination and be sent to the reporting clinician for diagnosis. Additionally, the relationship between the exposure to the image receptor and the digitised grayscale appearance of the final product is difficult to establish. Thus, it can prove extremely difficult to identify an overexposed image. Furthermore, overexposed images may be preferred by radiologists due to the reduced noise levels when compared to appropriately exposed images (A. K. Jones, Ansell, et al., 2015). Worryingly, it has been reported that a diagnostic image can be produced with an overexposure by as much as 500% (Moore et al.).

Conversely, underexposure of more than 100% can result in an increase in a specific type of image noise known as quantum mottle (Butler et al., 2010). Quantum mottle specifically relates to the number of x-ray photons, which exit the patient and form the image on the detector. Quantum mottle detracts from diagnostic information gleaned from the radiograph, due to the fluctuations in density it produces. Although the patient's anatomy may be demonstrated, a repeat exposure is generally required, due to the spatial resolution being compromised. Consequently, there is a risk that higher than required exposures are used, to ensure quantum mottle and repeat examinations are avoided (Mothiram et al., 2014). The need to determine exposure on digital images was highlighted by Workman & Cowan (1992), when they suggested the sensitivity indicator on laser images could have potential in this regard. Even though almost 30 years have passed since this issue was raised, there remains a level of uncertainty in the literature as to how to ensure MITs understand the significance of this issue.

It has also been recognized the EI is limited in its ability to demonstrate patient dose, as it only represents the radiation received by the image receptor. Other problems include EI variability due to: collimation; centring; body habitus; gender; size of image receptor; and source to receptor distance (Mothiram et al., 2014). In addition, computerised radiography (CR) equipment manufacturers' recommended EI values may be set at higher levels than required to produce a clinically diagnostic image. To overcome this, it was recommended that CR manufacturers reassess their EI values (Peters & Brennan, 2002). MITs should also ensure they are using an optimised EI level to reduce patient dose, rather than relying on manufacturer's recommendations. This supports the work of Butler et al. (2010) who undertook an experimental study to assess whether EI values vary in consistency in CR and FPDR systems, their reasoning being that EI numbers are an effective feedback tool when determining correct exposure selection. Anthropomorphic phantoms[16] were utilised and a clear description of the methodology was given. Butler et al. exposed the phantoms twenty times for each projection and body system. Why this figure was selected, was not stated. One interesting finding was that despite a consistent set of exposure factors being used, the EI values varied so much, they falsely implied double the radiation dose had been received by the detector. This was demonstrated by an increase in the EI from 1.88 to 2.21, as a logarithmic function this would normally suggest that radiation delivered to the receptor (and therefore the patient) was doubled. However, as the exposure settings had remained constant this could not be the case. This demonstrated that EI values can be unreliable in CR systems. There was no fluctuation demonstrated in FPDR systems, but the authors did not discuss why this might be the case.

Despite the known issues linked with using a non-standardised EI as a means to calculate dose, research continues to be produced which advocates this approach. Silva & Yoshimura (2014) undertook an experimental study relating the EI to exit and entrance doses for chest radiographs using a phantom. Despite the statement that the study was experimental, the number of exposures was not cited and dosimeters were placed "approximately" (p. 272). These factors make it impossible to repeat the experiment and call into question the reliability of the findings.

Another major issue with EI systems is they are manufacturer specific, which can lead to confusion among users. It was believed the introduction of a new standardised EI would lead to improved quality and dose optimisation (Seibert & Morin, 2011). The standardised EI compares the exposure to the image receptor to a target EI value. Any variation from the target value is plotted using a deviation index (DI). The DI is designed to give immediate feedback to the MIT as to whether exposure is correct or not. The DI provides a negative value (-) for an underexposed image, zero for a correctly exposed image and a positive value (+) for an overexposed projection (Moore et al., 2012). A DI of +3 indicates a 100% overexposure, meaning the detector received double the optimal exposure for the examination. A DI of -3 indicates an

[16] Anthropomorphic phantoms are traditionally used to calculate potential radiation doses. They are constructed to mimic human anatomy and the body's radiation attenuation characteristics.

underexposure of 50% (Guðjónsdóttir et al., 2021). The International Electrotechnical Commission predicted this approach would allow appropriate adjustment to exposure factors for repeat images, as well as giving an indication of dose to the image receptor consequently identifying exposure creep (International Electrotechnical Commission, 2008; A. K. Jones, Heintz, et al., 2015). Using a target EI and patient thickness measurements, Zhang et al. (2013) calculated specific exposures in a randomised control study on 180 children. They concluded that using patient weight and height allowed for accurate exposure factor setting and achieved target EI values. Thereby, reducing radiation dose in children undergoing chest, abdomen, and pelvis imaging.

The research demonstrates that there remains a level of confusion within radiography as to the role of the EI and its relationship to radiation dose. This is important, as despite the existence of national dose reference levels, MITs have ultimate control as to how much radiation dose each patient in their care receives. That is, MITs could potentially overexpose every patient and still be within the dose reference tolerance limits for the patients' examinations (Johnston et al., 2010). Mothiram et al. (2014) determined that it is the professional responsibility of MITs to ensure they understand radiographic equipment and that it is used according to the ALARA principle, which reflects the competencies expected of NZ MITs (The New Zealand Medical Radiation Technologists Board, 2018). A number of authors have suggested that further research and MIT education about the relationship between EI and dose, and dose optimisation is essential for digital imaging systems (Davidson & Sim, 2008; Mothiram et al., 2014; Tonkopi et al., 2012).

2.5 The impact of digital technology

Change is being driven globally in medical imaging due to: health sector reforms; cost savings and the need to improve quality outcomes; skills shortages; and new medical interventions as well as technological innovations (Cowling, 2008). Increased efficiency and improved patient outcomes have been cited as benefits associated with the introduction of FPDR systems in particular (Gardner et al., 2014; Lehnert et al., 2011; Moodley & Moodley, 2015). To ensure quality outcomes, it is essential that MITs have a good understanding of digital technology (Gillan et al., 2015; Uffmann & Schaefer-Prokop, 2009). However, there are concerns that this knowledge is questionable and that MITs are becoming deskilled, due to over-reliance on the equipment (Mothiram et al., 2014). This is supported by Rogers et al. (2010) who highlighted a lack of training, perceived ability, support, and a fear of new technology impacted on MITs' abilities to utilise digital equipment effectively.

Other studies have indicated training approaches should reflect individual learning needs (Floyd et al., 2015) and that Picture Archiving And Communication Systems (PACS) have influenced the way MITs work, specifically in regard to communication with radiologists, image processing and quality assurance (Larsson et al., 2006). Lundvall et al. (2014) found that specialised MITs experienced the production of radiographic images as an "autonomous professional area" (p. 51), which could reflect confidence in their roles and role expansion. This supported the findings of Niemi & Paasivaara (2007) who commented that technology was seen both as a challenge and also an opportunity for role expansion. Challenges include the changed nature of work with the move from analogue film systems to digital imaging systems, mastery of new technology following rapid changes, and taking on responsibilities previously undertaken by radiologists (Campbell et al., 2019; Frost & Sullivan, 2009; Moore, 2016). These challenges could lead to a reduction in both professional confidence and feelings of autonomy.

Professional confidence relies on the individual not only understanding their role and scope of practice but also the capability to demonstrate those skills and abilities (Holland et al., 2012). The authors expand on this concept by stating that professional confidence is inextricably linked to competence and professional identity. Professional confidence is initiated at undergraduate level and needs nurturing, as it takes time to develop. It is transient in nature and can be lost due to stress, anxiety and during periods of transition. Professional confidence levels can be lost when contradictory information is delivered and/or staff feel they have no control over the environment in which they are working. The researchers highlighted the need for ongoing educational strategies combined with working in a supportive environment, if professional confidence is to be developed and maintained. Capper (2008) suggested that professional confidence is also linked to competence in undertaking specific tasks. Based on Capper and Holland et al's findings it could be proposed that rapid technological changes, in conjunction with varied education initiatives and contradictory information, may lead to a loss of professional confidence within the medical imaging profession.

Prud'homme (2010) stated increasing use of high technology equipment in the 20th century, resulted in a stronger demarcation and division of work within healthcare. He added that the division between the "professional" who undertakes diagnosis and treatment of patients and the "technician" whose role is to focus on the equipment, had increased. He defined a healthcare professional as someone who assesses the patient's issues and determines what actions need to take place. While his work primarily related to hearing prosthetists and respiratory technicians, it could equally be applied to MITs. In Europe the term "Radiographer" is used in written English, to refer to staff with similar roles within diagnostic radiology, radiotherapy, and nuclear medicine. However, outside of Europe the term "technician" or "technologist" is used to reflect the predominantly technological nature of the role (Andersson, 2012).

In 2012/2013 the term "Medical Radiation Technologist" was changed to "Medical Imaging Technologist" in New Zealand, to encompass imaging modalities that do not use radiation to produce the images (The New Zealand Medical Radiation Technologists Board, 2013). This would have been an ideal opportunity to re-evaluate the use of the word technologist. However, there is no evidence to suggest this was undertaken. Interestingly, the Medical Radiation Practice Board of Australia uses the term "Medical Radiation Practitioner" which also encompasses the titles "Radiographer" and "Medical Imaging Technologist" (The Medical Radiation Practice Board of Australia, 2012).

Prud'homme (2010) concluded:

> At the opposite of such self-sustained, professional autonomy would be the technician, bound to machines that perform a predefined set of tasks. For this reason, the spread of technology has traditionally been associated with proletarianization, and machines described as vehicles for the deskilling of workers and the general "degradation" of work. In healthcare, technicians and other immediate operators of machines lack the opportunity to perform abstract, decisional operations like diagnosis and thus lack access to the privileged status of professional (p. 76).

This highlights that the increasing use of technology may have a negative effect on the ability of MITs to act autonomously. Consequently, creating another barrier to achieving professional status.

It is feasible to suggest possible links between the roles MITs undertake, professional nomenclature, professional confidence, and perceptions of professionalism. These could impact on clinical practice in a number of ways, not least those discussed by S. J. Lewis et al. (2008). Although Australian medical imaging practitioners are expected to adhere to a Code of Conduct which clearly outlines “standards of ethical behaviour and professional conduct” (The Medical Radiation Practice Board of Australia, 2014, p.5), S. J. Lewis et al. found their participants demonstrated a predominantly negative attitude towards ethical conduct, which was amplified by a lack of professional identity and subordination to medical practitioners. One reported impact on clinical practice was that the radiographers felt unable to question the need for certain radiographic examinations, which led them to undertaking procedures against their better judgment (S. J. Lewis et al.). It could be surmised that there is a potential link between this experience and the possibility that a “small” increase in patient radiation (through inappropriate imaging requests) was considered unimportant. It could be suggested that similar issues such as a lack of professional identity and feelings of subordination may also exist within the NZ medical imaging workforce.

The introduction of new technology, as well as changing the way in which healthcare staff work (Fridell et al., 2011; Lundvall et al., 2015), also provides an opportunity to revaluate inter and intra-professional working and professional identity (Korica & Molloy, 2010). The impact on feelings of autonomy within medical imaging has been described as variable (Aarts et al., 2017). Diminished autonomy has been linked to reduced decision making as a result of technological innovation (Ferris, 2009; Hayre, 2016). Whereas increased feelings of autonomy may be attributed to areas where MITs have assumed additional responsibility (Andersson et al., 2017; Larsson et al., 2006). Much of the research in this regard has been undertaken in Northern Europe and may not reflect the Aotearoa NZ context due to the differing ways the professions have evolved. Furthermore, Korica & Molloy (2010) identified that as new technology becomes embedded into practice, professional identities are formulated and change over time. As previously indicated professional identity is linked to professional confidence and competence, while training and educational approaches are areas which may impact on confidence and ultimately performance (Holland et al., 2012). MIT clinical competency is specifically related to patient safety, quality and minimising healthcare costs (Altolub et al., 2018). Although MIT practice has been reviewed in a number of studies, these have not been specifically related to the introduction and use of digital imaging equipment nor the NZ setting.

Despite the volume of research associated with the technical issues linked to the introduction of digital technology, for example, the fluctuation in EI readings for CR systems, plus manufacturers over-estimation of required EI values, there seems to be little associated with the impact it has had on the staff. However, A. Brown (2004) in a qualitative study, identified that MITs experienced stress due to an increasingly complex work environment where changing patterns of work and the range of tasks required have increased, combined with increasing technical and information technology (IT) skill demands and the need for an expanded knowledge base.

The ability to manage change effectively is important not only in terms of supporting the change process (R. D. C. Kumar, 2013) but also to reduce the types of stress indicated by A. Brown (2004). Additionally, specific measures are required for the successful implementation of new technology within the healthcare sector (Ashtari & Bellamy, 2019). A dominant factor in the successful adoption of new technology is that the change process should consider the influences of organisational power and control, which are considered more significant in the process than any overriding technical issues (Ashtari & Bellamy, 2019; Chetley & Vincent, 2003).

2.5.1 Change theory

People react to change in different ways in the context of change. Some find it stressful, while others enjoy the challenges it brings, such as the opportunity to gain new knowledge and understanding and improve clinical practice and/or professional standing (A. Brown, 2004). Change was highlighted as a significant stressor for MITs in a study by Verrier & Harvey-Lloyd (2010), and was related to a lack of information about practical aspects of the change and a lack of consultation or opportunity for discussion. There are several factors which influence how an individual responds to change. These include:

- Whether the change is created internally (within the individual) or externally imposed e.g. the introduction of digital imaging equipment into an imaging department.
- Who benefits from the change e.g. the employer, the employee, the patients, the shareholders.
- How the organisation has previously introduced change, combined with the expertise and resources it has to manage the change process effectively.
- The personality type and motivating factors of the individuals affected by the change.
- How the individuals have experienced and reacted to change in the past (Cameron & Green, 2004).

It is not only these factors which influence change but also the way in which it is implemented. Schein's model of transformative change specified that there are three phases that need to occur for change to be successful: 1) create the motivation to change (unfreeze); 2) learn and utilise new concepts (move); and 3) incorporate new concepts and meanings through internalisation (refreeze). He claimed that each individual experiencing change would feel learning anxiety initially. This is related to the potential of failing when trying to learn something new. Survival anxiety follows learning anxiety. Survival anxiety relates to the pressures associated with change and can be illustrated by a fear of getting left behind if the individual does not change. As such, learning anxiety is considered to be a restraining force and survival anxiety a driving force to change (Cameron & Green, 2004).

Schein (2002) identified that leaders need to reduce learning anxiety, rather than increase survival anxiety, to support transformative changes. In terms of educative processes, learning anxiety can be reduced by: formal training; the learner being involved; feedback; consistent systems and structures; and support groups (Cameron & Green, 2004). Therefore, the way change is communicated, supported, and identified will impact on whether it is successful. Success is governed by approaches at both an organisational and individual level (Abdekhoda & Salih, 2017; Loudon, 2012). One way in which the introduction of digital technology in medical imaging can be evaluated is through the application of change management theory. Utilisation of change management theory within radiology has been identified as a beneficial process and one which can support the integration of evidence-based practice (Munn et al., 2020; Rajiah & Bhargava, 2017).

The literature does not seem to have explored how MITs experienced the transition to digital technology and whether this influenced their knowledge and perceived competencies in using digital technology in their practice.

2.6 Budgetary constraints

Within the Organisation for Economic Co-operation and Development (OECD) member countries, radiology services are provided in state funded public hospitals as well as in private radiology practices. However, the way in which governments fund the public sector and the level of private practice varies from country to country. For example, in New Zealand, within the private sector a “fee for service” approach is used. Fees are obtained directly from patients or through reimbursement from insurance companies or the Accident Compensation Scheme (ACC). No fault compensation as provided by ACC is unique to New Zealand.

Reduced budgets can have a negative impact on staff morale and job satisfaction. In addition, it is recognised that staff training programmes, which are traditionally supported within the annual budget, are often one of the first casualties of a budget cutting round (Gardner et al., 2014; Owens, 2006). Given the financial constraints faced by organisations, it is important that cost effectiveness and quality of training provision are considered. However, economic evaluations of the benefits of training and CPD are rarely undertaken (C. A. Brown et al., 2002). Nevertheless, the need to ensure that MITs receive regular updates was highlighted by Gardner et al. (2014): “Budgets for educational seminars for all employees, but more specifically radiologic technologists, are important for compliance of radiation protection practices” (p. 116). They also found that larger employers were more likely to offer departmental procedures training and radiation safety education than smaller companies. It is not surprising therefore, that larger hospitals have a higher compliance with radiation safety requirements (Slechta & Reagan, 2008). While Gardner et al.'s literature review did not specifically relate to the use of digital technology, it is possible to postulate that poor radiation protection processes could transfer to the inappropriate use of digital equipment. The authors concluded their research with the comment that MITs should be given educational opportunities to ensure compliance with radiation safety requirements, regardless of budget levels. How this can be achieved and the potential implications were not specified.

S. J. Lewis et al.'s (2008) qualitative study reflected some of the ongoing pressures faced by MITs working in private practice, i.e. effectiveness is frequently measured in terms of productivity and financial gain. One radiographer described private practices as “pressure cookers” (p. 94), in relation to the need to get as many fee-paying patients as possible examined during the day. One way this was achieved was by radiographers taking “short cuts” (p. 94) by reducing the quality of patient care. The authors found senior management and radiologists perpetuated this approach. Although this research was undertaken in Australia, the concept is equally applicable to Aotearoa New Zealand, particularly as many private radiology practices are owned and managed by radiologists. One private provider in NZ reduced patients' appointment times from 20 minutes to 15 minutes, thereby increasing patient throughput. Not only did this affect staff, but it increased pressure on the patients to ensure they were punctual for their appointments. If patients were more than five minutes late, they had to be re-booked, as there was no longer any “slack in the system” (Receptionist A, personal communication, May 28, 2015). This created further difficulties as the radiography and reception staff frequently had to explain the policy to angry and frustrated patients, reportedly reducing staff morale and motivation. It could be suggested that there is a potential conflict of interest when a radiologist owns a private practice in relation to the justification[17] of x-ray examinations. Namely there is difficulty in maintaining an objective stance when evaluating the need for an examination, when each radiographic procedure generates income. The emphasis on financial gain highlighted by S. J. Lewis et al. (2008) could also influence whether private providers are willing and able to provide staff education as they look to increasing revenue.

---

[17] The type of examination must be justified and every examination should result in a net benefit for the individual or for the public health. The examination should be anticipated to influence the efficacy of the decisions of the referring clinician with respect to diagnosis, patient management, treatment, and final outcome…Justification also necessitates that a single person takes overall responsibility for the examination. This person, normally a radiologist, should be trained and experienced in radiological techniques and radiological protection (ICRP Publication 121, 2013)

Another major concern is that training budget cuts and staff shortages (due to moratoriums on staff replacement) make it difficult to release staff to attend educational courses (Gibbs, 2011). Staff shortages and cost have also been demonstrated as barriers to MITs undertaking CPD (Elshami et al., 2016). Although issues around paying for CPD were not reflected in the work of Stagnitti et al. (2005), who noted that despite differences in budget allocation for CPD between private and public employers, most respondents were prepared to share CPD costs with their employers. The differences in these outcomes could be due to the CPD requirements for each of those countries. For example, Elshami et al's (2016) study was undertaken in the Sudan when MIT CPD was voluntary not mandatory, whereas, Stagnitti et al. (2005) reviewed a number of healthcare professions in Australia for whom CPD was mandated. Another budgetary consideration is that travel costs to attend training events are a barrier, especially for MITs working in rural areas, including those in NZ (Bwanga, 2020; Henwood & Flinton, 2012). While costs and staffing levels are potential barriers to effective staff training, these are also affected by individual motivation and the workplace culture (Elshami et al., 2016; Kanamu et al., 2017). Despite this, there seems to be limited research as to whether budgetary constraints may have influenced the introduction of digital technology and consequently the training and support staff were offered.

2.7 Summary

This chapter has demonstrated that although the introduction of digital technology has occurred over the last 25 years, there remains a level of confusion within the radiography profession at a global level, in relation to the use of digital imaging equipment. Some of this is at a foundational level of knowledge and understanding. The need to ensure the profession has the correct educational training in this area is paramount. However, there are multifactorial issues which impact on the ability to produce effective training. Some of these issues relate to budgetary constraints, the integration of evidence-based practice, and cultural influences. Underlying all these factors are the historical influences associated with medical imaging, which continue to dominate and affect current radiographic practice and the ability for MITs to be considered as healthcare professionals.

The literature has demonstrated that there is a need to investigate key topics regarding digital technology such as factors which may have influenced MITs knowledge, understanding, and perceived competencies in the application of this technology in clinical practice.

In the next chapter, I describe the paradigm and methodology selected to answer my research question.

Chapter 3 Research Methodology

3.1 Introduction

In this chapter, I discuss the research methodology and methods used to answer my research question: **How has the introduction and ongoing use of digital imaging technology affected MITs in Aotearoa NZ?** The rationale for using a pragmatist philosophy, plus a mixed methods research methodology, is included. My position within the research is identified and an explanation of the research methodology is included.

3.2 Research paradigms

The term "paradigm" was originally coined by Thomas Kuhn (Kuhn, 1962). Since then, different meanings have been attached to it, but is generally understood to be a human construction of a "set of beliefs or worldview" which identifies the reality of the world and the place the individual has within it (Guba & Lincoln, 1994). Other authors use alternative terminologies such as "research methodologies" or "epistemologies and ontologies" (Creswell & Creswell, 2018. p. 5). Nevertheless, the researcher's worldview influences their thinking and the way in which they interpret the world. It encompasses axiology; epistemology; ontology; and methodology. It defines the philosophical assumptions of the researcher and underpins the research process (Kivunja & Kuyini, 2017). As such, it will also determine the methods adopted by the researcher (M. E. L. Brown & Dueñas, 2020).

Axiology is related to the values of the researcher, the context of the study and its potential value as well as the ethical issues to be considered (M. E. L. Brown & Dueñas, 2020). It includes the philosophical approach in decision making and a full appreciation of human values and behaviours throughout the research process. The axiological assumption is related to all of these aspects and whether they are made overt in the research process (Creswell, 2007).

Epistemology is related to the process of gaining knowledge. It is based on what knowledge is, how it may be acquired and communicated (Scotland, 2012). Crotty (1998) identified three epistemological viewpoints: objectivism, constructionism, and subjectivism. Objectivism proposes there is an objective truth that can be identified i.e.

realities exist regardless of consciousness, thus, the researchers see themselves as separate from the generation of knowledge. Constructionist understanding is created through interactive human engagement with the world, in which the subject and the object are inextricably interlinked. Subjectivist meaning is created from the ways in which the subject dictates meaning onto the object i.e. the ways the individual sees and interprets things.

Ontology considers the nature of existence and what is real. It incorporates an understanding of knowledge, truth, and reality i.e. what constitutes the real world and what can be learnt about it. For positivism this would equate to one verifiable reality, whereas for the interpretive paradigm there are multiple constructed realities (Denzin & Lincoln, 2011).

The methodology is the overarching strategy or plan as to how knowledge will be gathered within the research study. It governs the choice of methods used for data collection and analysis (Scotland, 2012).

The four major worldviews (paradigms) identified by (Creswell & Creswell, 2018) are postpositivist, constructivist, pragmatist, and transformative. The choice of paradigm and methodology selected for a research study is affected by a variety of factors, which include the researcher's worldview, the research focus, and the audience for whom the study is written (Creswell, 2014). The usefulness of any paradigm is dependent on the researcher being able to determine its ability to evaluate the research area, more effectively than another. The epistemological standpoint of my study was based on the pragmatic paradigm.

3.2.1 Pragmatism

Pragmatism was established principally from the work of Peirce, James, Mead and Dewey (Creswell & Creswell, 2018). Pragmatists believe that knowledge is both historically and socially constructed, however the value of that knowledge and how it is "known", is based on its ability to address context specific, practical questions. Unlike Cartesian philosophy which argues truth from a known and certain standpoint, pragmatism accepts that the evaluation and careful processing of errors can lead to their identification and elimination in the future (Hannes & Lockwood, 2011). Thus, a key feature of pragmatism is the contextualisation of knowledge, while the perceived benefits of that knowledge may change as the context differs. As such knowledge cannot be viewed as generalisable, rather it can be utilised when encountering new issues to review the problem and determine potential solutions (Long et al., 2018). Due to the ability to incorporate both qualitative and quantitative research methods, pragmatism is often claimed to be the paradigm of choice for mixed methods research.

It is important to acknowledge the classification of pragmatism as a paradigm, has been disputed by some authors. For example, Denzin & Lincoln (2011) state that it does not have any philosophical underpinning but rather focusses on the viewpoint that meaning and truth cannot be determined prior to an experienced event. As such it goes beyond the scope of a methodology. Additionally, the "neopragmatist" approach of Rorty, Habermas and West is so entrenched in "interpretive, hermeneutic" (p. 246) tradition that its compatibility with mixed methods research is refuted. Denzin & Lincoln stipulate pragmatism is neither a paradigm nor a methodology. Similarly, Biesta (2010) espoused that pragmatism should be viewed as a group of "philosophical tools" (p. 3) to resolve research questions rather than providing the philosophical underpinning of mixed methods research.

Morgan (2007) claims, however, that Kuhn's original definition of a paradigm is open to debate and could instead be considered as an epistemological stance and a shared belief system. A number of authors consider that pragmatism meets the definition of a paradigm, particularly when linked to Deweyan pragmatism (J. N. Hall, 2013; Johnson & Onwuegbuzie, 2004; Morgan, 2014). This philosophical approach is to answer the question what is "the nature of human experience?" (Morgan, 2014, p. 1048) through research communities with common aims and goals (Hannes & Lockwood, 2011). Therefore, the common arguments against the classification of pragmatism as a paradigm, which include the researcher taking an a-paradigmatic stance (in which paradigmatic viewpoints are ignored) or using the most expedient approach to the research focus, are overcome with the utilisation of Deweyan pragmatism (J. N. Hall, 2013; R. Hall, 2013).

While there are many different versions of pragmatism, a key tenet is that it is pluralistic and solution focused, wherein it attempts to find answers to real world dilemmas by using a problem-centred approach (Creswell & Plano Clark, 2017).

Furthermore, “pragmatic research is driven by anticipated consequences” (Cherryholmes, 1992, p. 13). That is, pragmatism accepts that different approaches can be utilised to answer research questions. Hence, it is particularly useful for research that cannot be answered through a purely scientific or constructionist approach. It acknowledges the epistemological differences between these approaches but does not see them as incommensurable (Bishop, 2015). Rather, it values both subjective and objective knowledge to ascertain the behaviours of participants, determine the beliefs behind those behaviours and the potential consequences of said behaviours (Kivunja & Kuyini, 2017).

Pragmatists recognise that to identify and eliminate errors, action is required to bring about change. For Dewey, action is the cathartic agent which creates change. To be effective, action must be guided by a sense of purpose and underpinning knowledge. Thus, there is an inextricable link between human reasoning, knowledge, and action, which changes the world. As a result, actions also drive cognitive and conceptual development (Goldkhul, 2012). Central to pragmatic research is Dewey’s concept of inquiry. The pattern of inquiry he promoted is more closely linked to practical problem solving than other philosophers linked to the development of pragmatism (Hannes & Lockwood, 2011). Dewey defined it as “Inquiry is the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituents, distinctions and relations as to convert the elements of original situation into a unified whole” (Dewey, 1938, p. 108). Therefore, it could be argued from Dewey’s perspective that the aim of pragmatic research is to produce knowledge which has positive consequences for people and society, using knowledge as a tool to solve problems.

The literature has identified that the use of digital technology has created issues within medical imaging practice, such as the overreliance on manufacturer pre-set exposures (which may or may not be accurate), and an increase in radiation exposure to ensure images of diagnostic quality, i.e. “dose” or “exposure” creep (Hayre, 2016). Namely, there have been unintended consequences following the introduction of digital imaging technology. These include gaps in MIT knowledge, which have influenced clinical practice (Hayre et al., 2017; S. Lewis et al., 2019a; Seeram et al., 2015). Levin & Greenwood (2011) state that pragmatism can be used to create an effective connection between theory and practice. Furthermore, pragmatism has been identified as a paradigm which lends itself to mixed methods research in which the researcher is focussing on problem solving (Greene & Hall, 2015). Therefore, pragmatism would seem an appropriate paradigm for my sequential exploratory mixed methods design, with two phases of data collection. Further detail on the factors which influenced my choice of paradigm and methodology for this study follow.

3.3 My worldview

As a researcher, I recognise that I will have brought my own values and beliefs into the research process (Creswell, 2007). My epistemological and ontological standpoints mean that this thesis reflects my interpretation of truth and perceptions of reality. This study aimed to find meanings in the way the transition to digital imaging had been experienced, MITs' knowledge and perceived competencies of digital imaging systems and whether the ongoing use of this technology may have influenced MIT clinical practice. As such the data and my interpretation of them, is situated within a specific moment in time and is not designed to produce generalisable findings.

Initially I struggled with defining my perspective. In considering the research paradigms, I initially felt more drawn to postpositivism. This was probably shaped by my training and work as an MIT. Despite various technological changes, medical imaging continues to rely on the ability to produce "quantitative information about the properties of anatomic tissues and their functions that relate to and are affected by disease" (Robb, 2006, p. 26). This statement indicates a link between medical imaging and the positivist or postpositivist paradigm. Similarly, the historical origins of medical imaging have also influenced the way medical imaging practice, research and development has been shaped. Specifically, this points to the patriarchal dominance of the medical profession, resulting in MITs having little autonomy to make independent decisions regarding imaging procedures. The managerial role of radiologists has allowed their beliefs and attitudes to predominate in medical imaging departments, perpetuating the "handmaiden" or "butler" relationship between MITs and radiologists (Ferris, 2005, p. 195). Further, the dominance of research paradigms have focused on the production of empirically based knowledge (Bunniss & Kelly, 2010). It is generally accepted that adherence to one paradigm will influence and predetermine how theory is developed for a specific discipline. As a result this will determine the knowledge used in practice (Weaver & Olson, 2006). When considering all of these influences, it is unsurprising that research within medical imaging has tended to sit within the positivist or postpositivist paradigms of objectivism (Newton-Hughes, 2015).

While I could appreciate the deterministic perspective of cause and effect, the reductionist approach and the philosophy of an objective reality which may be observed and measured, did not sit comfortably with me. This was because I was not solely interested in looking for a causal relationship between knowledge and clinical practice. I also wanted to explore the MIT experience of the transition process, to gain an understanding of the complexities and tensions that the adoption of new technology may have created. As such the study would incorporate MIT perspectives, which had been socially and individually constructed within a specific period of time, as well as statistical data related to knowledge and competency rankings.

Despite the previous commentary about the objective nature of medical image data and the influence of the positivist or postpositivist paradigms on medical imaging practice, subjectivity is inherent within medical imaging. Subjectivity is primarily created through individuals constructing and ascribing meaning to the quantitative image data presented before them. This subjectivity affects both MITs and radiologists in their daily tasks; for example, through MIT assessment of image quality or during the radiologist reporting process. For the MIT, image quality is determined by the physical characteristics of the imaging system, the technical factors selected by the MIT, plus human perception. EI values are seen as providing a quantitative measure to ascertain whether the correct exposure factors have been selected. However, documented difficulties using EI values due to their unreliability and a lack of MIT knowledge (Jamil et al., 2018; S. Lewis et al., 2019a; Seeram et al., 2015), suggest that a continued visual (and subjective) assessment of exposure factors is undertaken by MITs.

Digital imaging allows the MIT and the radiologist to apply different computer algorithms to manipulate and enhance the image, with the aim to improve the appearance of the image and therefore the diagnostic outcome (Seeram, 2019). This task is known as post-processing (Ween et al., 2005). Post-processing may be undertaken by the MIT at the workstation monitor or by the radiologist on the reporting monitor (Seeram, 2019). The monitors used by the MITs are frequently of a lower standard than that of the radiologists (American College of Radiology, 2017). This has been previously identified as a cost based decision, in an attempt to reduce overall costs when transitioning to digital imaging systems (S. Lewis et al., 2019b; Peer et al., 2006). The quality of the workstation monitor must enable the MIT to determine whether the image is of an appropriate standard or needs to be repeated (Fauber, 2016). This is particularly significant when assessing image noise levels, as image noise evaluation can be more difficult on low grade monitors (American College of Radiology). The variability in workstation set-up and monitor quality make it virtually impossible to ensure display comparability, introducing a level of subjectivity when assessing the diagnostic utility of an image (Butt et al., 2012; Reiner et al., 2003).

MITs also evaluate the diagnostic value of their images through their underpinning theoretical knowledge, combined with clinical site protocols. Makanjee et al. (2018) described MITs using both retrospective and current knowledge to support decision making. Coupled with the use of analytical and intuitive skills (Bowman, 1997), this introduces a further level of subjectivity, despite MITs reviewing their images against specific acceptance criteria. This is particularly prevalent when deciding whether a projection should be repeated and the answer is not “clear-cut”. In this scenario, the MIT has to consider on a case by case basis whether: an extra projection will provide additional missing information which is required to answer the clinical question; if the benefits of the increased radiation dose will outweigh any potential risks to the patient (Quinn & Bowman, 2014; Strudwick, 2013).

Subjectivity is also introduced due to variability in individual eye-brain performance, fatigue and external distractions (Alsleem & Davidson, 2015). These factors affect MITs and also radiologists during image evaluation and interpretation (Waite et al., 2017). Following completion of image acquisition, diagnosis is rarely a binary process i.e. normal/abnormal but a subjective process which relies: on the radiologist’s experience (Waite et al.), an understanding of radiologists inherent biases (Busby et al., 2018), and the ability to determine a differential diagnosis. It is recognised within medical imaging that radiographic appearances are not necessarily specific to one disease and may therefore represent multiple realities. It is the radiologist’s role to determine what those realities are and from there create a list of potential differential diagnoses (Eisenberg et al., 2010).

In essence, radiographic practice is focused on the interaction of individuals with technological equipment in the process of the diagnosis or treatment of disease (Hammick, 1995). The context specific nature of radiographic images was recognised by Strudwick (2014) who identified that the image encapsulates not just the science of producing an image from X-rays but it is also a record of the unique interaction that occurs between the patient and the MIT. Consequently, radiography has been described as both an art and a science (Baird, 1995; Benfield et al., 2020). This duality allows for flexibility when selecting methodological approaches to radiography research (Metsälä & Fridell, 2018). Medical imaging research may therefore utilise positivist/postpositivist, constructionist and mixed research methodologies (Scally & Brealey, 2010). Considering the duality of medical imaging practice, allowed me to conceptualise my position as a researcher. As such it assisted me in identifying the relevant paradigm and methodology for this study.

3.4 Determining the research paradigm and methodology

To help me determine the most appropriate paradigm and methodology, I considered the key drivers which had led to my research focus. Problems with the use of digital imaging equipment have been well documented (Hayre, 2016; S. Lewis et al., 2019b; Moore, 2016) and much of it seems to relate to a lack of understanding of the equipment. However, more importantly for me was the potential impact on patient care, specifically in relation to radiation protection. Both factors were influential in me developing my research question and can be related back to my career as a medical imaging practitioner. I believe the following experiences were notable in influencing me:

- As a Radiation Protection Supervisor in the UK, I lectured on the importance of radiation protection to General Dental Practitioners, MITs, Dental Nurses and Hygienists.
- I personally experienced the transition from F-S imaging to CR imaging. The level of training I received left me feeling my knowledge base had been eroded. This was amplified when I was unable to find satisfactory answers to my questions.

- As a medical imaging educator, I have a strong interest in educational pedagogies and knowledge transfer. In particular, I am interested in the synthesis of academic theory with clinical practice and experiential learning theory.

I became aware that despite the research indicating there were issues with digital imaging equipment, there seemed to be a paucity of evidence identifying the underlying reasons for these problems or potential solutions. This prompted me to consider how MITs resolve practical dilemmas through their clinical decision-making skills. For example, one issue is the comprehension of the spatial relationships of projection geometry and applying these when imaging paediatric patients or patients from trauma situations. In these scenarios, patients may not be able to co-operate or achieve the required anatomical positions to produce the desired result. Therefore, the MIT uses their knowledge, adapting their technique to create a diagnostic image while maintaining patient care and safety (Quinn & Bowman, 2014).

Due to the nature of their work, MITs are considered to be good at using their abilities to problem solve in the moment to achieve the desired results. That is, they consistently work out what needs to be done at the time and determine how it can be achieved, despite the contextual constraints they may be facing (Baird, 1996). Effective application of problem solving and clinical decision-making skills in healthcare and medical imaging have been linked to the integration of theory into practice, self-reflection and experiential learning (Baird, 2008; Standing & Standing, 2010). In turn, these have been connected to experiential learning theory and Deweyan pragmatism (Beaudin & Quick, 1995; Kolb & Kolb, 2009). Pragmatism as a research paradigm focusses on the historical and social context of a problem (Creswell & Creswell, 2018) as well as attempting to provide solutions to practical problems (Greene & Hall, 2015; Weaver & Olson, 2006). As a researcher, I was aiming to not only explore and understand why some of the documented issues associated with digital imaging may have arisen. I also wanted to produce knowledge which would have a practical outcome. As such my study reflected key tenets associated with the pragmatic paradigm (Greene & Hall, 2015; Prasad, 2021).

3.5 Mixed methods research

The underlying premise associated with mixed methods research is that there are benefits and drawbacks to both positivist/postpositivist and constructionist methodologies (Creswell & Plano Clark, 2017). Mixed methods design aligns with postpositivist, constructivist, transformative and pragmatist worldviews (Creswell & Plano Clark). The use of multiple paradigms within mixed methods is accepted by the authors, who commented that the researcher may alternate between a constructivist perspective during the qualitative phase to a postpositivist one in a survey. They concluded that the researcher's worldview may change during the research and that the worldview may differ according to the phase of the study. Neither of these are problematic if the researcher identifies, reflects, and discusses their worldview in the context of their work. However, Giddings & Grant (2006) highlighted that postpositivist assumptions underlie many mixed methods research studies and trying to move between different worldviews may lead to "unacknowledged contradictions" (p. 9) when interpreting findings. This is supported by Bishop (2015) who identified the importance of maintaining the epistemological integrity for each constituent part of a mixed methods study. It is therefore essential that the researcher recognises their epistemological, ontological beliefs and axiological values to ensure methodological congruence is demonstrated between the research question and the methods.

Mixed methods research permits the researcher to assess the area of interest from different perspectives, potentially allowing for a deeper understanding of the phenomenon than may be achieved by using one approach. This is particularly useful when making decisions relating to clinical practice. Research within the healthcare environment includes the investigation of highly complex and multi-layered processes and systems, which may necessitate the use of both quantitative and qualitative data to answer the research question. For example, qualitative research may be utilised to consider why or how a phenomenon occurs, or to illuminate an individual's experience, whereas quantitative research can determine cause and effect and produce generalisable conclusions. Using a mixed methods approach is valuable when "focusing on research questions that call for real-life contextual understandings, multi-level perspectives, and cultural influences" (Creswell et al., 2011. p. 4).

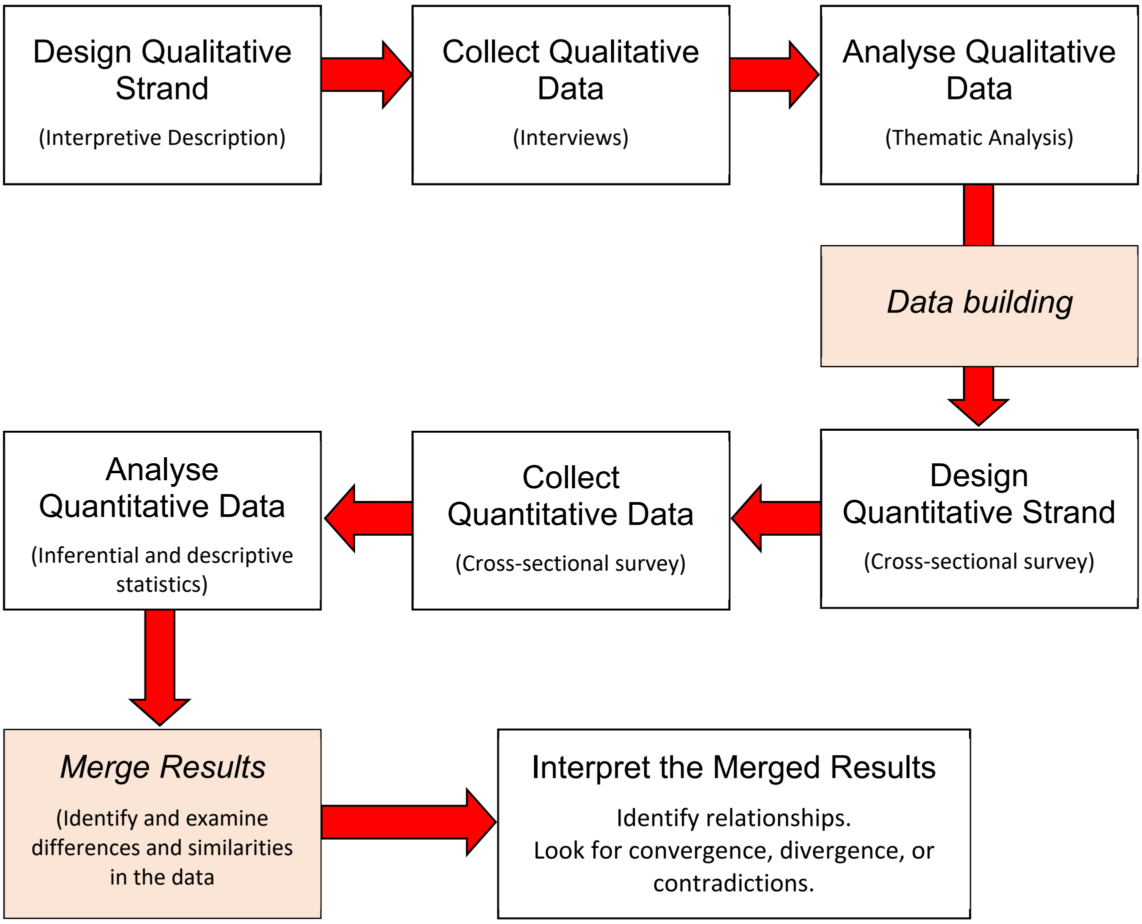
Other benefits of using a mixed methods approach are that complex phenomena can be researched. Plus, a rich and broad focus may be achieved through using different approaches to data collection (Giddings & Grant, 2007). Health related research can therefore lend itself to the use of mixed methods, which draws on the strengths of both qualitative and quantitative designs (Fetters et al., 2013). Disadvantages associated with mixed methods include the time-consuming nature of the approach, both at the beginning of the project and at the end, when the researcher is looking for convergence, divergence, or contradictions within the phases (Giddings & Grant, 2009; Larmer, 2009). Nevertheless, the use of mixed methods approach in clinical practice, where the positivist paradigm has historically predominated, can be beneficial. Although it can present difficulties in terms of mediating contrasting evidence, it has the potential to reveal important information, which hitherto was hidden or unreported (Larmer, 2009). My research question focuses on the use of digital technology in MIT practise, which is a complex phenomenon with multifaceted layers linked to a very real clinical issue. Therefore, it was considered appropriate to use a mixed methods research design to investigate the research aim.

While there is no overarching definition of mixed methods research, it does incorporate specific characteristics i.e. both qualitative and quantitative data strands are collected within the same study; mixing or integration of the data occurs; and the processes are undertaken in a logical order which reflects the aim of the study (Creswell & Plano Clark, 2017). Mixed methods approaches encompass a number of different designs. Determining which design to utilise depends on the area under investigation and the nature of the research question (Creswell & Plano Clark). Fixed (planned) or emergent designs are used in mixed methods. A fixed design is one in which the researcher has pre-determined both qualitative and quantitative data collection will be required. Conversely an emergent design is generally adopted when it becomes apparent, through the research process, that one method is insufficient to answer the research question. A typology-based approach is considered particularly beneficial for researchers who are inexperienced in designing and undertaking mixed methods research. As such they provide the researcher with a framework on which to base key decisions (Creswell & Plano Clark). One mixed methods typology is the sequential exploratory design, in which the qualitative information is collected and the data analysis allows for theme development, which is subsequently used in the partial or complete design of the quantitative data collection process (Creswell, 2013). I determined that a sequential exploratory design would be the most useful in answering my research question: **"How has the introduction and ongoing use of digital imaging technology affected MITs in Aotearoa NZ?"** Exploratory sequential designs prioritise the gathering and analysis of qualitative data in Phase One. From there the researcher is able to create a quantitative second phase supported through the development of an intervention for example (Creswell & Plano Clark, 2017), or as in my case, a survey.

Mixed methods data analysis frequently combines statistical and thematic analysis, in conjunction with crystallisation and data conversion, which are considered to be specific to mixed methods. Tracy (2010) highlighted the benefits of using crystallisation, particularly within the "constructivist, critical or postmodern paradigms that view reality as multiple, fractured, contested, or socially constructed" (p. 844). This is because it encourages the researcher to utilise a variety of data types created by different methods to create complex "partial understanding" (p. 844). In so doing, it gives the potential for each data source to provide an important, unique, and complementary rather than competing perspective to the phenomenon. Through these approaches the researcher is able to ensure they interpret the data sets and results to determine how the analysis answers the mixed methods research question (Creswell & Plano Clark, 2017). This is supported through identification of the weighting and timing allocated to each component, and decisions about how mixing of the qualitative and quantitative data will occur (Creswell & Plano Clark). Timing is considered not only in relation to the data collection but also when data analysis occurs. Weighting refers to the level of importance the qualitative and quantitative strands are given and whether the entire study is methodologically congruent (Creswell & Plano Clark). The mixing decision is dependent on the aims of the research and relates to how the two strands are amalgamated, encompassing more than just combining two sets of data (W. Zhang & Creswell, 2013). Amalgamation can take place at different stages in the research process and may occur in a variety of ways. These are known as connecting, building, merging, and embedding, with one or more of these seen within a single research study (Fetters et al., 2013). *Connecting* occurs through the sampling strategy i.e. the participants from one phase are recruited for the other. This type of synthesis may occur whether the research is a convergent or sequential explanatory design. *Building* happens at the design stage in a sequential exploratory design, when the second phase data collection develops from the first. During the methods stage, amalgamation through *merging* occurs when the data sets are brought together to be compared and analysed. This generally occurs after analysis of individual data sets. Amalgamation via *embedding* occurs when the collection and analytical process link together at numerous points. Embedding may include any combination of merging, building, or connecting. However, the key aspect is the repeated linkage of the quantitative and qualitative data collections at multiple points (Fetters et al.). Both building and merging were drawn on in my study and Figure 2 below provides an overview of my approach.

Figure 2

Flowchart of mixed methods exploratory sequential design



Note. Adapted from Creswell & Plano Clark, 2017 & Fetters, Curry, & Creswell, 2013.

Two phases were incorporated within my study design. Phase One aimed to gain an in-depth understanding of how MIT's have experienced the introduction and ongoing use of new technology, and its perceived impact on practice. Interpretive Description was considered an appropriate methodological choice in this first phase given its focus on developing understanding and insight into complex clinical situations. The first phase used individual, semi-structured interviews to gather thick data and contextual understanding from practising MITs who had experienced the introduction of digital technology. Analysis of the Phase One data helped inform the survey design for Phase Two. In Phase Two, a self-administered cross-sectional survey was designed to capture quantitative data relevant to MIT knowledge and perceived competency, and explore statistical relationships between these constructs. The development of the survey, examining contradictions across both data sets, identifying overlapping themes and adding breadth and depth to the study, were all key to answering the research question. Although there was building through the development of some questions for the survey, the focus of the survey was also complementary and explored distinct aspects of the phenomenon compared to the qualitative data. Therefore, full merging and data interpretation took place after the quantitative phase. It was anticipated that resultant data sets would produce either complementary or disparate findings which would lead to an in-depth understanding of the current knowledge and perceived competencies MITs have of digital imaging and its application, plus an understanding of what MITs experienced when this technology was introduced and its potential impact on practice.

3.6 Interpretive Description

Interpretive Description aligns with the interpretive/constructivist paradigm and uses aspects from naturalistic inquiry, grounded theory and ethnography (Thorne et al., 2004). Interpretive Description draws on the general tenets of the interpretive/constructivist paradigm in that:

- reality is experienced holistically and is affected by the attitudes, beliefs, and meanings that individuals give to their experiences;
- interactions between the researcher and the study participants are inevitable and will affect both parties, as well as the knowledge constructed between them;

- findings are time and context bound;
- causal relationships are impossible to determine as "causes and effects are inextricably intertwined";
- the nature of inquiry is value bound (Guba & Lincoln, 1982, p. 242) .

Interpretive Description differs from other methodologies as it does not draw on a specific philosophical lens. Rather through the focus on complex clinical practice issues, it acknowledges disciplinary-based assumptions and may also incorporate practice-based theory, knowledge, and experience. The purpose of Interpretive Description is to allow the researcher, through an analytic and inductive approach, to deepen their understanding of clinical phenomena (Thorne et al., 2004).

Interpretive Description is not designed to create new truths but looks to search for and understand the truth that already exists. It does this through the recognition of broad themes and patterns to highlight how phenomena may be similar or relate to each other. As such, Interpretive Description is well suited to research seeking to consider human experience and behaviours in the clinical environment and/or evaluating significant problems related to practice (Thorne, 2016). Interpretation is created and guided by informed questioning and critical reflection, which can then be used to inform discipline-specific practice. Typical questions are related to the thoughts and feelings experienced by people when encountering certain challenges or transitions. The use of the existing literature and knowledge base is considered vital and creates the primary "theoretical scaffolding" (Thorne, 2016, p.60). From this initial framework the researcher can determine the specifics of the research method. However, as the study progresses the researcher should move away from their initial position, as "alternative conceptual emphases and intrigues arise" (Thorne et al., 2004, p. 5).

For this study, I undertook a critical literature review to gain an understanding of what was already known about the transition to digital imaging. This allowed me to confirm that problems had been identified with this transition, and there was a gap in the literature as to how some of these issues may have arisen or could be resolved. The second component in scaffolding the study requires the researcher to position themselves within their discipline, specifically because Interpretive Description recognises that the researcher's actions and thinking will influence and shape the research process and outcome (Thorne, 2016). This study is situated within the Medical Imaging discipline. My experience as both a practitioner and educator within this field have influenced all aspects of this study, including the literature review, the formulation of the research question, the choice of methodology, and the language I have used. Throughout the study it was important for me to recognise that my experiences would influence the assumptions and conclusions I may draw.

Given that my research sought to answer clinically focused questions relation to MIT practice, I considered Interpretive Description to be an appropriate methodology to utilise in Phase One.

3.7 The link between Interpretive Description and pragmatism

While Interpretive Description is situated within the constructivist paradigm, Thorne (2016) stated that it is positioned midway on a scale which ranges from objective reality at one end and subjective impression at the other. She continued that it uses both socially constructed knowledge and factual information to create meaningful understandings. This indicates a potential link to pragmatism. Namely, pragmatism accepts different methodological approaches can be used to answer research questions and Interpretive Description accepts that different analytical approaches can be used to support interpretation.

The connection between human knowledge, reflection and the development of potential solutions or changes is explicit within both Deweyan pragmatism and Interpretive Description (Biesta, 2010; Thorne, 2016). In terms of philosophical underpinnings, Thorne stipulated that as Interpretive Description is outside of a "theoretical tradition" within social science research, studies do not need to be undertaken with a specific philosophical approach. However, one may draw on, and introduce, philosophical perspectives as the research progresses, when it feels appropriate in order to address the aims and purpose of the research (Thorne). This is a factor which clearly resonates with pragmatism, as the focus is on flexibility and plurality of methods to address the aims and purpose of the research and to ensure the research has practical utility. Furthermore, Thorne's identification that critical reflection of what is known as a requirement to inform clinical practice, links to

Deweyan pragmatism and the need to create knowledge and understanding through experience (praxis) and reflection.

Dewey considered "truth", to be constructed through the process of problem solving. These constructions were considered neither absolute nor random (Hickman, 2009). Dewey encapsulated this in the term "warranted assertibility" (Neubert, 2009, p. 25). Interpretative Description creates "tentative truth claims" in relation to clinical practice (Thorne et al., 2004, p. 7). Like pragmatism, truth is not absolute nor arbitrary, rather it is a constructed contextual understanding based in part on experiential knowledge. The identification of five commonalties between constructivism and pragmatism were discussed in depth by Reich (2009). These are:

- the rejection of metaphysics i.e. the positivist belief that knowledge is created through empirical means;
- knowledge is constructed and situated within a cultural context;
- the need for democracy i.e. the more varied and numerous the shared interests of a group, the more development and growth there will be;
- constructions of reality are created as potential solutions to problems, these constructions are not random but occur from inquiry;
- learning is created through inquiry, values generated via shared communication, and leads to desired growth.

The last point highlights that Dewey's concept of the learning process is the main "precursor of constructivist learning theories" (Reich, 2009, p.64). The relevance of these factors within my research study relate to the complex contextual nature of medical imaging practice.

In summary, there is a link between Interpretive Description and pragmatism. Interpretive Description is designed to critically evaluate clinical issues and what is already known. It attempts to seek out and test alternative approaches and their potential outcomes in an effort to inform understanding and improve clinical practice (Thorne, 2016). Pragmatism requires critical reflection of what is known, followed by action and further evaluation in an attempt to "create knowledge in the interest of change and improvement" (Goldkhul, 2012, p.6).

3.8 Cross-Sectional surveys and pragmatism

Cross-sectional surveys are widely used in healthcare research and are able to produce results which may support the development of policy guidelines or clinical practice (Ellis, 2014). Cross-sectional designs are used as an exploratory approach to produce information or describe attitudes or behaviours about a specific phenomenon, at a particular point in time (Bethlehem, 1999). They are also particularly beneficial for evaluating the prevalence of a phenomenon or problem (R. Kumar, 2014). However, as the information produced will relate to the population being studied at that moment in time, cross-sectional studies are unable to determine cause and effect (Heddle, 2002). Similarly, pragmatism is considered to be an approach which does not expect to find causal links as a result of inquiry into a specific phenomenon, but looks to clarify meanings (Cherryholmes, 1992). Any causal links which are uncovered are considered transitory and context bound (Feilzer, 2010).

Cross-sectional surveys collect quantitative, qualitative or a combination of qualitative and quantitative data, which can be used to generate new hypotheses (Ellis, 2014). The processes used in a cross-sectional surveys include: identification of an area warranting investigation; the generation of a research question; hypothesis testing; and discovery of any association between variables (Mann, 2003). The link to pragmatic inquiry is evident through Johnson et al.'s (2017) description that for Dewey inquiry starts with a “feeling that something is amiss” (p. 73). This allows for an issue to be identified and the creation of a hypothesis. The hypothesis is reviewed to check whether revisions are required and subsequently tested. The link between cross-sectional designs and pragmatism is also seen in Miettinen's (2000) comment that Dewey identified inquiry as an experimental process through which knowledge could be created. Specifically, the identification of an issue via observation is used to create theories and hypotheses which are then tested through action. The testing may not confirm hypotheses but can provide new insight, knowledge or support the formation of new theories (Elkjaer, 2009; Miettinen, 2000), once again aligning with cross-sectional designs.

An advantage of a cross-sectional survey design is that it is considered to be an efficient way to initially explore an area of interest and determine whether further study would be useful. Occasionally undertaking such a survey will rule out alternative explanations of a phenomenon (Spector, 2019). This suggests that a cross-sectional survey design would reflect a pragmatist approach of basing the choice of research methods on the practicalities of what will work best in practice (M. E. L. Brown & Dueñas, 2020).

In summary, cross-sectional study designs can be linked to pragmatism through a data capture process which is time and context bound. Neither cross-sectional designs nor pragmatism claim to identify cause and effect, or findings which can be generalised to another population. Furthermore, Dewey's process of inquiry and the stages adopted during a cross-sectional design are similar. Therefore, the choice of a cross-sectional survey for Phase Two was considered to be methodologically congruent.

3.9 Summary

Ensuring congruence between the research study and its design, governed the choice of paradigm and methodology. These were also affected by my epistemological and ontological perspectives, as well as my professional discipline. The pragmatic paradigm is one well suited to answer my research question, given its orientation to solving practical problems (Kaushik & Walsh, 2019). A mixed methods design provided a viable approach to evaluating the transition to digital technology. This was due not only to its alignment to the pragmatic paradigm, but also because it allowed me to gain an in depth understanding using both qualitative and quantitative data collection and analysis. For the interview phase, Interpretive Description was an appropriate methodology, as it is aligned to a changing health care environment and focused on informing clinical understanding (Hunt, 2009; St. George, 2010).

This chapter has considered my choice of paradigm and methodology. I have described some of the benefits and drawbacks of mixed methods research, and my choice of a sequential exploratory design. I have identified my choice of Interpretive Description as an appropriate methodology for Phase One of the research and have considered the links between pragmatism and a) Interpretive Description and b) cross-sectional survey designs.

In the next chapter, I discuss the methods employed in undertaking this research study.

Chapter 4 Method

4.1 Introduction

In this chapter, I describe the methods used to answer my research question **"How has the introduction and ongoing use of digital imaging technology affected MITs in Aotearoa NZ?"** I consider how each phase of the two-phase sequential exploratory mixed methods design was utilised to answer the research question. I describe the sampling and recruitment processes I adopted, how issues of trustworthiness and rigour were met, approaches to data collection and analysis, and how ethical considerations were incorporated into the research.

4.1.1 Research questions for each phase

Phase One was designed to gain an in-depth understanding of MITs' personal experiences of the introduction and ongoing use of digital technology. The guiding research question for this phase was **"What are the experiences and perceptions of MITs regarding the introduction and ongoing use of digital imaging technology?"**

Semi-structured interviews were used to answer this question. Interpretative Description was used to analyse the data and generate themes, which subsequently supported the creation of the cross-sectional survey for Phase Two.

The purpose of Phase Two was to describe and identify factors influencing MITs' knowledge and understanding of digital imaging and its application, as well as their perceived competence in using digital technology. The research questions linked to this phase of the study were:

1. **What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application?**
2. **What factors are related to MITs knowledge of and perceived competence in the use of digital technology?**

To address these research questions, they were broken down into more specific objectives as follows:

1. In relation to clinical practice, do MITs understand:

a) how digital systems respond to different levels of radiation exposure?
b) how different functionalities of the equipment influence best practice?
c) whether their practice is meeting the ALARA principle?

2. What factors are related to MITs' knowledge and understanding of the practical application of digital technology? It was hypothesised that:

   a) MITs who learnt about FPDR or CR in their undergraduate programme would demonstrate higher levels of digital technology knowledge.
   b) MITs who had received training in FPDR or CR technologies would demonstrate higher levels of digital technology knowledge.
   c) MITs who spend more time using FPDR or CR equipment on a weekly basis would demonstrate higher levels of digital technology knowledge.

3. What factors are related in NZ MITs' perceived competence using digital technology? The aim was to describe MITs' self-perceived competencies in the use of digital technology, and identify whether sociodemographic characteristics or context specific factors were associated with feelings of competency.

The development, piloting, and distribution of a cross-sectional, self-administered survey with a set of pre-defined questions was used in addressing these questions.

4.2 Participants

MITs were eligible to participate if they held a current Annual Practicing Certificate (APC) and were working at least 50% of the time in planar radiography. MITs were excluded if they were working under an NZMRTB supervision agreement. These agreements indicate that the MIT is not currently considered to be competent to practise without direct or indirect supervision. Additional inclusion and exclusion criteria specific to each phase are detailed further below.

4.2.1 Phase One

MITs who met the above eligibility criteria were included if they had experienced the change from film to CR and/or FPDR. They were excluded if they were clinical tutors employed by Unitec Institute of Technology, due to the power differential that existed between myself as the academic leader of the Unitec Medical Imaging programme and their line manager. This could have led to participant vulnerability or potential conflict of interests.

4.2.2 Phase Two

There was no need to specifically include MITs who had experienced a change to digital technology in this phase, as the key focus was MITs' knowledge in relation to digital imaging. As such, all MITs who met the study eligibility criteria outlined above were included, unless they had already engaged in the research process either through participation on the study expert panel or pilot group (see page 80 for more details).

4.2.3 Sampling

For Phase One, purposeful and theoretical sampling was undertaken. Purposeful sampling was used to identify potential participants who would be able to provide in-depth information and knowledge relating to their experiences of the introduction of digital technology (Patton, 2002). The sampling approach primarily focused on capturing a diversity and breadth of experience. Analysis took place alongside data collection and so after the first few interviews, theoretical sampling was used to explore and refine preliminary analytical ideas (Thorne, 2016). The benefit of this approach was that as I began to consider patterns and themes within the data, it allowed me to determine whether what was being evidenced was anomalous, related to the study design, or reflected the participant cohort in some way. It permitted me to consider which individuals it would be helpful to interview to support the construction of themes.

Theoretical sampling was also undertaken to review findings i.e. what were the similarities and differences between and within groupings. I became aware that I had initially only interviewed participants who had been exposed to a change in technology within one imaging department. I was interested in exploring whether people who had used digital technology in more than one environment, experienced the same challenges and benefits. Early participants also spoke about the support networks they used including students, and so I also sought to invite participants who worked in an environment where students were not on placement, to consider whether this had an impact on support and practice. I was also keen to investigate whether the introduction of new technology presented itself differently to MITs who had learned about digital imaging systems as part of their undergraduate degree. Therefore, the sample included both those who had been taught about digital imaging systems in their undergraduate education and those who had not.

The sample size in Interpretive Description can vary with the primary focus on ensuring there are sufficient numbers to provide the required insight into the clinical issue under investigation (Thorne, 2016). Ten participants were recruited for Phase One. This was considered sufficient to allow for a rich, in-depth understanding of this phenomenon. Using a small participant number is also supported when the documented and anecdotal evidence indicates that the issues under investigation are commonly found in clinical practice (Thorne). "Information power" can also be utilised when determining the appropriate sample size for a qualitative research study. Information power is specifically linked to the premise that the more information participants have in relation to the specific research topic, the fewer the number of participants required. The factors which influence information power are "(a) study aim, (b) sample specificity, (c) use of established theory, (d) quality of dialogue, and (e) analysis strategy" (Malterud et al., 2016). If the research aim is narrow and very specific, as in my research study, then a small participant group is appropriate. The participants' level of knowledge and experiences of the research focus affect the sample specificity: the higher the level of knowledge and experience, the lower the sample size required. A high level of existing evidence and theoretical knowledge linked to the research focus supported the use of a smaller participant number. Similarly, clear and effective communication and an exploratory analytic approach increase the information power (Malterud et al.). When considering these factors in relation to my study, the size of my participant group is supported by:

- the narrow research aim;
- the use of purposive and theoretical sampling ensuring a high sample specificity;
- the level of existing knowledge associated with the introduction of new technology into medical imaging (as indicated in my literature review);
- my knowledge about the subject matter, combined with my interpersonal and communication skills ensured a high-quality dialogue; plus
- utilising an exploratory in-depth analytical approach to this phase.

Finally, it should be recognised that although the aim was to get as broad a spectrum of experience as possible, this was ultimately affected by the MITs who consented to be interviewed.

For Phase Two, participants were recruited through convenience (non-probability) sampling, i.e. a flyer was distributed to all MITs who were members of the New Zealand Institute of Medical Radiation Technologists (NZIMRT). Convenience sampling is used to target individuals who are accessible to the researcher and are likely to be easily recruited. Convenience sampling was used as it is considered an uncomplicated and economical technique to collect data (Sedgwick, 2013).

A link to the survey was emailed from the NZIMRT database to all 1793 NZ members (The New Zealand Institute of Medical Radiation Technology, 2019). The front pages of the questionnaire included an introductory letter, with details about the study as well as ethics approval information. This resulted in 12 responses. The initial invitation was followed up with an email reminder three weeks later. Due to the lack of responses, a link to the survey was distributed via social media (NZIMRT user group) which brought the total number of responses to 43, of which 23 were incomplete and not usable. To achieve a higher response rate, I attended an Auckland/Northland NZIMRT branch study day and provided the electronic link to the attendees and paper copies of the survey for people to complete if they wished to do so. Paper copies were provided in a blank envelope and an unattended collection box was left at the study day venue, so that confidentiality and anonymity could be maintained. Eventually, the total number of surveys received was 91 of which 49 were complete.

It was difficult to determine an accurate response rate, because assessing the number of MITs who met the inclusion criteria could only be estimated. Neither the NZMRTB or NZIMRT databases specify the proportion of time MITs spend working in planar imaging. My estimation was based on APCs issued by the NZMRTB in 2018, discounting APCS with a condition or more than one scope of practice. Namely of 3113 APCs issued, 50% seemed likely to meet the inclusion criteria i.e. working 50% time in planar imaging and not under a supervision agreement (The New Zealand Medical Radiation Technologists Board, 2019). Using 50% as a baseline indicator, suggested a potential total pool of 896 NZIMRT members, and a survey response rate of 10%. Nevertheless, this calculation relies on several external factors, such as the accuracy of my supposition about NZMRTB members, whether this could be accurately transferred to another group, and the currency of the NZIMRT database which would influence the number of deliverable survey links.

It can be difficult to achieve high response rates to electronic or postal questionnaires, with rates declining since the 1980's (Fincham, 2008), restricting the number of responses and potentially creating nonresponse bias (Teddlie & Tashakkori, 2009). The survey was designed in a way to facilitate increased response rates (Dillman, 1991). A pilot was undertaken, which not only helped ensure clarity for participants but also allowed me to give an estimation of the time required to complete the survey. A personalised email was sent via the NZIMRT, the use of which has been reported as increasing response rates (Schaefer & Dillman, 1998). Reminders are also considered to be helpful in increasing response rates. The use of reminders was limited to a total of three to avoid any feelings of participant coercion, plus exceeding this number is unlikely to result in an improved response rate (Marshall, 2005).

4.2.4 Recruitment

As indicated above, the primary method of recruitment for both phases was distribution of flyers available to NZIMRT members. This approach meant MITs across settings (e.g. working in District Health Boards and private practice) and with a diverse range of experience (e.g. recent graduates to more experienced practitioners), would be given the opportunity to learn about the research and consider their participation. For Phase One, a combined flyer and participant information sheet (Appendix A) were sent to the 690 members of the Auckland branch which extends from Kaitaia to Mercer. Given the wide range of clinical practices and equipment used in this region, plus the diversity in breadth and depth of MIT experience, limiting recruitment to one branch and geographic location was unlikely to adversely impact on the sampling aims previously described. For Phase Two, distribution of the survey was initially via a flyer, containing a URL link to the survey (Appendix B), emailed to all members of the NZIMRT by the NZIMRT secretary, with follow-up strategies as described above.

4.3 Phase One: Data collection

In-depth semi-structured interviews were used to generate data. The interviews aimed to garner information around the perceived impact of the introduction of digital technology for MITs and their experience of its introduction and use. The interviews were predominantly undertaken at the participant's dwelling or at a local café, away from their work location. To ensure my personal safety, I followed a specific protocol when interviewing participants in their home. Due to distance and participant availability, two interviews were undertaken via Skype. The participant made the venue decision to ensure they felt as comfortable as possible and to minimise disruption to their schedule. Prior to commencing interviews, a hard copy of the Information Sheet plus two copies of the Consent Form were given to each participant to read (Appendices A and C). Soft copies were emailed to the two participants who were interviewed online. The participants were offered the opportunity to ask questions or seek clarification prior to signing the consent forms. The participant kept one copy, the other I retained and stored in a secure location.

The interviews were recorded on two separate devices in case of mechanical failure. The interviews ranged in duration from 45 to 90 minutes. Key prompts were utilised to keep the interview focused on the phenomenon of interest, but the interview approach allowed for a more in-depth exploration where appropriate, allowing me to remain open to ideas raised by participant. Careful phrasing of the questions was undertaken to ensure I did not 'lead' the participant. Example of indicative questions are in Appendix D. Additional prompts were used as probes to further explore responses to these questions, such as: "*can you tell me more about that; how did that feel; how did that affect you*?" (Creswell, 2009). The questions were asked in any order, allowing a level of flexibility in the interview process. This was beneficial as it allowed for follow up on any unexpected responses (Grix, 2001). This was also facilitated by my note taking during the interview. Questions in relation to equipment orientation and any additional training requirements were added for those participants who had used digital equipment in several environments. Furthermore, questions exploring how different systems compared were included for participants who had used both CR and FPDR. These included the benefits and challenges associated with each system and radiation exposure settings.

I was very aware that my own values and perspectives, coupled with my experiences as an MIT and the introduction of digital technology, could inadvertently affect the interview process. Therefore, I ensured that I did not reveal my personal experiences to the participants. This also prevented the participants assuming we had shared knowledge and understanding, potentially limiting their responses (Thorne, 2016). At the end of each interview a koha, in the form of a grocery voucher, was given to each participant as a token of appreciation. Each interview audio file was password protected and subsequently transcribed verbatim by a professional transcriptionist, who had signed a confidentiality agreement (Appendix E). Subsequently listening to the audio recordings, I noted my initial impressions and the questions these prompted.

To support reflexivity, immediately after each interview I made journal entries, considering what had gone well and not so well. For example, after the first interview I noted how nervous I had been, writing I was "unsure how this would play out" and "my participant helped put me at ease by making me a cup of tea!" I also felt that the interview seemed somewhat "stilted" as I had regularly referred to my question list. Further, I believed I missed some opportunities to use follow up questions. I rectified this by noting these follow up questions during the subsequent interviews. Through reflection, I recognised that my feelings were due in part to the fact that this was the first interview and I really wanted it to be successful. Prior to the interview I had concerns my role as an educator could create a power imbalance (and barrier), which may have made my participants reticent to disclose their thoughts. Further, I was aware of the need to achieve a balance in my approach where I was not unduly influencing the interview process, whilst not being unresponsive. As I undertook more interviews, I realised that it was my nerves which predominantly influenced the effectiveness of my interviewing style and that despite my initial concerns all my participants were very willing to share their experiences with me.

In Interpretive Description, data collection and analysis run concurrently to facilitate the confirmation, testing or exploration of concepts as they arise. Therefore, as data analysis occurred, periods of reflection were undertaken before data collection continued. During this process, I used memos (example in Appendix F), mind-maps and my journal to note ideas and their relationships to each other, as well how my personal assumptions were influencing my analysis. For example, I felt shocked by one participant likening an x-ray machine to a fax machine and another who seemed completely disengaged following her introduction to digital technology. Recognising this was a personal reaction, enabled me to ask stand back from the data and consider what I was focussing on and why (Thorne, 2016). Further, the reflective process allowed me to modify/add questions for future interviews, for example I observed “it would be helpful to consider what mechanisms the participants use to determine accuracy”. Finally, the data analysis and reflection process also informed the theoretical sampling approach described above.

4.4 Phase One: Data analysis

The analytical process in Interpretive Description draws on tools to aid the researcher to develop an understanding of the data, create meanings, discover relationships and finally recreate the data into findings. Thorne (2016) suggested drawing on whatever analysis techniques are necessary to make sense of the data and shape practice insights. Therefore, one approach is not recommended over another. Rather, the suggestion is that a range of tools and methods are used which best suit the research questions. I used reflexive thematic analysis (TA), as described by Braun & Clarke (2021) to analyse the interview data. Reflexive thematic analysis acknowledges the knowledge and skills the researcher brings to the coding process (Braun & Clarke, 2020), allowing the researcher to determine relevant patterns within the data (Thorne). As thematic analysis may sit along a deductive or inductive continuum, it permitted me a data driven inductive analytical approach rather than a theory driven deductive process (Terry et al., 2017; Thorne, 2016). This process allowed a thorough review of each MIT’s experience, identifying differences and shared commonalities among the participants. Six analytic phases are traditionally utilised during reflexive thematic analysis (Braun & Clarke, 2006):

1. Data Familiarisation.

   Following transcription, each interview was checked against the audio recording for accuracy. This was the start of my data familiarisation process, given that it allowed me to begin developing an understanding of what was being said. Thorne et al. (1997) advised that the most appropriate analytical method is achieved when the researcher is immersed in the data repeatedly, prior to beginning analysis. This ensures that deep and meaningful interpretations are created. Therefore, I carefully read each interview script several times, looking for patterns or meanings and my initial thoughts were captured in a note book.

2. Initial code generation.

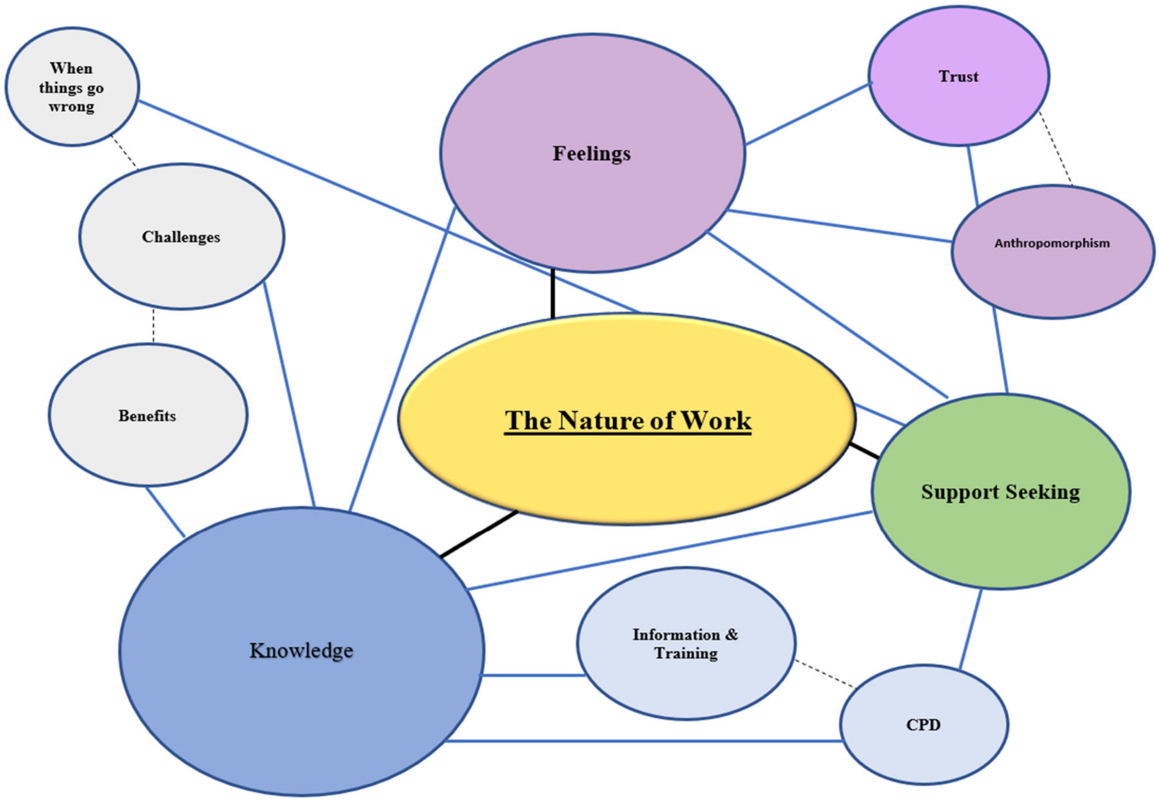
   Potential areas of interest were noted by using highlighters to mark the interview scripts and by writing notes in the margins. Code generation was supported by writing interview memos summarising my thoughts and feelings. Subsequently participant quotes and codes were collated into an Excel spreadsheet, with each code given a different colour (example in Appendix G). The colour filter was used to sort and group codes together (Bree & Gallagher, 2016). This process resulted in the production of 78 codes.

3. Searching for themes.

   Mind maps and interview memos helped me consider how the codes related to each other and sort the codes into potential candidate themes. Sorting also required constant re-immersion in the data, and included revisiting the interview transcripts as well as my Excel spreadsheet, to ensure I had not overlooked anything important. Eleven potential themes were created which subsequently became four main potential themes and seven subthemes, illustrated in Figure 3 below.

Figure 3

Mind map illustrating potential candidate themes and subthemes



4. Theme review

   The codes and participant quotes were reviewed to check for consistency and coherence within each theme (Braun & Clarke, 2006), specifically whether the extracts within each theme related to each other and the theme itself. For example, some of extracts I had within the “challenges theme” were better placed in the “knowledge theme” and “information and training sub themes”. Cross checking the themes against the entire data set allowed me to discard some of the themes and subthemes, such as “when things go wrong”, as there was not enough data to support them. Writing a summary statement for each theme in a reflective journal supported my thinking. The journal was used to record my methodological decisions and the reasons for them, for instance the removal of “anthropomorphism”, which I realised was an aspect of particular interest to me but again did not have sufficient data to support it as a either a theme or subtheme (Thorne, 2016).

   The themes were also reviewed to ensure they were distinct from each other and yet interlinked to provide an overall understanding of the data (Braun &

Clarke, 2006; Terry et al., 2017). This was achieved through revising my thematic map three times before the final version was created, resulting in five themes: “natural evolution- the transition process”; “health and safety”; “it means nothing to me”; “little things are the stumbling blocks”; and “the change to clinical practice- the losses and the gains”. Each theme incorporated several subthemes.

5. Theme definition and naming.
   Writing concise theme summaries allowed me to gain a deeper appreciation of each theme and subtheme. During this process I explored what the data in each theme was indicating and how it related to my research question. The working titles were modified and a final thematic map captured the themes and subthemes (Appendix H).

6. Report creation
   The theme summaries and thematic map formed the basis of my Phase One findings and discussion chapters. Data extracts were used both illustratively and analytically in relation to the research question and existing literature as evidenced in Chapters 5 and 6 (Braun & Clarke, 2006; Terry et al., 2017).

Comparison against Braun & Clarke’s 15 point checklist of what constitutes good thematic analysis confirmed my approach was consistent and appropriate (Braun & Clarke, 2006). Interpretive Description also aligns with thematic analysis in the following ways:

- data immersion is followed by an inductive approach to coding;
- coding allows different facets of the research to be collated and arranged into patterns or themes;
- initial themes are subject to review and refinement during the analytical process;
- thematic mapping is utilised to support theme and sub-theme development and revision (Thompson Burdine et al., 2021; Thorne et al., 1997).

I was therefore satisfied that constructing themes using thematic analysis was appropriate and methodologically congruent.

4.5 Trustworthiness in qualitative research

Guba & Lincoln (1982) identified that the trustworthiness of qualitative research can be determined through credibility; transferability; dependability; and confirmability. However, Morse et al. (2002) commented that this has tended to cause researchers to use "post-hoc" evaluations of trustworthiness rather than identifying how "verification strategies" (p. 17) were used during the research process, resulting in a post research evaluation of trustworthiness, as opposed to ensuring and supporting trustworthiness during the research study. Strategies identified as underpinning trustworthiness included:

- methodological congruence between the research question and the methods adopted;
- sampling sufficiency, achieved when the participants have knowledge of the research subject;
- concurrent data collection and analysis;
- themes generated in the data are checked prospectively (as new data is collected), and retrospectively against the existing data set.

All of these areas have been articulated within my thesis. For example, the use of purposive sampling and the description of reflexive thematic analysis. Morse et al.'s strategies align with Thorne's (2016) identification that trustworthiness in Interpretive Description studies can be demonstrated through epistemological integrity; representative credibility; analytic logic; and interpretive authority (pp. 233-235).

4.5.1 Epistemological integrity

Epistemological integrity is evidenced through clear linkage of the researcher's epistemological standpoint, the research question, research design and methods used to interpret the data (Thorne, 2016). Congruency has been demonstrated through:

- the discussion of my epistemological position in Chapter 3. Namely, knowledge is created through an individual's experiences and their interactions with the world. As such knowledge is socially constructed and context specific;

- the overarching research question reflecting the aim of pragmatic inquiry. This serves to support change and improvement thought the creation of new knowledge;
- congruence between the research methodology (discussed in Chapter 3);
- the data collection and analytical approach (discussed in this chapter) and
- my interpretation of data (in chapter 5).

4.5.2 Representative credibility

Representative credibility is demonstrated when the claims made in the study align with the sampling method (Thorne, 2016). Purposive sampling ensured that participants had experienced the phenomenon being explored i.e. the transition to, and ongoing use of digital technology.

Credibility was supported through active and ongoing data immersion, allowing for a deeper level of understanding than would be achieved by a more superficial approach (Braun & Clarke, 2019; Thorne, 2016). The feedback received on a presentation of my initial findings (as described in the final chapter) indicated that the study resonated with the MIT audience, further supporting representative credibility.

4.5.3 Analytic logic

To demonstrate analytic logic, the researcher needs to clearly articulate the decision-making processes used in the analytical phase of the study. The notes, mind maps, reflections and memos I used throughout, created an audit trail documenting the analytical process and theme generation (Thorne, 2016). Examples of my reasoning processes are seen in the interpretation of participant quotes provided in Chapter 5. Furthermore, identifying the use of Braun & Clarke's (2006) approach to thematic analysis provided additional insight into my decision-making processes.

4.5.4 Interpretive authority

Interpretative authority is the expectation that the researcher’s interpretation is trustworthy and reveals “constructed truths” beyond the biases of the researcher (Thorne et al., 2004, p. 6). Namely, whether the claims are plausible within their situated clinical context (Thorne et al.). This required me to identify and reflect on the biases I brought to the research process. Checking my interpretations (Thorne, 2016) against those of NZ MITs was achieved through analytical discussions with colleagues and peers. Furthermore, feedback on my initial findings indicated they were considered credible, as described in section 4.5.2.

4.6 Phase Two: Data collection

The purpose of this phase was to collect data that would a) reflect a group of MITs' knowledge, understanding and perceived competence regarding digital technology; and b) explore the factors related to their knowledge and perceived competence in using digital technology.

A purpose-built survey was designed to capture and explore the following areas: self-perceived competency and knowledge and understanding of digital imaging equipment, including radiation dose management and image quality.

4.6.1 Self-perceived competency

Rogers et al. (2010) highlighted a lack of training, perceived ability, support, and a fear of new technology impacted on MITs' abilities to utilise digital equipment effectively. These could lead to a reduction in self-perceived competency, professional confidence, and feelings of autonomy. For example, professional confidence relies on the individual not only having an understanding of their role and scope of practice but the capability to demonstrate those skills and abilities (Holland et al., 2012). Participants' perceptions of competency were assessed using a self-ranking system. Specifically, MITs were asked to rate their perceived competencies against a range of statements, rating their level of competence on a 5-point scale. The perceived competency options were: "high"; "good"; "average"; "low" and "none". The statements were arranged in subdomains as indicated in Table 1.

Table 1

Competency subdomains and related competency statements

Subdomain	Competency statement
Radiation dose subdomain	Adjusting exposures to suit patient body habitus
	Ensuring patient dose is As Low As Reasonably Achievable
	Manipulating exposure factors in computed radiography (CR)
	Manipulating exposure factors in digital radiography (FPDR)
	Ensuring doses remain within Diagnostic Reference Levels (DRLs)
Image evaluation and quality subdomain	Recognising equipment faults from the image artefacts produced
	Evaluating the diagnostic quality of the image in relation to the clinical indications
	Optimising image quality by increasing the contrast to noise ratio
	Performing post-processing procedures
Existing equipment use subdomain	Adjusting exposures to suit patient body habitus
	Ensuring patient dose is As Low As Reasonably Achievable
	Manipulating exposure factors in computed radiography (CR)
	Manipulating exposure factors in digital radiography (FPDR)
	Ensuring doses remain within Diagnostic Reference Levels (DRLs)
	Evaluating the diagnostic quality of the image in relation to the clinical indications
	Optimising image quality by increasing the contrast to noise ratio
	Performing post-processing procedures
New equipment use subdomain	Using new equipment, immediately post training
	Ongoing use of new equipment, one month post training
	Ongoing use of new equipment, six months post training

4.6.2 Knowledge and understanding

There are concerns that MIT knowledge of digital technology is questionable and that MITs are becoming deskilled, due to over reliance on the equipment (Hayre et al., 2017; Mothiram et al., 2014). This has also been reflected in the nursing profession as discussed by Sandelowski (2000). She posited that over-reliance on equipment could lead to a loss of skills, particularly if nurses assume that the generated data is correct. MIT knowledge and understanding as well as standard operating procedures were evaluated using questions relating to equipment design/use, radiation exposure, digital technology education and quality assurance procedures.

4.7 Survey development

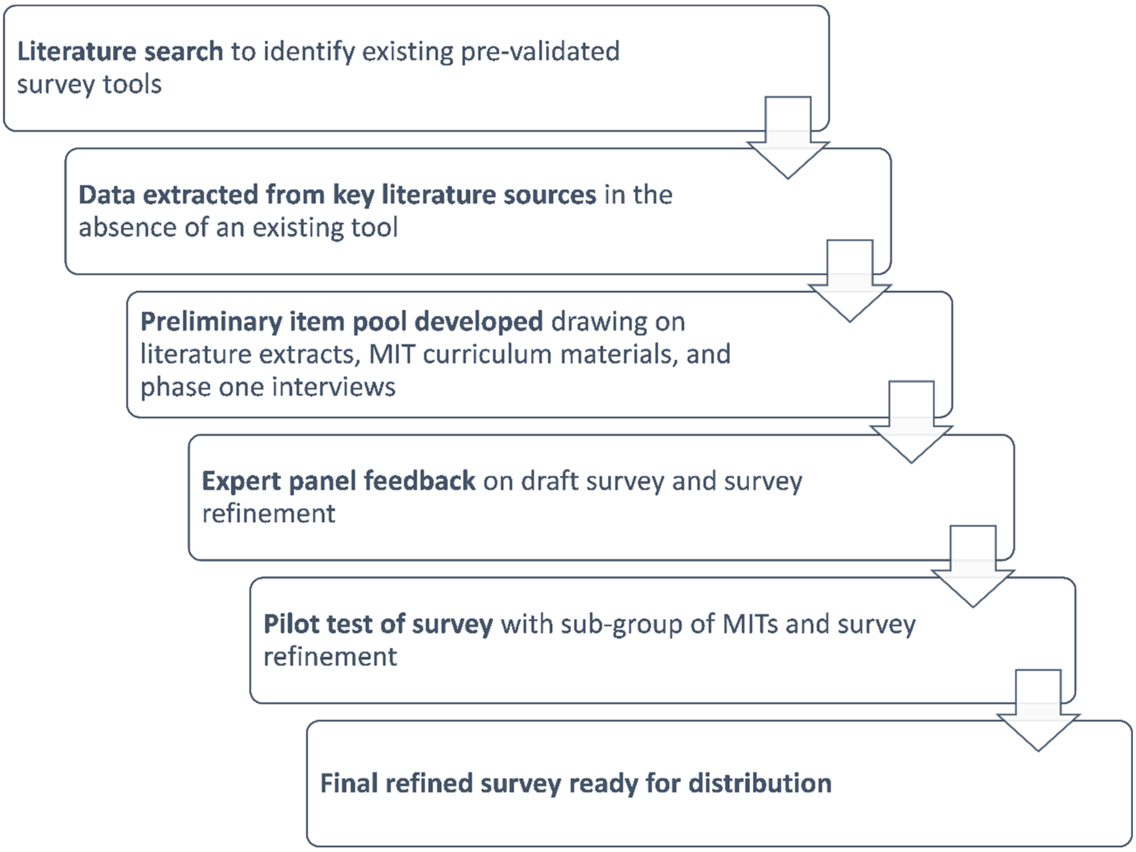
Ideally a pre-existing valid and reliable survey would have been utilised, allowing for data comparison with other studies. Nevertheless, the use of a pre-validated tool does not guarantee that a question, or the tool, will be effective when used in another context (Dillman et al., 2014). A literature review was undertaken to identify existing surveys regarding MITs' use of digital technology in clinical practice, and the impact technology has had on their self-perceptions of competency and confidence. Health science databases, including EBSCO Health, Informit Health Collection, Proquest, Science Direct and Scopus, in conjunction with Google Scholar were used to retrieve literature. Several search terms were used which included 'radiog*', 'digital technology', 'medical imaging', 'competence', 'exposure creep', 'CPD', 'education', 'radiation protection', 'knowledge', 'quality', 'CR', 'DR', 'MIT' and 'MRT'. Google scholar citation lists and article references were also used to widen the search field and likely responses.

The search was limited to full text articles, written in English after the year 2000. This removed the need to use translation services, allowed for critique of the articles, and the articles were more likely to reflect current knowledge and practice. The time frame was expanded beyond the last five years to access articles relating to the introduction of this technology. In many countries this was at the beginning of the 21st century, although in some cases, the use of digital imaging equipment for planar radiography did not occur until 2012 due to the high cost of replacing radiography equipment (J. Haven, personal communication, 29th October 2015).

Due to the limited number of useful results, the search terms were expanded to include other health professions e.g. nursing and physiotherapy. In addition, an afternoon was spent with the Library Knowledge Specialist (Medical Imaging) to enhance the likelihood of success. However, these searches did not reveal a survey which reflected the focus of the study. Therefore, I decided to design a survey for my study, a visual representation of the process is given in Figure 4 below:

Figure 4

Outline of the key stages of the survey development



The survey was created using components from:

- A study by Morrison et al. (2011) considering image quality and dose management in paediatric digital imaging in the United States of America.
- Multiple choice questions (MCQs) currently used for undergraduate medical imaging students, to assess basic knowledge and understanding of the equipment. These questions have been assessed and evaluated via Unitec's moderation process. The moderation was conducted by two lecturers, one of

whom is a qualified MIT with experience of using digital imaging equipment and the other a medical physicist.

- The Radiographer Competence Scale as developed by Andersson, Christensson, Fridlund, et al. (2012).
- A survey undertaken by Farajollahi et al. (2014) reviewing MITs' knowledge of "parameters and safety issues in plain radiography" (p. 1.) Unfortunately, the questions used in the survey almost entirely related to the use of F-S radiography and were therefore unsuitable for this research. However, components which could be utilised included background data relating to education, length of time from graduation, and work experience.

Based on Morrison et al.'s study, additional questions were developed to determine the amount of time quality control activities were undertaken, for example re-processing or image manipulation. In addition to the substantive questions, questions were used to capture general demographic information including age; gender; ethnicity; years since qualification as an MIT; employment status and highest academic achievement.

A preliminary item pool was generated through the use of the literature cited above, Phase One interviews and by discussion with experts in the field to assure content validity (Rattray & Jones, 2007). The aim was to ensure the items pool covered both self-perceived competency, and knowledge and understanding of imaging equipment, as highlighted above. A mixture of open and closed questions, response options (e.g. multiple choice), case study scenarios and rating scales were used. An expert panel was formed and pilot testing undertaken (both detailed further below) to ensure and check for content validity. Furthermore, ongoing reflection of the research question and the items was undertaken to maintain relevancy (Oppenheim, 1992). Using a self-administered survey meant that any results would only apply to the Aotearoa New Zealand population sample used. However, using multiple clinical sites and selecting an appropriate sample size, improved the likelihood of the participants being representative of the target population. Finally, literature associated with survey design such as: format; question type; survey length; content, pre-testing; piloting and response rates was used to support the construction and validation processes (Dillman et al., 2014; Marshall, 2005).

A panel of six experts agreed to assist in the initial development and pilot stages. The panel were selected due to the range of knowledge and experience they had. The panel comprised:

- Two experienced medical imaging lecturers. One based in Aotearoa New Zealand, with local knowledge and a variety of clinical experience from working in New Zealand. The other worked in the United Kingdom with extensive knowledge in the use and function of digital imaging equipment. Both were also involved in teaching digital technology to undergraduate medical imaging students. They were experienced in course and curriculum design and were able to comment on the quality of the questions and their resonance, or lack thereof, to the research questions.
- Two charge/senior MITs from different DHBs within the Auckland and Waikato regions. These senior staff had experienced the introduction of digital technology into their departments and were also using it on a daily basis.
- An experienced medical imaging lecturer/programme leader who had returned to clinical practice. She had experience in several key areas such as curriculum design, the introduction of digital equipment to her clinical practice, and her role as a superuser[18] responsible for training staff in the use of equipment as her clinical site.
- An academic advisor/senior lecturer whose domain of expertise was related to teacher professional development and learning design; survey design and analytical skills. Therefore, she was also able to comment on the structure and quality of the questions.

The draft survey was emailed to the panel in Microsoft™ Word format. All questions and specific instructions were included. The panel reviewed the draft items checking for clarity, construction and relevance based on the work of Terwee et al. (2007). A rubric was provided to facilitate the feedback process, plus a one-page summary of Phase Two of the research proposal and related hypotheses. The panel were also given

18 A superuser is defined by the Oxford Living Dictionary as “a user of a computer system with special privileges needed to administer and maintain the system; a system administrator.” This term has been adopted within the NZ Medical Imaging community to mean someone who also has the added responsibility for staff training relating to specific equipment.

the opportunity to provide additional comments in relation to the survey. The survey was modified in response to feedback; for example, the wording of some questions was revised to provide additional clarity.

The survey was then pilot tested to check the feasibility of the survey tool. The pilot group were the MITs who had been interviewed during Phase One, plus three MITs who had no prior knowledge of the research question. Using the latter group, added a level of rigour to the pilot process, as they completed the survey with no preconceptions. The pilot group represented a sample group from the target population. They were asked to complete the survey through RedCAP™ (to replicate Phase Two data collection processes) and provide feedback using a feedback rubric, to capture their overall opinions of the survey as well as clarity, timing, and question order. The feedback rubric distributed to the expert panel and pilot groups is attached as Appendix I.

The cross-sectional survey (Appendix J) contained different types of questions to explore the topic areas of MIT knowledge, understanding and perceived competency and are captured in Table 2 below. The competency based questions were deliberately placed in the first section of the survey, to capture the participants perceptions prior to the MCQs which assessed knowledge and understanding. This was to try and reduce the likelihood of the MCQs influencing the participants initial feelings and self-perceptions of competency (Oppenheim, 1992).

Table 2

Survey questions relating to MIT knowledge, understanding and perceived competency of digital imaging technology

Topic areas	Survey questions
MITs' understanding of how digital systems respond to different levels of radiation exposure.	Multiple choice questions relating to equipment design and use Questions relating to radiation exposure and education
MITs' knowledge of how different functionalities of the equipment influence best practice.	Multiple choice questions regarding equipment design and use Applications-based questions
MITs' understanding as to whether their practice is meeting the ALARA principle.	Questions relating to radiation exposure, image acquisition, quality assurance and education
The methods MITs employ to evaluate the quality of their performance.	Questions relating to quality assurance, quality control work station and education Three applications-based questions
Factors relating to MITs' perceived competencies in the use of digital imaging technology	Competency-based questions

An online data management software, RedCAP™, was used to administer the survey and to support data management and storage. The research information sheet was provided in an electronic format on the first page of the survey. Anonymity was ensured by the removal of information such as email addresses and ISP addresses before the data was accessible to me. Participants were able to withdraw at any point and stop answering questions. However, they were also advised that they could not withdraw any responses made up to that point, due to the configuration of the system.

The sixty five item survey was subdivided into eight sections and covered the following areas:

A. Self-ranking competency scale
B. Image acquisition weekly activities
C. Quality control weekly activities
D. Factors impacting on quality assurance

E. CR and FPDR education received
F. Multiple choice questions assessing digital knowledge
G. Multiple choice questions relating to clinical applications
H. Demographic information.

Key variables were collected in Sections B, C, E and H such as: weekly equipment utilisation; education and training; demographic information. A more detailed breakdown of the variables is included in Table 3.

Table 3

Key variables collected in the survey

Basic demographics	Age
	Ethnicity
	Gender
	Current position
	Employment status
	Number of years post qualification
Education	Highest medical imaging qualification
	UG education CR
	UG education FPDR
	UG education film/screen
	Formal PG training in CR
	Formal PG training in FPDR
Training	Received applications training in CR
	Received applications training in FPDR
	Number of hours of applications training
	Applications trainer background
	Undertook applications training in CR
	Undertook applications training in FPDR
	Alternative resources used to support learning (e.g. journal articles/texts)
Experience	Experienced transition from Film-CR
	Experienced transition Film-FPDR
	Experienced transition CR-FPDR
	Experienced transition FPDR-CR
	Time spent using the equipment on a weekly basis

4.8 Data checks

Statistical analysis was performed using the IBM Statistical Package for Social Sciences™, Version 26.0 for Windows Inc (SPSS, SPSS Inc, Chicago, IL, USA) software. Prior to analysis, the data set was screened and checked for errors, as described in the following sections.

4.8.1 Logic checks

Logic checks were undertaken to review the data and determine whether there were any inconsistencies. These logic checks included ensuring all participants met the inclusion criteria and that there were no obvious aberrant entries. For example, the number of years qualified was checked against the undergraduate qualification attained, the number of years qualified reviewed alongside CR or FPDR education and training at undergraduate level indicated. Where single responses were required, e.g. age range or undergraduate qualification, the data were checked to ensure only one response was indicated. One survey was removed from data analysis as the participant did not meet the inclusion criteria (was not working 50% of the time in planar imaging), leaving 49 utilised in data analysis.

During the logic checks, it was noted there was an error in the phrasing of one statement in the perceived competency section of the survey. Even though the question had been reviewed by the researcher, the expert panel, and had been included in the piloted survey, it was not identified until this point. The statement incorrectly asked the participant to rank their competencies in optimising image quality by reducing the signal to noise ratio. It should have stated optimising image quality by increasing the signal to noise ratio (Seeram, 2019). Due to this, the statement was removed from the data set and not included in any analysis.

A discrepancy in some responses regarding FPDR undergraduate education and training were also identified. This anomaly may have been due to ambiguity in the question, or may reflect the fact that there was a mismatch between learning the theory as an undergraduate (education) and the application of the process in clinical practice (training). Errors in data entry were corrected e.g. participants who had a diploma as their highest qualification and/or had been qualified over 25 years would not have learnt the theory of FPDR as undergraduate students. For all other affected participants, their entire data set was reviewed to determine the reason for this apparent discrepancy. For example, of all the participants who indicated they had FPDR undergraduate education, three specified they did not have FPDR training. On reviewing the transitions experienced, they had all transitioned between CR and FPDR, suggesting they may have learned the theory as undergraduates, but were not placed in clinical sites which used FPDR at that time. As all three had been qualified over five and less than ten years, this would support this supposition, given the time frames in which FPDR has been introduced in NZ.

One participant had been qualified for 12 years and had experienced FPDR training as an undergraduate but not FPDR education. Her data indicated that she had received CR education as an undergraduate; training in both CR and FPDR as an undergraduate but experienced no imaging modality transitions. This suggests that she may have had a student placement where both CR and FPDR equipment was used but was taught the theory of CR only during her undergraduate education. This was also supported by the number of years she had been qualified.

Although I was reasonably satisfied that these components of the data set accurately recorded the participants’ experiences, I decided to keep the FPDR undergraduate education variable and remove FPDR undergraduate training from the data set. This was because there remained some uncertainty as to whether the participants would differentiate between education and training as I had intended. In any future surveys re-phrasing, further explanation of these categories, or a free text box for participant additional information would be highly recommended.

4.8.2 Assumptions of normality

Data assumptions were reviewed prior to analysis. For example, the use of histogram analysis to look at distribution, levels of skew and kurtosis; the number of samples; independent groups and whether the data were categorical, continuous, or ordinal. Assumptions of normality identified most of the data were not normally distributed. Despite there being only small differences between the mean and the 5% trimmed mean for many of the competencies, Shapiro-Wilk p-values were assessed for all individual competencies, competency domains, and the MCQ domains, to determine whether the data distribution were significantly different from normal (Pallant, 2016).

A Shapiro-Wilk test is useful in small study samples, with a range between zero (non-normality) and one (normality) (Barton & Peat, 2014). Apart from the utilisation of existing equipment subdomain and total competency score, all data demonstrated abnormal distribution (Table 4). Where an abnormal data distribution was evident, non-parametric tests were used. These were the Kruskal-Wallis test for comparing the differences between the scores of three of more groups, and the Mann-Whitney test to compare the scores of two groups.

Table 4

Data distribution

Competency/Domain	Shapiro-Wilk Value	Skewness	Kurtosis	Mean (SD)	5% Trimmed Mean	Outliers ID
Adjusting exposures to suit patient body habitus	0.000	-0.20	-1.14	4.45 (.54)	4.47	-
Ensuring patient dose is As Low As Reasonably Achievable	0.000	-0.13	-0.71	4.35 (.57)	4.38	-
Manipulating exposure factors in computed radiography (CR)	0.000	-1.80	2.97	4.16 (1.12)	4.29	8, 18, 34, 35
Manipulating exposure factors in digital radiography (DR)	0.000	-1.42	3.01	4.20 (.87)	4.29	11, 22
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	0.000	-0.31	-0.70	4.24 (.66)	4.27	-
Recognising equipment faults from the image artefacts produced	0.000	0.034	-1.18	3.98 (.75)	3.98	-
Evaluating the diagnostic quality of the image in relation to the clinical indications	0.000	-0.62	-0.55	4.49 (.58)	4.53	-
Optimising image quality by increasing the contrast to noise ratio	0.000	-0.45	-0.23	3.82 (.86)	3.85	-
Performing post-processing procedures	0.000	-1.21	2.07	4.31 (.74)	4.39	11, 42
Using new equipment, immediately post training	0.000	-0.44	0.14	3.78 (.77)	3.81	-
Ongoing use of new equipment, one month post training	0.000	-0.42	-0.75	4.29 (.68)	4.32	-
Ongoing use of new equipment, six months post training	0.000	-0.66	-1.75	4.63 (.49)	4.65	-
Radiation dose subdomain	0.003	-0.07	-0.84	21.33 (2.65)	21.42	-
Image evaluation and quality subdomain	0.057	-0.14	-0.11	20.43 (2.81)	20.51	-
Existing equipment use subdomain	0.158	0.08	-0.73	41.76 (4.79)	41.81	-
New equipment use subdomain	0.005	-0.43	0-.55	12.69 (1.66)	12.75	-
Total competency domain	0.500	-0.001	-0.58	54.45 (5.88)	54.51	-
MCQ Knowledge subdomain	0.014	0.47	-0.49	3.63 (1.75)	3.57	-
Total MCQ domain	0.037	0.59	0.02	4.12 (2.08)	4.04	11

4.8.3 Validity

Although face and content validity were assessed during the design and piloting of the questionnaire, I wanted to check the internal consistency of the survey, given that it was newly developed for this project (and not a pre-validated survey). Therefore, Cronbach's alpha was calculated for each of the following domains and subdomains:

- Total competency domain
- Radiation dose competency subdomain
- Image evaluation and Image quality competency subdomain
- Equipment use competency subdomains
- Total MCQ domain
- MCQ knowledge subdomain
- MCQ applications subdomain

The results of these calculations are specified in Table 5 below.

Table 5

Cronbach Alpha score

Domain/Subdomain	Cronbach's Alpha	Number of items
Total Competency	0.850	12
Radiation Dose	0.703	5
Image Evaluation and Quality	0.708	4
Existing Equipment Use	0.803	9
New Equipment Use	0.799	3
Total Multiple Choice	0.660	11
Knowledge Multiple Choice	0.622	8
Applications Multiple Choice	0.124	3

Different authors suggest different values indicate an "acceptable Cronbach's alpha score" (Tavakol & Dennick, 2011; Terwee et al., 2007). However a frequently used threshold is 0.7 (Pallant, 2016; Rattray & Jones, 2007). In reviewing the scores, it was clear that all the competency domains and subdomains met or exceeded this figure. Initially I had created an "MCQ applications subdomain" with three items. However, the Cronbach's alpha score of 0.124 made it obvious that these variables did not fit together in one domain as they were assessing different areas of knowledge (Taber, 2018). Subsequently these were treated as separate items rather than as a subdomain. The slightly lower value for the “total” and “knowledge” MCQ sections was deemed acceptable, following review of the inter-item correlation matrix, and ensuring that all items in the data set were correctly scored.

Factor analysis was not considered to be a useful adjunct, due to the small sample size, small number of variables in each domain, and the small number of participants to MCQ questions (items) i.e. 49 participants to 11 items. Additionally, factor analysis is typically used to reduce a large number of variables to a smaller more manageable set (Pallant, 2016). As each of the questions within each domain were related to specific and different clinical components, it was not felt that there was overlap between the variables. For all these reasons, factor analysis was not undertaken.

4.8.4 Correlation

Quantile-quantile (Q-Q or scatterplots) and Spearman rho rank order correlation tests, were undertaken on the data prior to analysis to establish whether there were positive or negative correlations between the variables and the strength of that relationship, if any (Pallant, 2016).

Significant outliers were identified, as they may adversely affect the correlation coefficient (Pallant, 2016). They were checked against the raw data to ensure they had been accurately recorded. None of them were more than four Standard Deviations from the mean. Additionally, the mean was reviewed against the 5% trimmed mean values and did not demonstrate a large impact caused by the outliers. All of these considerations resulted in none of the outliers being removed from the data set.

4.9 Regression modelling

Regression modelling was undertaken to determine whether there was a predictive relationship between the independent variables and specific dependent variables, reflecting the approach of Andersson, Christensson, Jakobsson, et al. (2012).

There were a range of dependent variables identified to address the Phase Two research questions and to support hypothesis testing as highlighted in Table 6 below:

Table 6

Regression model dependent variables

To assess the predictors of:	Dependent Variable
MIT knowledge of how digital imaging systems respond to different levels of radiation and whether their practice is meeting the ALARA principle.	MCQ score for knowledge subdomain
MIT knowledge of how different functionalities of the equipment influence best practice	Total MCQ score
How MIT self-rate their competencies	Total competency scores
MIT self-rated competencies in relation to patient radiation dose and the ALARA principle.	Competency scores radiation dose subdomain
MIT self-rated competencies in relation to the use of existing imaging equipment	Competency scores existing equipment subdomain
MIT self-rated competencies in relation to the use of new imaging equipment	Competency scores new equipment subdomain
MIT self-rated competencies of best practice in relation to image quality and evaluation.	Competency scores image evaluation & quality subdomain

The dependent variables were selected from different sections of the survey to explore the topic areas of MIT knowledge, understanding and perceived competency (Table 2).

Prior to analysis, I assessed the data to ensure they met the assumptions for regression modelling. This included reviewing whether: the data were normally distributed; the dependent variable was continuous; there was any evidence of collinearity between the independent variables; there was a linear relationship between the variables being assessed; the variables exhibited homoscedasticity; and significant outliers were identified. Although the data were not normally distributed, Schmidt & Finan (2018) argue that linear regression has a robust assumption against normality violations and as such will provide appropriate results when there is sufficient data. The amount of data was deemed sufficient according to Austin & Steyerberg (2015). Collinearity is problematic in a regression model as positive correlations can cause the coefficient to be overestimated and vice versa (Tabachnick & Fidell, 2007). The correlation analyses I had previously undertaken were utilised during this phase of data analysis. The Q-Q plots were reviewed for evidence of non-linearity and homoscedasticity. As previously discussed, none of the identified outliers were removed from the data set.

The independent variables were rank ordered according to most or least clinical significance. Predominantly, I made these decisions from reviewing the literature. However, where this was not feasible, I used my own clinical experience and judgment to assist me in the decision making (Tabachnick & Fidell, 2007).

For the categorical data used as independent variables, dummy coding was undertaken to determine whether these variables were predictors of either competency ratings or knowledge. The literature was reviewed to help determine which of the groups were most appropriately selected for the baseline group. However, I was unable to find supporting evidence that related to this subject area and the domains under review. Although A. Field (2009) suggests using the majority group as the baseline group, I wanted to ensure the reference groups were clinically viable. Therefore, each categorical variable was reviewed in turn to achieve this.

A forward stepwise approach was adopted, requiring each independent variable to be added to the model one at a time. The independent variables were added according to their clinical relevance (Appendix K). As each independent variable was added into the model, it was assessed for statistical significance, using a probability of F value ranging from an entry value of 0.05 to a cut-off value of 0.10. Confidence levels of 95% were also recorded. Occasionally, the addition of an independent variable caused an increase in the F value such that it exceeded the cut-off value of 0.10. In these circumstances, the collinearity between the variables was further reviewed to support decisions as to which variable should be retained and which removed. The clinical ranking system also supported the decision making process.

4.10 Phase Two: Data analysis

Four categories were created based on the years since qualification, similar to the approach taken by Andersson, Christensson, Jakobsson, et al. (2012). The participants were grouped as MITs with short (0-5 years); medium (5-15 years); long (15-25 years) and longest (>25 years) time since qualification. The sample characteristics were used to compare the groups and determine any differences between them.

In the descriptive analysis, demographic characteristics such as age, gender and ethnicity were reported overall and by undergraduate education versus postgraduate training group, and transition to CR or FPDR groups. Means (95% CI), standard deviations, medians and quartiles were reported for continuous variables and analysed using Student's t-test (for parametric data) and Mann-Whitney U-test (for non-parametric data). Cross-tabulations were reported for categorical variables for each MIT grade (i.e. staff, team lead, charge MIT) and analysed using Chi-Square statistic (or Fisher's exact test when cells were less < 5).

Multivariate analysis was used to determine if specific attributes such as time since qualification, frequency of use of equipment, level of applications training, type of applications training, weekly use of CR or FPDR systems, affected the results.

Inferential statistics were gathered through the forward stepwise linear regression model to compare the number of correct MCQ correct responses between different groups, to identify whether these key variables affected MITs' knowledge and understanding of digital technology. Furthermore, I evaluated whether specific variables affected perceived levels of competency in the use of digital technology. Selection was undertaken with each outcome based on information criteria primarily, using standard selection heuristics. A priori identified confounding variables were adjusted for in the analysis and others were assessed empirically. Inferences were based on a 5% significance level and two-sided alternatives.

4.11 Reliability and validity in quantitative research

Reliability, validity, replicability, and generalisability are used to determine rigour in quantitative research (Bryman et al., 2008). Reliability refers to the consistency or repeatability of the tool (Flinton & Owens, 2010). A measure with high reliability should produce similar results in different contexts but under the same test conditions (Roberts & Priest, 2006). Utilising Cronbach's alpha helped assess the reliability of the questionnaire (K. M. Brown et al., 2015; Taber, 2018).

Validity refers to the extent in which inferences can be made from the research i.e. does it measure what it is designed to measure (LoBiondo-Wood & Haber, 2006). Internal validity relates to how the researcher has approached issues of bias and the effect of confounding variables on the inferences drawn. The approaches taken to assess internal validity are outlined above. Roberts and Priest (2006) specify that external validity is demonstrated if the study participants are representative of the population of interest i.e. whether the findings can be generalised to the target population.

Replicability is associated with the transparency of the research process (Bryman et al., 2008), specifically whether the researcher clearly identified the processes undertaken, such that an independent researcher could reproduce the study (Peels, 2019). This chapter identifies the approaches taken including survey design, sampling, data collection and data analysis strategies.

Generalisability relates to the ability to apply the findings to alternative contexts. The participants were representative of the NZ MIT population and met assumptions of external validity. However, the small sample size will mean generalisability of the findings is limited.

4.12 Rigour and validity in mixed methods research designs

Establishing rigour in mixed methods research goes beyond meeting the individual criteria for qualitative and quantitative studies. However, there is limited consensus on the criteria to be applied (K. M. Brown et al., 2015). The Good Reporting of a Mixed Methods Study (GRAMMS) guidelines have been identified as one way to guide the evaluation of quality in mixed methods research (K. M. Brown et al., 2015; O'Cathain, 2010). The GRAMMS guidelines include six criteria (O'Cathain et al., 2008 p. 97). The criteria and how these were met in this study are outlined in Table 7.

Table 7

GRAMMS criteria for assessing rigour in mixed methods research

Criterion	Requirement	Strategy and Relevant Chapter
1.	Describe the justification for using a mixed methods approach to the research question.	Chapters 1 and 3 discuss why a mixed methods methodology was used for this study.
2.	Describe the design in terms of the purpose, priority, and sequence of methods.	Chapter 3 describes why a sequential exploratory design was selected, and how the phases and research questions relate to one another.
3.	Describe each method in terms of sampling, data collection and analysis.	Chapter 4 outlines the processes for sampling, data collection and analysis.
4.	Describe where integration has occurred, how it has occurred and who has participated in it.	Chapter 1 identifies the integrated research question. Chapter 3 discusses the integration processes. Chapters 7 and 8 explain how the quantitative study expanded on the qualitative findings. Chapter 9 provides a synthesised discussion of the findings from both phases of the study.
5.	Describe any limitation of one method associated with the present of the other method.	Chapter 3 identifies why an individual qualitative or quantitative study would have been inadequate to answer the research question.
6.	Describe any insights gained from mixing or integrating methods.	Chapter 9 discusses the insights provided through the synthesised findings.

Validity threats in mixed methods research are specifically related to the design used by the researcher, as each core design provides alternative approaches to gather and interpret data (Creswell & Plano Clark, 2017). The three validity threats associated with a sequential exploratory design and how these were minimised, are summarised in Table 8 (Creswell & Plano Clark, 2017, p. 252).

Table 8

Validity threats in Sequential Exploratory Designs

Validity Threat	Strategy and Relevant Chapter
Not building the quantitative feature based on the qualitative results.	Chapters 1, 5 and 6 outline how the qualitative results were used to develop the survey.
Not developing rigorous quantitative features.	Chapter 4 describes the survey development and pilot testing.
Selecting participants for the quantitative test that are the same individuals as the qualitative sample.	Chapter 4 outlines the sampling procedures for both phases. Resulting in a larger sample group in the quantitative phase.

Consideration of trustworthiness or rigour specific to each phase has been incorporated in the relevant sections in this chapter.

4.13 Ethical considerations

Ethics approval was granted by the Auckland University of Technology Ethics Committee (Appendix L).

In addition to the ethical processes interwoven throughout this chapter, informed consent for the interviews was gained through the provision of an information sheet (Appendix A); the opportunity for participants to ask questions prior to the interviews and the completion of a consent form (Appendix C). Only limited confidentiality could be assured. Participants were advised in the Information Sheet and Consent Form that should they reveal malpractice, which could endanger patients, I may need to disclose this to the New Zealand Medical Radiation Technologists Board. It was recognised that this may have influenced the data by limiting or changing the responses participants gave to the interview questions.

Participant identity was protected by each participant being given a pseudonym for use in the final report and any subsequent publications or presentations. This was specified in the Information Sheet and Consent Form. In addition, a confidentiality agreement (Appendix E) was signed by the transcriptionist.

It was not anticipated there would be risks to the participants in either Phase One or Two of this study. If Phase One participants became significantly distressed or embarrassed, for example identifying poor clinical practice or a lack of knowledge in the interview, the AUT counselling team offered support if required (Appendix M).

In Phase Two, information relating to the research and that phase of the design, was situated on page one of the survey. Consent Forms were not required for the survey, as data collection was anonymous and completion was considered to equate to consent. The issue of breaching confidentiality did not arise, as the survey allowed responses to remain anonymous by removing IP and email addresses. A unique identifier was allocated to participants completing the survey as I did not have access to their details. This was specified in the information provided prior to proceeding to the online survey.

4.14 Summary

This chapter has described the methods utilised in this research study. I have incorporated the data collection and analysis strategies for the both phases of the study. I have considered how rigour, credibility, trustworthiness, and validity were incorporated into the qualitative and quantitative components.

In the following chapter, I present the findings from the Phase One interviews.

Chapter 5 Phase One Interview Findings

5.1 Introduction

In this chapter, I show that the overarching theme identified in this phase was that the introduction of digital imaging constituted a **shift in medical imaging practice**. Consequently, the changes to MIT practice seemed to contribute to a set of **unintended consequences** which could adversely impact on the delivery of high-quality care. The principal factors seemed to be related to the transition process, in conjunction with unexpected tensions created through the use of the technology. For instance, there was the potential for MITs to inadvertently overexpose patients to radiation through a lack of understanding of exposure indicator values, collimation creep, and exposure creep; coupled with a system which facilitated the taking of repeat images. In addition, the increased speed of the digital imaging process had created a situation where there was an expectation for MITs to increase their workflow and throughput. A resultant decrease in MIT-patient communication, and increased pressure on MITs from the increased workload, was perceived to increase the likelihood of errors. It is possible to view these examples as detractors to the provision of effective person centred care.

A detailed account of the main theme and subthemes with supporting data follows. The shift in medical imaging practice is described within four subthemes. In section 5.2.1. I describe how the speed of the transition was experienced by the participants. Section 5.2.2 describes the task driven training approach. Section 5.2.3. considers the language barriers that were encountered during the transition. Section 5.2.4 considers the influence of digital technology on support mechanisms and autonomy.

Section 5.3 discusses how digital technology created unintended consequences which exacerbated some of the tensions and complexities that exist in medical imaging practice. These are considered under the following subthemes: the effects of increased speed; a safer cleaner process; and balancing radiation dose.

5.2 A shift in practice

The participants conveyed that the level of transition this new technology would require in terms of knowledge and practice was underestimated. They inferred that this was because the change to digital imaging was simply perceived as a technological change, as opposed to requiring a more fundamental shift in MIT practice, which was ultimately how it was experienced. Namely, it was viewed as a transactional process replacing one technology with another. When moving from F-S systems to CR, many staff simply considered it as replacing one type of cassette with another, with image processing undertaken through an alternative daylight system. Subsequently, the impact of moving from CR to FPDR was minimised in people's minds, and simply considered to be the next step in the use of digital imaging. The underlying premise for many staff was that having become used to CR imaging and therefore digital imaging, FPDR was not anticipated to provide any specific challenges.

5.2.1 Speed of introduction

Many participants reflected on the speed of the transition to digital imaging, predominantly through comments related to the level of training available and the number of training hours offered. For example, Sandra revealed *"we were trained a week before we went live. So, we had basically a week to train every single radiographer."* In this example, she observed the very short space of time between equipment installation and becoming operational, which governed how much training could be offered. Elizabeth suggested one reason for the fast turnaround was because *"I don't think anyone really realised that there would be issues transitioning."* Her observation suggested that the move to the digital environment was considered no more significant than previous changes, such as the changeover from wet to automatic processing.

A fast installation period was considered important by those who worked in private practice, where it was essential to reduce the downtime associated with the equipment installation i.e. it was cost driven. Victoria, who worked in private practice, highlighted the need to maintain income generation:

> *"They [Engineers] did it [installed the equipment] over a weekend. We were only shut for a couple of hours on a Friday night, so they could remove the old stuff and have it running again by Monday morning. That was really good, we didn't lose any business there."*

Victoria identified minimal disruption to the business, both in terms of the changeover occurring out of hours as well the fast turnaround time. She noted using an alternative vendor would have increased downtime, "*with xxxx [vendor] we'd have had to shut for a week. And we just can't afford to do that*". She commented that while the price difference in the two equipment tenders did not vary significantly, the deciding factor was the installation time. Tenders also detail the level of training to be provided by the equipment vendor. However, Victoria did not discuss this nor did she reveal any specific concerns. Rather, she commented "*there wasn't a huge difference [between CR and FPDR] so we didn't need as much training with the DR"* and noted training had been virtually halved to approximately three days for FPDR, compared to a week for CR. Victoria seemed to be applying her familiarity with CR equipment and digitised images directly to FPDR systems and identified no concerns about her capability or competency.

The level of training experienced by the participants varied considerably and seemed contingent on the number of staff to be trained, staff availability (due to shift work, for example) as well as the speed of the installation. In some instances, the superusers received training over two to three days, with general staff receiving significantly less. Here Sandra, a superuser, relates her experience of the introduction of CR:

> *"We had I think a day and a half or two days training on the system and obviously it's completely different to conventional. It's all these new tools and computer fangled everything. Basically, the training for us was, this is how you acquire your images… We had to consolidate everything we [i.e. the superusers] had learned in sort of one and a half days into four hour training sessions for radiographers. So basically, all we could tell them was how to use the system. This is the button you press to get this, this is how you send your images to PACS. That was it. There was nothing on algorithms or processing, any of that kind of stuff because we didn't understand the importance of it because we didn't have that information available to us at the time."*

Sandra recognised the limitations of her training as a superuser and the consequences of compressing information for the staff she was expected to train. This reinforces the idea that the training was reduced to the bare essentials of digital image production. In her comment, Sandra reflected that more complex concepts such as postprocessing algorithms[19] which ultimately affect image quality were excluded (due to time

[19] Postprocessing algorithms are computer software operations which allow the MIT and the radiologist to manually manipulate a radiographic image to enhance its diagnostic value.

constraints). Consequently, this created a gap in the MIT's knowledge, which they were not necessarily aware of. In hindsight, Sandra recognised this gap in her training demonstrated reliance on the trainer to determine what was relevant and what could be omitted. She observed some fundamental areas, such as how the imaging plates respond to kV and mAs, were *"deemed to be insignificant by the apps specialist."* Their omission could suggest there was a lack of understanding of MIT practice and/or the theory associated with CR plates response to radiation. Sandra did not question the trainer at the time as:

> *"We didn't know what we didn't know. You don't know at the time whether it's right or wrong. You just are told something and that's what you know and you're assuming that the person that's telling you knows about it."*
>
> (Sandra)

Sandra demonstrated reliance on the trainer for the correct information. However, she recognised that this was also governed by the level of knowledge the trainer had acquired: "*There was one application specialist, they did know about the dose values but they didn't really understand everything about it"*. In these examples, Sandra indicated an expectation the trainer would be well informed and knowledgeable about the equipment. This was premised on the fact that, as representatives of the manufacturer, they would have all the necessary pre-requisite knowledge. Furthermore, the role of applications specialist came with an expectation (from the trainees) that the specialist would have the required skills to teach all staff effectively.

Participants such as Christine initially relied on the skills and knowledge of the applications specialist over that of their colleagues. Here, she recognises that relying on colleagues may not be the most appropriate approach:

> *"I missed some of the applications training… I would be on evening shifts for example or weekends… So, what I did sort of learn I had to learn from my colleagues and that was okay… I think that's disadvantageous, you pick it up sort of ad hoc and you learn bits and pieces from other people but they might not necessarily be 100% in it...."*
>
> (Christine)

Although her colleagues were willing to help her, Christine believed the applications specialists were best placed to provide the training, due to their greater technical knowledge. Furthermore, colleagues were more likely to misunderstand, misinterpret or completely overlook key information compared to applications specialists. Her comment suggested that peer teaching created the possibility of replicating poor practice through learnt behaviours. However, the transition to FPDR affected Christine differently. While from one perspective she was willing to defer to the application specialist's knowledge, she started questioning what she had been told:

> *"We have an application specialist herself suggesting that all you have to do is create an algorithm that will process lateral hips nicely for you. And then 'you don't need a filter, as you've been trained' [Application Specialist] ... And we challenged that, 'what are you on about, mate?' You always use a filter because the exposure setting is for the densest part of the hip, that's where you want the image and you'll lose the detail on the other part… Maybe I need to go back to school a little bit, but it doesn't sit right with me that we don't need to use the tools of our trade to even out densities. To maintain the optimal image quality and they're sort of suggesting 'oh don't worry about it' [Applications Specialists] which I can't, I don't know enough to sort of say nah [expletive] you know what I mean!"*
>
> (Christine)

Christine revealed the underlying tension between the application specialists' knowledge and the specialised radiographic knowledge of MIT practice. She appeared to experience conflict between her own theoretical knowledge and clinical expertise versus the information disseminated by the applications specialist. This conflict was manifested as distrust of the specialists' information, which increased when the specialist was unable to support their statements with facts or evidence. Christine recognised her training had been insufficient (even as a superuser) to understand the equipment *"from a technology perspective truly, you know truly understanding it*." In this way, she highlighted that the change to digital technology had provided limited theoretical knowledge she could apply in her practice. This suggested a level of discomfort she had not experienced previously with F-S systems.

Participants' reflections suggested the introduction of digital imaging was assumed to be part of medical imaging's natural evolution. Therefore, the move to digital imaging was viewed in a similar way to previous technological changes, such as the move from wet processing to automatic processing, and ultimately the daylight processing of images and therefore the significance of the change had been underestimated. This perspective influenced the way in which the change process was managed, as the underlying assumption was it would be a smooth transitional process with minimal impact on the way MITs work. This was reflected in the fast transition period. The speed of the transition impacted on the level and type of training which could be provided in the designated timeframe. Further, the level of training provision was affected by purchasing decisions, as it was specified as a cost in the tendering process. When combined, all of these factors ultimately impacted on the provision of quality training.

5.2.2 Task driven training

The training participants received (whether it was from the applications specialist or the superuser) appeared to be based on technical aspects i.e. how to produce an image rather than underlying theoretical concepts. Sandra's identification that the key tenet of her training was "*if you press this button this is what happens, you press that button this is what happens",* illustrates the training approach. A process, where the MIT was simply required to select the correct button in the correct order to create an image, resulted in a training method which appeared to encourage a surface level of learning. Sandra described her experience as one which encouraged MITs to practise without considering the purpose and consequences of their actions, potentially contributing to the negative stereotyping of MITs as simply being "button pushers".

Participants identified concerns about being viewed as a button pusher and yet the way they had been conditioned to accept the machine settings, created the very situation they were trying to avoid. For example, Elizabeth stated:

> *"I've got one colleague who just pushes the button on the machine, and doesn't even know what the exposure says on it. And I was like how do you not know? She's like, "it was an ankle and I think it's set at 78 [kV]" [MIT]. And that's what she uses. And I said to her "that's far too high, that's a mistake, you need to change it" and she goes "oh well it shouldn't be set like that then" [MIT]. Yes, it shouldn't, but you should also know that that's far too big a dose for an ankle."*

Here Elizabeth is referring to the use of anatomical programmed radiography (APR) systems where the MIT selects the exposure factors by choosing the icon or phrase which represents the body part to be imaged and required projection. This reduces the need to manually select the kV and mAs values to produce a diagnostic image and, in theory, reduces exposure selection errors (Bushong, 2017). Nevertheless, there is an underlying expectation that MITs adjust exposure settings to minimise patient radiation exposure (Bushong, 2017) and Elizabeth recognised her colleague was not using the equipment appropriately. The need for thorough equipment training to practice safely was recognised by other participants. For example, Michaela identified her training had been rudimentary:

> *"I wouldn't say my training was the ins and outs of what the algorithms are or how that affects your radiography, but on a basic level I guess I was explained how to use it and that there are a few features on the machine to help you."*

Michaela indicated her training provided her with a basic overview of how to use the equipment but omitted detailed explanations of the way the software worked. Her tone of voice in the interview suggested she was neither unduly perturbed nor dissatisfied with this way of teaching and seemed to accept this level of instruction was the status quo. Despite this she added:

> *"I don't feel completely happy that I know everything about the machine because of my training. I mean, I got shown how to use it and everything like that, but I do feel like some of the problem solving practice I don't know. Like yesterday we had trouble with a chest x-ray… we ended up x-raying the patient three times for one image and then we had to take them to another room because the machine wasn't really working"*
>
> (Michaela)

Michaela indicated although she felt capable of using the equipment on a day-to-day basis i.e. producing images, she lacked sufficient knowledge to trouble shoot equipment faults, suggesting she was able to perform her role competently when the equipment was working effectively. However, when the machine malfunctioned this was no longer the case. While the process of determining and repairing equipment faults lies within the domain of the engineer or vendor (Seeram et al., 2015), being able to recognise a fault's presence and/or identify its cause, may allow MITs to resolve simple issues or stop using the equipment before a patient is overexposed. Michaela recognised her limited understanding of the technology had impacted patient care, i.e. repeating an image several times before changing to another imaging room. While implying discomfort, Michaela made no specific comments about increased patient radiation dose or the link between knowledge, understanding and competency. This suggested the complexities of the transition process had created knowledge gaps which may have affected the day-to-day practical application of the technology. Christine supported this:

> *"Don't do that [repeat an image] if you're not sure what the error is, that's the worst thing you can do…You know you've got to trouble shoot first and make sure the detector is not broken. Do a test x-ray say sorry [to the patient] don't just say 'oh well that didn't work, so I'll take it again'… It's a lack of troubleshooting and proactiveness"*

Christine recognised that simply repeating an image without establishing the root cause of equipment errors, did not reflect good practice. Unlike Michaela, she felt that failing to *"troubleshoot"* was due a lack of MIT motivation or the adoption of a passive approach to the situation. Nevertheless, like Michaela, other participants revealed an incomplete understanding of the physical principles of image production:

> *"I still have no idea how any of this CR and DR actually works, I just know the end result. I don't know the physics of it any more than I know how the fax machine works. It just happens and as long as I get the end result I've moved back from thinking I need to know how this goes. I just need to work with it."*
>
> (Karen)

Karen suggested she felt capable of using the equipment to produce diagnostic images, without detailed understanding of the inner workings of the equipment. While her analogy clearly articulated her thoughts, it did not reflect the very different functions of fax machines and x-ray equipment. Nor the fact that fax machines do not emit radiation, seemingly minimising any concerns associated with using the equipment. Furthermore, the move to digital imaging seemed to have reduced the level of knowledge Karen felt she needed. She summarised her perspective as:

> *"I found a way that it [the equipment] works for me and whether that's the correct way and I wouldn't say I'm really understanding it [the equipment]. But I know how to make it [the equipment] work for me so that I get decent radiograph".*
>
> (Karen)

Karen was not concerned about fully understanding equipment functionality, providing she could achieve the end result i.e. a clinically diagnostic image. Consequently, she had created her own idiosyncratic approach to achieve an image. She measured her success through the lack of negative critique from the radiologists "*as usual I've had no complaints because you don't really get feedback unless it's gross*." Karen assumed her approach was acceptable, as she had not been advised otherwise. However, the lack of radiologist feedback could merely indicate the quality of her images was satisfactory in aiding diagnosis or management of disease. Karen's response here did not consider whether the best possible image was produced at the lowest patient radiation dose achievable.

Several participants recognised their training had been insufficient and created workarounds to overcome their lack of knowledge, identifying this as "*muddling through*". For example, Judith commented *"I just learn it as I go. Just from having to work on a computer all day, using a phone, using an iPad. Just muddling my way through it*". Here Judith is using the term *"muddling through"* in relation to learning about new technology and computers in general and she felt regular use of the equipment helped support her understanding. The definition of "muddling through" indicates achievement without planning or effort (Merriam-Webster, n.d.-b). However, "muddling through" was a strategic approach to overcoming knowledge deficiencies for some participants, such as Mary, "*I can remember we fiddled and farted around, and we got it right*". Mary identified her approach provided a temporary solution, enabling her and a colleague to complete the imaging process for a patient, while suggesting their methods had not been the most efficient. Samantha identified a similar approach of doing whatever was necessary, to produce an image:

> *"But at the time, you just kind of muddle your way through! You're like oh, we'll figure this out. You don't think oh who's the superuser? Who should I go to? Is there a named person? It definitely would have helped if somebody at the time would have said to me this person is the go to person for anything to do with that."*
>
> (Samantha)

For Samantha the issue also related to knowing who to go to for support. In the immediacy of the situation, she relied on her own knowledge and that of her peers to work through the problems. Samantha observed her lack of comprehension about equipment functions and the impact it had on her:

> *"Suddenly I feel like I don't know any more. So that's changed. Am I maybe more reliant on what they [Applications Specialists] tell me? Maybe I'm using the machine in a way that's more kind of button pushing. Because I don't know… I'm more reliant on what the settings are because I feel like I don't understand any different".*
>
> (Samantha)

Here Samantha revealed dependence on pre-set exposure factors ("*the settings"*) generated by process driven training. Samantha felt conflicted when this was coupled with information disseminated by the trainer, such as *"you should keep our settings, our settings are optimal, so if you're going to use this machine you should use it on our settings"*. Samantha's anxiety was exacerbated by the apparent disconnection between the theory she had been taught as an undergraduate and what the applications specialist stated. Her discomfort meant she no longer felt she had sufficient knowledge to practise to the best of her capabilities. Prior to the introduction of digital technology, Samantha inferred she had confidence in her knowledge (based on sound theoretical foundations) and the application of that knowledge in clinical practice. Following the transition process, she felt confused and unsure, questioning her understanding of previously grasped concepts and whether these had fundamentally changed due to digital technology. This resulted in her feeling she had no choice but to use the equipment in a way that was alien to her, relying on the manufacturer pre-set functions rather than careful consideration of the exposure settings for each individual patient. As such, she recognised that this transactional approach had influenced both her confidence in her competency and her clinical practice in a negative way.

The focus on the technological aspects of the digital imaging equipment during training contributed to the technology being experienced as a "black box". The phrase "black box" has been used metaphorically in rehabilitation, to highlight the many aspects which influence patient rehabilitation and it is not always possible to view each aspect's efficacy or impact in isolation (Hart et al., 2014). The term "black box" is also used to describe a complex electronic device. When the device is utilised, the end results are visible. However, the internal mechanisms are normally hidden and considered to be somewhat mysterious to the user (Merriam-Webster, n.d.-a). The analogy of a black box which can be manipulated externally, with no knowledge of the internal workings, was also used by Guba & Lincoln (1982) discussing research in the "rationalistic paradigm" (p. 234). It is the latter two definitions that are relevant here. The training received by the participants seemed to focus on a surface learning approach and relied heavily on the "*how to*" aspects of the equipment rather than the "*whys and therefores*". This could have impacted MITs' understanding of exactly *how* the equipment worked to produce an image. This ultimately appeared to affect the level of knowledge they could assimilate, with consequences for their clinical practice. Furthermore, these findings suggested my participants' potential to produce an image, without fully understanding how that image was achieved.

5.2.3 Lost In translation

The levels of knowledge the participants felt they required, varied between the participants. For example, Samantha's response and levels of discomfort, described above, was in contrast to other participants such as Karen, who summarised her feelings as:

> *"Do I need to understand everything? I don't think so. As long as it's working right. I mean all of the QA [Quality Assurance] stuff, I'm not even sure if they [Applications Specialists] understand to be perfectly honest. Half the time when you talk to the physicist and then you talk to the guys that actually put the equipment in, they're not always on the same page. So, I don't think I have to be."*
>
> (Karen)

Karen had observed differing levels of knowledge amongst applications specialists, physicists and engineers. She implied that if the "technology experts" have varying degrees of knowledge, gaps in her own understanding were acceptable. Karen's perspective was that MITs are not expected to have the same knowledge as the other professionals. However, Karen suggested she relied on the equipment to function and her limited understanding may not support her performing quality control tests. This is in conflict with the requirement for MITs to be able to undertake specific required quality control procedures related to medical imaging practice (The New Zealand Medical Radiation Technologists Board, 2018).

The differing viewpoints and variation in reactions, highlights that MITs are not a homogeneous group. Rather they are likely to have differing learning needs during the transition process and this appeared to have been overlooked during training. For instance, it seemed to be taken for granted that trainees were all familiar with computerised technology and the language that accompanies it. However, Judith illustrated this was not always the case:

> *"When we got CR, I didn't even know what an app was. They were talking about an apps person coming around to show you what to do. And I was thinking what's an apps person? I had no idea. That was before I had apps on my phone, I didn't know what an app was. And I didn't know it was to do with applications either I just thought app, what the heck is that?"*
>
> (Judith)

Judith was completely unaware of some common terms used in digital imaging when it was introduced. This did not just relate to the terminology used by the manufacturer and the applications specialist, but to the terms used within her own team. "Learning a new language" was a concept several other participants reflected on, whether it was due to the introduction of new terms such as "app" or the use of phrases which either seemed nonsensical to staff, or which were used in an unexpected way. Karen revealed:

> *"There was an applications person there who talked about 'dose'. And how you select 'dose' on the machine. Which I found a little bit confusing because we didn't use terms like that and we didn't use steps like that."*

Karen's difficulty arose when both she and the applications specialist used a key term in completely different ways. MITs do not "select dose", they select exposure factors which influence the overall radiation dose the patient receives. For an MIT, the term "dose" would be a physical measurement of the amount of radiation a patient received, calculated by a medical physicist. In addition, Karen suggested the process used by the applications specialist was not reflective of MIT practice. The lack of a shared language appeared to contribute to a disconnected relationship between Karen and the applications specialist, which reduced the application specialist's credibility in Karen's eyes. Samantha experienced a similar situation, *"they're [Applications Specialists] using words like 'this machine is kV hungry'. Hey, what does that mean? I don't know what that means!"* The applications specialist advised her to adjust her manual exposure factor settings in a way that did not make sense to her. Additionally, the choice of words reflected a "dumbing down" of the type of information that is key to radiographic practice and seemed to be coupled with a patronising hierarchical attitude towards the MITs. This attitude was one that Elizabeth had also experienced:

> *“The people [Applications Specialists and Engineers] who are dealing with it, they’re just not relatable. The guy who comes and deals with our CR, talks to me like I’m a moron. And I really hate it. Yes, I may not understand all the little logistics things that you’re talking about, but why not change your approach to how you talk to me about it? Don’t just talk in computer jargon and when I look at you with this blank bored face because I don’t know what you’re saying, think that I’m a moron, because I’m not.”*
>
> (Elizabeth)

Elizabeth identified the challenges she had faced due to a lack of shared language and understanding. This had caused her distress and an inability to effectively communicate with the applications specialist or engineer. Elizabeth implied she felt these individuals considered themselves to be superior to her. Samantha and Elizabeth’s reflections are reminiscent of the subordination of MITs which began in the early history of medical imaging i.e. the separation of medical doctors, engineers (and physicists) from the equipment operators (Decker & Iphofen, 2005). (Refer to section 2.3.1 in the literature review).

The language difficulties and issues the participants described, suggested these could have influenced their knowledge and understanding of the technology, as well as their ability to interact effectively with the applications specialists. Potentially resulting in the participants taking a more atheoretical approach to their practice than previously.

5.2.4 Changes to support and autonomy

The working environment influenced not only the level of training some participants were able to access, but also whether they felt comfortable identifying they needed extra support. For example, Judith, Karen, and Samantha felt unable to ask the application specialist questions or seek further clarification. *“At the time, I was in a room with five, six other people so I just nodded, okay, does anyone else not know what that means?”* (Samantha). Samantha seemed to feel uncomfortable asking questions in front of colleagues and she did not want to appear to be the only one who did not comprehend what the trainer was referring to. Overcoming knowledge limitations through peer support was an approach the participants utilised. For some this was readily accessible *"we're quite an open little department. And we're not afraid to ask for help"* (Mary), but this was not the case for everyone. For example, Elizabeth commented:

> *"When we teach the students, they've got that student label, so if they make a mistake it's okay. Whereas as a qualified [MIT] you get frustrated, you should know. You've done your time as a student, you're meant to know it all, that's not the way it is."*

Elizabeth perpetuated a commonly held belief that while it was acceptable for students to make mistakes and ask questions, this was not something expected of qualified staff. As such she did not feel able to seek support and probably had unrealistic expectations of herself. This resulted in her feeling increasingly frustrated about her lack of knowledge and not knowing who to approach for support. The inability to feel comfortable to ask questions of her peers, compounded the notion of the technology as a "*black box*". This was also illustrated by Samantha who had only just come to the realisation that:

> *"…we're all learning altogether at the same time and that it's okay to not know and that everybody's on their own different paths. Some people have learned straight from DR, some people have learned from film. So, we're in a department that's really mixed and I always have been in that situation, since I've qualified. But I think I'm just much more appreciative of the challenges that brings now for people. I just think that if we talk about it openly, and that we acknowledge and celebrate it, you know 'we're all good at different things and it's okay that some of us have never used this thing before' and there are some people that are really slow to learn and other people that just get it straight away. Like I said it's always been like that, it's just that now (I don't know whether it's the culture of the department that I'm in more than anything) we're all happy to say that we don't know."*

Samantha recognised that staff learning needs were different and also appreciated the work environment may influence staff learning i.e. workplace culture and associated team dynamics.

Unexpected changes to inter-professional working, and the resultant impact on the work environment, were clearly articulated by the participants. For example, the advent of teleradiology had resulted in a situation where radiologists were frequently no longer on-site and therefore less accessible to the participants for advice or support. Karen highlighted her method for reviewing a patient's images and determining the need for additional projections:

> *"You either message a radiologist or you just add the extra views and then you put a message in [PACS], 'I've done a blah, blah, blah because I can see so and so, or highly suspicious of a fracture, so I've done an extra view'. We use our own initiative to prove or disprove things if we can see it there. And the A & M [Accident and Medical] doctors will come and ask you 'do you think that could be a so and so or blah, blah, blah'? and so 'well I can do you another view', so we do it that way round."*
>
> (Karen)

Karen described her approach to evaluating potential pathologies on an image and how she looked to support patient diagnosis through additional imaging, either via instruction from the off-site radiologist or by discussion with the referring clinician. In her example, she appears to have increased feelings of autonomy in that she uses her initiative to take further images to facilitate diagnosis and also through being asked for her opinion. Previously, referring clinicians would bypass MITs and approach the radiologists directly (Brady, 2021).

In contrast, other participants, such as Elizabeth, discussed how the introduction of FPDR had reduced feelings of autonomy:

> *"You could push a button and the machine would move independently around the room and just set itself up for an x-ray and would cone and do everything for you. I really didn't like it, to me it was taking everything away from my job. You literally are a button pusher with that machine. You don't have to set up [the equipment] all you have to do is tell your patient to stand in the middle. Then you can walk out and push a button, you don't even need to position your patient because you could effectively tell them where to stand, you're not needed".*
>
> (Elizabeth)

In her reflection of using an FPDR machine, Elizabeth implied that the functionality of the equipment was reducing the need for a qualified professional to operate it. She seemed to feel that the equipment was taking over key components of her role and minimising her professional standing. Another difficulty was other health professionals' lack of awareness of radiology imaging processes and systems. The change to FPDR had exacerbated this limited understanding:

> *"80% of patients that come through the hospital use radiology, but most departments don't know what we do. Don't know when we go through a change, don't realise just how important things like the computer systems are... I think radiology is kind of left. It's always their problem, it's no one else's that things are going wrong, you just sort it out yourself because that's what you do."*
>
> (Elizabeth)

Elizabeth reflected that despite large numbers of imaging referrals, other departments and clinicians were unaware of how the imaging department functioned. While this could be due to poor inter-departmental communication, she suggested it was created through isolation. In this example, Elizabeth is considering the physical separation of the imaging department from other clinical areas but also increased relational isolation. A rise in relational isolation appeared to be because of reduced communication opportunities, due to radiologists being off-site (geographical isolation) and new MIT work processes. Samantha highlighted this, *"You take your form and you go into the room and you work by yourself".* While MITs may have previously imaged patients single-handedly, the introduction of FPDR has resulted in image review taking place in the x-ray room, rather than in a shared environment such as the viewing room where other MITs would be present. This isolation and its perceived impact on inter-professional practice was also identified by several the participants. For instance,

> *"We've become slightly more isolated. CR and DR isolated us because we used to talk to the radiologists... Now we're just groping on the computer and message them [Radiologists] but you don't actually talk to them anymore! I think that's a disadvantage. We used to learn a lot from the radiologists when you used to take the films to them, pop them up in front of them. And they would say 'oh look at that blah, blah, blah' and you'd say 'what do you think that is?' and you would talk to them. And that's gone now. That just doesn't happen anymore."*
>
> (Karen)

Karen again revealed the level of interaction between MITs and radiologists had reduced and while she felt more able to exercise her own judgement (as indicated previously) she also identified a loss of educational opportunities, which may have been taken for granted previously.

Teleradiology seemed to have influenced patient care, for example, the ability for radiologists to interact with patients; check their clinical history prior to imaging, to support the selection of the correct protocols; and discuss image findings, had largely disappeared.

> *"They [patients] can't get to talk to a radiologist. Whereas in the past if a patient came for a mammogram and it [the diagnosis] was cancer, they [patients] would often talk to the radiologist as well. That doesn't happen anymore because they [radiologists] are not onsite. So maybe that does impact on them [patients] a little bit…The great majority of them [radiologists] would sometimes come out and talk to them [patients] but they definitely don't get that anymore, there's nobody there. They're [radiologists] at a computer somewhere!"*
>
> (Karen)

Karen recognised PACS systems had removed the opportunity for radiologists to communicate with patients directly. This had the potential to affect the quality of patient care. Radiologists were unable to clinically review the patient and confirm the most appropriate imaging procedure or projections to support the clinical diagnosis. Therefore, the change in radiologist working processes had created increased reliance on MITs to gather additional patient information through clinical history taking. MITs are not generally trained in patient interview techniques, which require different skills compared to confirming request form information with the patient (Egan & Baird, 2003). Furthermore, the reduced time MITs spend with patients led Elizabeth to ask "*Are you missing vital clues that you could be giving the radiologist to help the diagnostics?"* for example noting patient signs, such as the level of movement in an injured limb.

5.3 Unintended consequences

The participants identified the change to digital imaging had brought with it some clear patient benefits. However, virtually all of these were countered by significant drawbacks, directly related to MIT practice and subsequently the quality of patient care. In this way, the participants revealed a series of underlying tensions and complexities associated with the transition to, and ongoing use of digital technology, which created further unexpected consequences.

5.3.1 The effects of increased imaging speed

An increase in the imaging speed and therefore overall efficiency, was considered by several participants to benefit patients. One aspect of increased speed was reflected through the immediacy of FPDR image viewing with no processing delays, in contrast to F-S and CR systems. Instant image viewing had several benefits, one of which was indicated by Michaela, in reference to mobile radiography on the wards or in the Emergency Department (ED):

> *"when you're taking it to the patient's bedside, then the doctor's able to look at their x-rays straight away. With a lot of the machines you can put a TV screen on the column of the mobile, so doctors make decisions at the bed space."*
>
> (Michaela)

As a result, medical staff were able to make clinical decisions more quickly and review and revise treatment plans accordingly, which would be in the patients' best interest. Michaela linked this example to previous scenarios (such as Intensive Care Unit [ICU] mobile rounds) where ten or more patients may have had chest x-ray examinations. Processing all the CR cassettes at the end of the round, meant it could take between one to two hours before those images were available to the referring clinician. Considering ICU patients (although monitored) are extremely unwell and may require rapid intervention at short notice, there is an obvious benefit to images being available immediately. Michaela added another advantage in that all patients were *"done faster and they're on their way quicker".* Here she recognised the speed of the FPDR system meant patients were able to be sent back to the ward, or home, in a timely manner supporting effective and efficient patient care and minimising patient inconvenience.

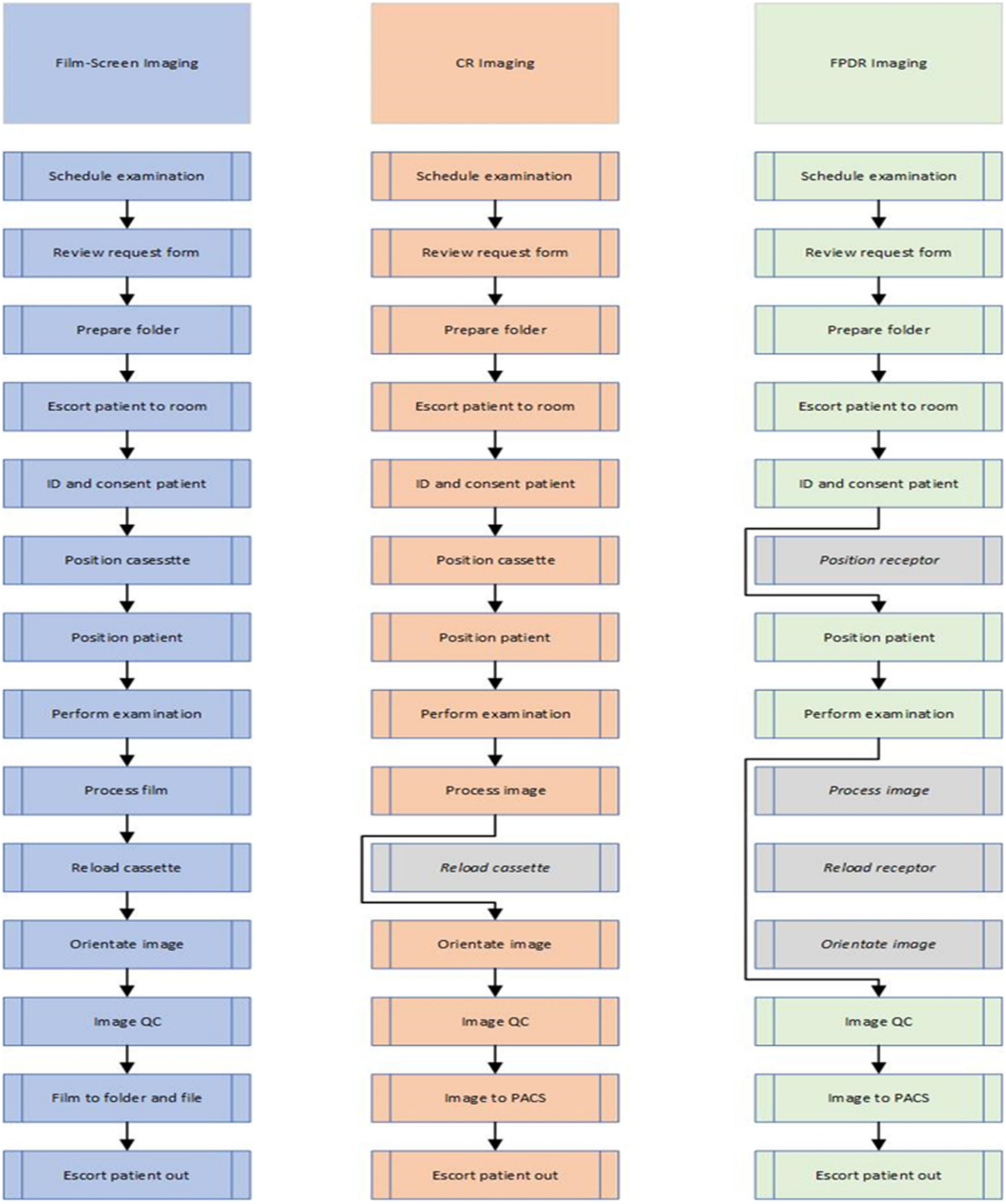
Closely related to speed and efficiency, was the realisation FPDR systems facilitated the undertaking of repeat imaging with minimal disruption and discomfort to the patient, as re-positioning was made easier. This was highlighted by Victoria:

> *"I remember one patient who was in a wheelchair. She was a quadriplegic, she had fallen out of a wheelchair… it was good that you didn't have to take the film out behind her and try and reposition her. You could leave the film where it was and change the tube or her angle to get what you needed, so that was very helpful."*

Victoria recognised the benefit from the patient's perspective in this example and in her more generalised comment *"if you've got someone in pain, you've only got them in position for a very, very limited time".* Therefore, there were clear benefits to the patient, and alongside this, MIT clinical practice had been made easier through the image production process. The change between F-S, CR and FPDR systems is depicted in Figure 5 below and illustrates where steps (depicted in grey) have been removed as technology has progressed. The FPDR process clearly indicates fewer steps and is therefore time saving for both patient and operator. Further, the instantaneous viewing of the resultant images allows the patient to relax out of the required position more quickly and for fast remedial action if repeat images are required.

Figure 5

Flowchart demonstrating the basic stages of image production for F-S, CR and FPDR systems



Note. Adapted from Bushong, 2017 p. 284; 294 & 304

Nevertheless, the increase in speed had not always led to increased efficiency and had in some cases impacted on the perceived standard of care patients received. Samantha reflects this in her experience following the introduction of CR:

> *"They [MITs] were rushing through an ED list by themselves and we did 24 hour shifts then … and they [MITs] were just like 'select that, stick the cassette in, get the next cassette, stick the cassette in, get the next one' and getting things muddled"*

(Samantha)

In this example, Samantha is recalling MITs working over a twenty-four hour period in a busy emergency imaging department with significant pressure to image potentially large numbers of acutely unwell patients. Her comments reflected a conveyor belt approach had been adopted to process the CR cassettes and complete the patients' investigation. That is, the patients' demographic information was selected on the processing unit, the CR cassette was then placed in the unit and processed. As soon as the image was visible, that cassette was removed and the next one inserted.

The busyness of the department created a situation where the MITs found themselves having to work quickly and not always able to think before acting. The speed and the way the MITs felt they were expected to work, coupled with the image display, "*their image was coming up huge on the screen in the middle and the [patient's] name details was coming up small in the corner*" (Samantha), created a situation where incorrect patient identification details were added to images. This scenario had the potential to lead to significant outcomes for the patients concerned, such as misdiagnosis or contraindicated treatment. The need to minimise patient identification errors and prevent incorrect imaging examinations being undertaken, was also identified by Michaela:

> *"Before each patient we have to print off the form … and write for example their name and date of birth. Because what was happening was people [MITs] were going into the room and saying 'hi dah, dah, dah, what's your name?' and then you'd forget by the time you got around to what you're doing…So that [printing the request form] slows down the workflow a little bit which I guess is good. We actually take the time to read the form, we check it in the room answering questions they [patients] have like 'why am I having this x-ray?'... I guess when things are moving quite fast, you get patients in quite quickly and they leave quite quickly and x-rays are taken that way."*

In this situation, the imaging department had reverted to creating hard copies of the request form rather than using the soft copy, to ensure the correct patient had the correct procedure, thereby reverting to a process which was supposedly outdated and extraneous following the introduction of digital technology. This was because the Radiology Information System captures all the information that was previously written on a hard copy request form. Michaela recognised the technique of printing request forms and MITs taking the time to read through them in the imaging room, reduced patient identification errors and allowed for increased communication with patients. As such it created an opportunity for creating artificial spaces for patient-MIT interactions to occur.

The speed of the imaging process had also created an expectation to be able to work more quickly. Michaela summed it up:

> *"It's very go, go, go is how I would describe the change. It just comes up virtually and instantly with DR so, the workload has changed. It's faster. So, get the patient in, get the patient out, get the next one in. That's what I've experienced."*

Despite the creation of pauses in workflow as described above, Michaela identified that the number of patients she was expected to image in a shift (and therefore her workload) had increased, while the overall level of patient interaction had reduced. She conveyed a feeling of working on a factory production line which was consistent with Samantha's comments about CR cassette placement (above) and the transactional nature of the digital imaging process.

Working more quickly appeared to have inevitably led to other mistakes which resulted in repeat imaging. Christine admitted:

> *"I've made a couple of mistakes where you're in a rush. You grab the detector and you grab the grid and you're helping someone and then you quickly take your x-ray and you both go 'oh no' because you get a blank image."*

Here Christine was reflecting that 'in the moment' it was relatively easy to forget to activate the wireless detector, an action required to ensure the detector captures the image data. She also reflected how the speed of the process has had a negative effect on clinical practice and the production of high-quality images:

> *"it's the pressure to do it well but also do it quickly, diagnostic versus brilliance. In a way that's where DR has maybe muddied the waters a little bit. Whereas we [MITs] were allowed to go 'oh hang on, just keep moving a little bit. Just let me try this and let me try that' and spend a couple of extra seconds talking to someone. Whereas now it's kind of like 'stand there, turn 45 hold that position, not enough joint*

> *space, alright turn a bit more,' you know, instead of lining them up… to get a true joint space."*
>
> (Christine)

In her example of taking an image of a patient's shoulder, Christine reflected that in the past MITs were able to take the time to think through patient positioning while talking to the patient. They would use their knowledge of anatomy and radiographic positioning and the needs of the patient, to try and ensure the initial image was correct first time. However, the expectation to work quickly (facilitated through digital technology) and the ease of taking repeat images, meant there was less impetus to get it right first time. Rather, MITs tended to use the resultant images for feedback on their technique, simply retaking images to correct their mistakes. In Christine's opinion, the use of FPDR had resulted in a "non-thinking" culture in image production. The resultant outcome was acceptable, rather than excellent quality images.

John also indicated MIT practice may have been adversely impacted by the speed of the digital systems and the consequent expectation for a higher throughput of patients. He felt the ability to logically plan during the imaging examination had been reduced and consequently, there was an increased likelihood of mistakes happening:

> *"When you're working too quickly and you're constantly forced to switch your focus from one patient to the other (and of course each patient's needs are quite different) then you find your mind will either lag behind a little bit or your focus will drift."*
>
> (John)

John recognised that simply due to the processing cycle, F-S systems had created time in the imaging examination for MITs to reflect and consider what further actions they may need to take. However, the immediacy of digital imaging results had created a situation where:

> *"It's almost position the patient, take the picture and bam there it is! And you go through your mental check list, 'what if I have this, can I see this, is everything good? Excellent. Next!' And then you have the next patient and you read the request form, 'what are they looking for?' and so there isn't that forced pause between images."*
>
> (John)

Taking both of Johns' quotes together, he displayed some concern over the increased speed of the imaging process and felt there had been benefits to the slower paced aspect of F-S systems which were now lost. The "mind lag" comment indicated a worry that he could still be mentally processing one patient's examination while imaging another. His comments suggest this lack of concentration could lead to a negative impact on patient care, more specifically an increase in error rates which could result in repeat imaging or wrong patient data potentially leading to incorrect diagnoses. The notion of reduced patient care due to a fast imaging process was also reported by Elizabeth:

> *"We timed the amount from when the patient walked in the room, to when you put their pictures through and said 'you are free to go', you can do it in three and a half minutes. That's not long to have patient interaction, if you're pumping through and you're busy."*

Elizabeth reflected that the potential for increased efficiency, had come with a trade-off of increased workload and the need to work quickly (*"pumping through").*

Associated with increased workload, the participants conveyed concern about the potential for staff burn-out. Due to the increased speed of digital imaging, increased patient throughput had occurred without a corresponding increase in staff numbers, thereby increasing staff workloads. Many of the participants recognised this, although they had different ways of resolving it. For example, Michaela identified she felt able to work more quickly to keep up with an increased work rate *"I guess the workflow being faster doesn't bother me, because I feel like I can work with faster and I can keep up with the pace*". Michaela seemed unperturbed by needing to work more quickly, and did not reveal any concerns about sustaining it long-term. Neither did she discuss the potential for a reduced quality of care, as highlighted by Christine in her comment *"diagnostic versus brilliance".* Despite this, Michaela's comment *"keep up with the pace"* suggested a need to maintain working quickly, with little external control over this aspect of her work. John supported this when he revealed his concerns:

> *"It [Digital Imaging] tends to also increase the tempo, because we can do more x-rays quicker, they [Clinicians] will send more patients quicker and you get to levels where you basically won't get a chance to almost sit down. And one has to take conscious step to try and slow down or, I guess you just burn yourself out."*
>
> (John)

John articulated the reality a faster imaging system had created an expectation that MITs could accommodate a greater number of patients. He conveyed a need to create artificial delays not only to support patient care, but to allow himself to have some control over the pace of his work. John identified how he achieved this:

> *"I force myself after each patient, to go through the full classic student evaluation. 'Marker, position, artefacts, anatomy, exposure'. The whole thing. I go through that check list, and then I have a brief chat with the patient as to what we've done, how we've done it and I have just a little bit of patient interaction. I think it helps me slow down a little bit and makes the patient experience a little bit better. Rather than 'alright, next!'."*
>
> (John)

Image review is generally a shortened process when undertaken by qualified MITs (due to clinical experience) and frequently does not encompass the formal step by step process encouraged for student MITs. John revealed by reverting back to the structured approach, he felt better able to meet the needs of each patient, while allowing himself to mentally catch up and create a "breathing space" between patients. His comments also reflect the "production line" transactional nature of medical imaging had been exacerbated by the speed of FPDR and the impact this was having on patient interactions. John, along with some of the other participants, had identified the creation of individual processes within his practise in an attempt to maintain quality standards and safety, rather than relying on these being systematically produced.

These examples highlight that while the introduction of FPDR had increased the speed of medical imaging, and provided an opportunity to improve efficiency and increase throughput, there was also a detrimental effect. Namely, the potential for reduced safety for both patients and staff and decreased quality standards of care.

5.3.2 A safer, cleaner process

Many of the participants identified their initial perception of the move to digital radiography was that it would be a safer, cleaner process. Their principal reasoning was based on the removal of darkrooms and the processing chemistry associated with F-S radiography, combined with the reduced manual handling requirements of FPDR. Film processing was considered an unpleasant but necessary component of the imaging chain. The participants conveyed a dislike for the industrial nature of film processing, the noxious fumes, and the need to use personal protective equipment when dealing with hazardous chemicals. Samantha recalled that "*we had chemical spills, it stunk, it smelt, it was hot*" and Karen highlighted that "*not breathing in all those fumes that has to be a benefit*". Film processing was identified as source of frustration for Samantha:

> *"I was in the middle of a really busy list by myself, and the developer was beeping because it was running out. 'Oh, you're not serious!' The blue developer and the red fixer and you had to know which ones to go in which pots. So, getting rid of all of that is just huge in terms of the day to day working environment. The pressure's a lot less [with DR], because you have less things to worry about."*

While Samantha understood the need to respond to the chemistry replenishment alarm, the fact that it sounded while she was alone and imaging patients in a busy environment, had been distracting and a cause of disquiet. For other participants stressors were related to the fact that MITs were often expected to undertake basic troubleshooting if the processor broke down:

> *"With the film processor you were forever taking screwdrivers out and cogs were going in. You always tried that before you called anybody else in. I've certainly enjoyed moving away from that."*
>
> (Karen)

Karen's comment suggested she appreciated not being expected to attempt repairs and feeling relieved she had been able to move away from the more technician-based aspects of the role. Conversely, Elizabeth expressed irritation that many equipment faults have to be assessed by other staff, such as the PACS team or engineers:

> *"If something's gone wrong with the computer there's only, an endless spectrum of what could be wrong, and I think it's a lot more difficult to try and pinpoint what's wrong. But you're expected to know how to fix a lot of the problems because it's your equipment, you should know it… I can go over the checklist on the CR unit and it says there's a problem sending to PACS…Then I have to call the PACS people and they have to do it from their end but they're busy, it took us three weeks when we had a PACS issue …to work out what was wrong. And I had doctors coming over shouting 'Why can't I see the pictures? Why aren't they being sent through?' People are thinking that you're useless as a radiographer because the only answer you've*

got is I don't know."

(Elizabeth)

Elizabeth indicated additional stress was created due to dependence on other staff and potentially significant delays in solving faults. Her stress was compounded by her perception she was expected to take ownership of the repairs herself. So, while having responsibility for repairs was perceived as a burden of older technology, not being able to repair the machine oneself was a frustration of new technology.

The reduced level of manual handling following the introduction of FPDR reduced physical stress on the MITs. For some, this was specifically related to the carrying of large numbers of cassettes: "*we might do 10 or 15 patients and only at the end you process all those 10 or 15 cassettes*" (Michaela). This was also reflected by Judith:

> *"It's the physical thing of not carrying a load of cassettes with CR and definitely with film. With CR we only had a limited number of cassettes to use- use some of them, go back and use them again. But say I was doing a thigh and extremities [Radiographic examinations], I'd carry the whole lot [Cassettes] in with me, dump them down on the chair, pick them up, under the patient, down on the floor, pick a new one up. So, it's just completely got rid of all the carrying. I think if you've got back problems, that would have saved a lot of people. They might have been able to carry on longer without that sort of physical thing going on."*

Judith described the process she used when undertaking several examinations on one patient. She had a specific approach which allowed her to try to be as efficient as possible, taking all the cassettes into the room at once, while ensuring she knew which cassettes had been used to avoid a double exposure. Although this saved time as she did not need to locate a new cassette between each projection, she recognised the cassettes were heavy and using them in this way had the potential to cause injury. Indeed, she suggested the reduced physical impact on MITs through the introduction of FPDR may mean they are able to continue to work for longer.

Physical strength as a result of carrying F-S or CR cassettes was also considered by Karen. However, unlike Judith she seemed to consider this had been negatively impacted following the introduction of FPDR:

> *"From a physical point of view, I don't think radiographers are going to be as strong as they used to be. I think they're going to have to watch their body strength because we used to get so much practice at upper body strength. Carrying cassettes around which you don't do anymore, and then suddenly you have to haul a massive big patient. I know we're all taught safer lifting and people don't do things on their own anymore, but it's still an effort to move a large person."*
>
> (Karen)

In this quote, Karen is identifying her concern that MITs will no longer have the physical capacity to manoeuvre patients on the x-ray table as a result of not carrying cassettes. Nevertheless, many participants commented the level of physical manipulation of patients had been reduced following the introduction of FPDR. This was as a direct result of not having to change a film or CR cassette between projections. While this was seen as beneficial, the participants conveyed concern that an easier and faster way of working had led to the possibility of increased repeat imaging and therefore increased radiation dose to patients.

5.3.3 Balancing radiation dose

As previously discussed, the advent of digital imaging was expected to reduce patient radiation dose, principally due to a lower likelihood of repeat imaging being required (Huda et al., 1997). This was related to the much wider exposure latitude of digital systems compared to F-S systems, making them more tolerant of incorrect exposure selection by MITs. Furthermore, the change from CR to FPDR allowed for a further decrease in patient exposure, due to the increased dose efficiency of FPDR detectors (M. B. Williams et al., 2007). Finally, the reduced likelihood of images being lost, misplaced, or repeated due to human error (compared to F-S systems) was an additional benefit of digital imaging systems. However, my findings make clear that not all these radiation dose savings appear to have been realised, as highlighted in the scenarios below.

Radiation dose saving measures were discussed by the participants as an advantage of digital imaging. Savings could be achieved for all projections through lower exposure factor settings. For example, Victoria stated she was using exposure factors in FPDR which were *"20-30%"* lower compared to CR systems. Elizabeth also conveyed this, when she discussed how the use of much lower exposure factor settings had affected her:

> *"They've [Exposure Settings] dropped a lot. I think the average chest x-ray exposure was 109 [kVp] and 1 [mAs] on DR. Whereas I was used to using 125 [kVp] minimum and a 3 or 4 [mAs]. It just really threw me. I was scared that I was going to have repeat a whole lot of pictures because the mAs was so tiny that it wasn't going to be enough. So that took a whole mind shift- that it was okay to use tiny exposures because it was still going to give me an acceptable picture. But it was learning a whole other set of exposures, that are then not transferrable…At least my film exposures I could translate onto CR. Whereas DR it was two separate ball games."*
>
> (Elizabeth)

Elizabeth considered the magnitude of this change had been greater than she had anticipated and it had taken her some time to adjust to using smaller exposure factors. She had needed to adopt a different way of thinking and approaching exposure factor choice, as the FPDR exposure factors were so much lower than she was used to. This transition was made more difficult by the requirement to modify knowledge from her previous clinical practice. For both Elizabeth and Victoria, not only was the drop in exposure factor settings significant, it also illustrated a change in medical imaging practice.

Another aspect of dose saving, previously promulgated by equipment manufacturers, was the wider exposure latitude of digital imaging systems, which made them more accepting of less than ideal exposure factors. This was conveyed by the participants through the idea that precise exposure factor setting was less critical with digital imaging than had been in the past. For example, Karen commented, when comparing FPDR with F-S systems:

> *"We were so careful with exposures because we had to be. Because if you were four kV different, you didn't have a picture half the time. Whereas now it doesn't matter…as long as you're in the ball park you're going to get a picture. It's not like the old days where it was absolutely crucial".*
>
> (Karen)

Karen recognised that while it had previously been essential to correctly expose a F-S cassette, this was not the case for FPDR and as a result this had influenced MIT practice. Specifically, precise and accurate judgements in exposure factor selection were no longer necessary. This feeling was reported by other participants such as John:

> *"One had to be diligent with all factors including exposure … because if you screwed up the mA factors by just a little bit, the film would either be greyed to hell or overexposed, black."*

Both Karen and John reflected their belief a diagnostic image would result, if the MIT selected factors that were reasonably accurate rather than completely precise. This was due to the computer's image processing software. Other participants who conveyed a similar approach included Mary:

> *"I'm relaxed about exposing; for instance, a baby of 500 grams to a kilo, you can you can use the same exposure. And from a kilo to three kilos you can use the same exposure. Whereas with film you had to adjust a bit more. So, you don't have to be as precise."*

Mary's comment reflected that previously exposure factors had to be adjusted according to the weight of a baby to produce a diagnostic image. With FPDR, Mary no longer considered a weight difference of 500 grams to 1 kilo, or 1 kilo to 3 kilos, as needing specific exposure factors. She summed this up as *"on the old system of film you could really muck up a study by having the exposure slightly wrong".* Whereas with FPDR accurate exposure setting was seen as less important.

Overall, the participants suggested a more relaxed attitude towards exposure selection, which they generally considered to be a positive outcome of digital imaging. However, full consideration of the impact of the radiation dose on the patient was not necessarily identified. This point was encapsulated in Karen's comment *"people [MITs] don't worry about the exposure so much if they're going to get an image".* Suggesting the importance of exposure factor selection had been backgrounded following the introduction of digital technology.

Reduced human error was reported by some participants as reducing patient radiation dose. For example, Judith indicated:

> *"No more lost films. Sometimes, we used to give a patient a film, when we were using film, put it in an envelope and he used to take it down the corridor to give the doctor. I used to try and retrieve it at the end of the day, we just couldn't find them [films], they were lost. The patient didn't take them home. In the clinic, where were those things [films]? Just disappeared."*

Her experience suggested patient images could be lost within the course of a day. Consequently, if the patient returned for a follow up medical appointment, they needed repeat imaging due to film loss. However, other participants observed that the risk of films being lost and subsequently repeated was not eliminated entirely following the introduction of digital imaging. Despite FPDR manufacturers arguing it was *"incredibly unfortunate and incredibly rare to genuinely for real lose the image in its entirety and have to repeat"* (Christine) this was not always been the case. Christine expanded*:*

> *"We've found images disappeared, sounds like an odd description but they just went into the ether. They came up for processing, you send for a couple of seconds and then it'll just whoosh…It's enough to see it and you go 'oh yeah, great' and then it disappears, 'oh, where did it go?' And then you click a few buttons and you go 'where did it go?' And you go scratching your head and you go, 'so I took it, there was an audible cue, it was processing, I saw the little processing bar, got to completion, it showed up and then it disappeared'… It must have been interference from a WIFI perspective not quite in sync… It tries to retrieve information that was detected…Had about a 50/50 success rate…we've lost images."*

Christine revealed she had experienced images being lost due to WIFI issues when the FPDR system was initially installed, which resulted in repeat imaging.

Another error associated with F-S imaging was the possibility of films being fogged in the darkroom and requiring a repeat examination, which Christine termed darkroom *"Russian roulette"* i.e. there was a high likelihood that a mistake would be made processing the film, which would render it useless. Samantha agreed that mistakes were less likely in the digital environment:

> *"I think we can trip up less as an MRT. Previously we could fog the film in the dark room. We could choose the wrong film, we could put the film in the cassette the wrong way up."*
>
> (Samantha)

Here Samantha is discussing different issues which could arise in the darkroom, either when developing a film or loading new film into the cassette, ultimately resulting in non-diagnostic images which needed repeating. Both Christine and Samantha felt the risk of human error during the creation of the images was reduced. As a result, there was less likelihood patients' images needed to be repeated, helping to reduce radiation dose to the patient.

The participants also identified that while patient radiation dose had been reduced in some areas, digital technology also provided the means to increase radiation dose in other areas of their practice. These were predominantly related to exposure creep; the use of EI values; collimation creep; and "looking good".

Exposure creep

The possibility of overexposing a patient through "exposure creep" was alluded to by Samantha and Sandra. Exposure creep is a known risk in digital imaging. This is because an underexposed image will most likely need repeating due to quantum mottle or noise. However, an overexposed image may be redeemed through the computer algorithms. As such there can be a tendency for MITs to set higher factors than required leading to "exposure creep". Samantha commented *"it's* [Digital Imaging] *more forgiving* [of exposure choice] *but actually in the same respect that means that you can set a bad exposure and get away with it*". She recognised the risk of MITs using overly high exposure factors to avoid the need to retake their images. The potential for MITs to unconsciously opt for higher exposure setting was also expressed by Sandra:

> *"There is also a big thing called exposure creep, it's well documented. They're [MITs] choosing between two exposure values...it's a subconscious thing, 'I'll just give it a little bit more, because it won't matter and I'll know that I've got a good picture.' That's dangerous."*

Sandra's comment revealed significant concern about the occurrence of exposure creep. She felt undeliberate and poor decision making was occurring in radiographic practise. Poor decision making was also emphasised regarding the use of exposure indices. With the introduction of digital imaging, MITs could no longer rely on visual assessment of the image to ascertain over or under exposure, which was the case for F-S systems. Exposure index (EI) review is now the principal process by which an MIT determines whether to repeat an under or over exposed image.

Issues with EI values

The EI value is used to confirm whether the detector has received an appropriate level of radiation to produce a good quality image (Fauber, 2016). Nevertheless, Samantha recognised that, similar to exposure creep, EI values were not always consciously considered or fully comprehended by MITs:

> *"He [Applications Specialist] was like 'can you remember?' [Exposure index range]. And you can hear people [MIT superusers] whispering 'is it 500? Is it 100, is it 50?' People genuinely didn't know. They were like 'oh yeah that's it' when he said it's '100-300'. I know that it's not 100% reliable but this is the only parameter at the moment that you think you've got, and you still don't know what it is! 'But the images look fine though!' [MIT superusers]. It just surprised me that people don't know, they just don't, it doesn't sort of cross their mind."*
>
> (Samantha)

Samantha voiced her surprise that senior staff, who as superusers were frequently responsible for undertaking staff training, were unaware of the most basic premise associated with exposure indices i.e. the range into which an acceptably exposed image should fall into. Rather than using the EI values as a determinant of image quality, the MITs chose to rely on visual assessment and evaluation. Although this process had been utilised for F-S imaging, its use in digital imaging is known to be flawed because of computerised data manipulation.

Another flaw in this approach is related to the difference in the quality of the monitors available to MITs compared to the radiologists' monitors as highlighted by Samantha:

> *"I remember being frustrated because when you got the images on the workstation they looked generally okay. But then when we sent things through to PACS, the radiologists would send them back and say 'they need repeating because they're noisy'. You [Radiologists] say 'well it's out of range' but it looked alright for me but it doesn't look alright for them. So how are we supposed to know then if …we can't see the image the way they see it."*

In this example, Samantha indicated she had at one time assessed her images visually rather than using the EI values. At the time she had not fully appreciated the differences in image display between her workstation monitor and the high grade diagnostic monitors used by radiologists. It only became apparent when she had to recall patients for additional imaging, as the initial image quality was too poor for the radiologists. Subsequently she focused on the EI values to help her determine image quality. Visual review rather than considering EI values seemed to have been supported by a known lack of EI reliability, which some participants had personally experienced.

> *"I don't take any notice of EI because there's so many other factors can influence it. Like how much of the cassette you've used and there are so many other vagaries, I take no notice of EI, no notice whatsoever."*
>
> (Mary)

Mary identified she was aware of many elements which have the capacity to alter EI values and because of this she had chosen to disregard the value altogether. Karen also disclosed she sometimes chose to ignore EI values if she "knew" the exposure she had given the patient should result in a good quality image:

> *"You do a DP [Dorsi-Palmar] hand and you get a good EI, you just turn that hand a fraction, and suddenly you get this totally bizarre EI. And you've got to keep remembering it's [the algorithm] reading this bit and it's reading that bit as well. It's not just reading the bony part that you're looking at. It's a guide you know, it's not a bible… But sometimes I just know I gave it a good exposure, and 'that EI is rubbish, that's not the patient and that's not me, that's the machine I'm just going to ignore that'. I wouldn't repeat something just because the EI was abnormal whatever. I would first use all the tools, to see what was going on. You can't trust the machines all the time, they are just a machine."*
>
> (Karen)

In this respect, Karen demonstrated she understood how EI values were created and an appreciation of why they may vary. Unlike Mary, she decided to use the EI as a supporting mechanism to determine whether to repeat an image, rather than ignore it. These examples highlight three very different approaches to EI values and image evaluation: Samantha relied on them completely because of differences in monitor resolution; Mary completely disregarded EIs; and Karen used them in conjunction with other factors to assess image quality. Using personal judgement and clinical experience to determine whether an image should be repeated rather than just the EI value, was adopted by other participants.

A more fundamental lack of engagement with EI values was revealed by Elizabeth:

> *"EI means nothing to me, because I look at picture and it looks fine…. There's a big focus on EIs and I tend to glaze over and go 'oh yeah looks about right'. But I wouldn't have any idea. Even on the system I use at the moment, I don't know what the set EIs are… And if they [MITs] say the EI is low, I'm like 'but your picture is fine'. There's just this gap there that I don't understand. 'The picture is fine and yeah your EI is low but your picture is fine, it's diagnostic, why are you redoing it?' I still don't understand it. But to me, EI isn't a reason to repeat a picture. But if I understood how they [MITs] got to that maybe I would repeat more."*

Here Elizabeth identified that similar to other participants she did not use the EI values as a means to judge image quality. Like them, she chose to depend on a visual assessment of the image. Her reasoning seemed to be based on a lack of understanding as to how EIs are generated and their relationship to exposure choice. She did not necessarily see this is a negative, as she indicated that her approach led to a reduced number of repeat images. While this suggested a radiation dose saving for her patients, she did not necessarily link this to the diagnostic outcome for her patients nor an appreciation that a visually acceptable digital image may be significantly overexposed.

In summary, the EI value bears a relationship to exposure factor settings and thereby the radiation dose received by the patient, as it reflects the radiation incident on the detector after exiting the patient. Therefore, a failure to understand how EI is determined, its relationship to image quality, and patient radiation dose, left patients vulnerable to inadvertent overexposure.

Collimation creep

Many participants identified concerns about "collimation creep" as a potential cause of patient over exposure. The term collimation creep was used to reflect a process where MITs extended the irradiated area beyond the region of interest. Thereby, irradiating a larger portion of the patient's body than necessary, leading to an increase in radiation exposure to the patient. Similar to exposure creep, Christine felt MITs extended their collimation field to reduce the risk of repeating an image, by ensuring they would capture the entire region of interest. She phrased it as *"DR allows you to be naughty"* as the receptors are larger than the F-S or CR cassettes previously used, and as such FPDR allows MITs to extend the radiation field unnecessarily. Christine continued that

"I've found it's awful practice to just go 'whatever I'll fix it afterwards'" suggesting a situation in which MITs expand the radiation field and then reduce its appearance on the final image by cropping or post-collimating the image, therefore hiding poor practice. Michaela supported the notion of collimation creep commenting:

> *"To be honest people probably all do it, collimate out when they don't need to. They are doing a knee x-ray and you can fit that on an 18 x 24 cms [detector] possibly and most use 24 x 30 cms [detector] but then some people you want a bigger size. You tend to collimate out because you're using big detector, so I guess that's not a good radiation protection. Collimation wise you tend to want a bigger area, I guess."*
>
> (Michaela)

Here Michaela recognised that the provision of large detectors could subconsciously encourage MITs to extend the radiation field. While she accepted that is was not good practise, she suggested it was so prevalent that everyone was prone to do it. Karen also discussed the same issue:

> *"When you've got a big image plate, they [MITs] seem to feel they need to always fill it. It's like you used to do a knee on an 18 x 24 cms [detector] so really that is all you need. You don't need half way up the femur and half way down the tib and fib to do your knee. I think the collimation stuff is probably the radiation safety they [MITs] need to be looking at."*
>
> (Karen)

In her reflection Karen considered just how much additional anatomy MITs may irradiate unnecessarily. While she accepted that MITs had a professional responsibility not to do this, she also believed that the manufacturers held some accountability through the production of FPDR detectors which were larger than had been available for either F-S or CR imaging. Christine also conveyed this:

> *"Resolution is one of the things they [manufacturers] market. They go 'hey you get the best resolution, no matter what size. If it's a 24 x 30 detector size or the 40 x 55 [detector] it doesn't matter'. And then it's like 'cool this doesn't matter. I'll use the big one and I'll never miss again' creeps up. I can understand our human nature, rather use the big one than use the little one and maybe miss it."*

Christine recognised that in some respects it was natural for staff to default to using a larger detector. However, like exposure creep, collimation creep had tended to become unknowingly integrated into clinical practice.

While discussing the issue of collimation creep, Karen illustrated an example of seemingly contradictory practise *“a bit of lead placed over gonads when they’re [MITs] doing a little finger but they irradiate half the leg when they go to the knee*”. This example re-iterated the issue of collimation creep and identified MITs had not linked this to poor radiation practice. i.e. using lead rubber protection over the gonads when it may not be required, while over-irradiating the patient by increasing the collimation field unnecessarily. This seeming disconnection was also revealed when the participants discussed the principle of ALARA and the provision of the best possible practice. Christine’s comment *“ALARA is important. It’s obviously ground into us, in our rules”* identified that balancing radiation dose risk versus benefit, is a key tenet of imaging practice. So much so that it is re-emphasised until it becomes second nature and something MITs should consider during each radiographic examination. Yet, the participants’ narratives around the introduction FPDR highlighted there was an impact on clinical practice that is counter to this principle.

Looking good

A lack of effective radiation protection was also revealed when the participants discussed the ease of digital imaging compared to F-S or CR imaging. The immediacy of image display, combined with the detector being in situ, was thought to facilitate an increase in the number of repeat projections taken by MITs. Karen related it to the ease of patient set up and image processing time:

> *“The picture comes straight up, you haven’t walked away, down the corridor, and spent 15 minutes processing it and then look at it. You flick it [image] straight up and you go ‘okay, I can get that a bit better’. And then you have to go ‘is this for the patient’s benefit or is this just so I look better?’… It’s like ‘oh if I just turn [the patient], I’ll get a better image.’ You will, but is that going to help the patient? You’re irradiating them again, just so you look good.”*
>
> (Karen)

Karen realised there was a temptation to repeat an image in the hope of gaining perfection, which had been exacerbated by the speed of the digital processing cycle compared F-S systems. She realised the need to consider the potential benefit to the patient before repeating an image, but she felt her colleagues may not always be so meticulous. A lack of rigour appears to have been supported through the ease of FPDR imaging. Mary supported this, when outlining her approach to repeating an image *"I think 'am I doing this to make myself look good?' … I say to the students or the newbies, 'do not repeat that to make yourself look good, sure it's not brilliant but it's perfectly diagnostic.'"* Both Mary and Karen suggested the ability to "look good" had been facilitated by the ease of repeat imaging in FPDR. Specially, MITs may be tempted to repeat images (in the pursuit of perfection) to impress the radiologists with their proficiency and enhance their reputation, at the same time overriding considerations of patient radiation dose. Previously repeat images were only undertaken if the end result was likely to influence patient management, therefore this finding suggests a change in clinical practice. As FPDR images are no longer reviewed in a viewing area with their peers, it is assumed that this practice reflects a desire to impress the radiologists and not their colleagues.

Elizabeth recognised she was more likely to repeat an image now than previously:

> *"If I need to do a repeat, I am probably less afraid to do one [repeat] now, because it's not like I had to go out of the room, and I had to put it [cassette] through [the processor] then I had to come back. It's more they're [the patient] already in that same position, I'll just quickly whip off another one [image].*
>
> (Elizabeth)

Like Karen and Mary, she recognised her approach was due to the speed of the process and the fact that minor adjustments could be made immediately and simply, as the patient remains in the initial position. Her comment about being less afraid reflected increased confidence that her repeat image would be an improvement on the original. This could be due to immediate review of the initial image, with the patient and the detector still in place. Therefore, with FPDR it was much easier to make minor adjustments and achieve a better result. Whereas with F-S or CR systems, there was the need to completely re-position the patient and the cassette, and no guarantee that the repeated image would be of a higher quality. Michaela also felt that repeats were more likely for the same reason:

> *"Probably people do more repeats. The detector's already under the patient, already there and you look at it [image] straight away. 'Oh, it's rotated' or missing something so you end up doing it again because it's [detector] already there and it's easy. Rather than 'oh I have to disturb the patient.' It's more troublesome to take another few minutes to x-ray them [with F-S or CR systems]. I think it becomes a little bit easier just to repeat x-rays."*
>
> (Michaela)

While Michaela had come to the same conclusion as Elizabeth, she had approached it from the patient's perspective rather than that of the MIT. Namely, she considered the potential patient discomfort as opposed to MIT tasks. Elizabeth expanded on her thoughts of the ease of repeat imaging *"I can see that as being a bad thing with some radiographers because they'd constantly be taking more repeats instead of focussing on the initial getting that position right*". She envisioned that the ease of repeats may develop into a lackadaisical attitude towards getting the patient and the equipment correctly positioned initially and MITs using repeat imaging as a means to achieve a diagnostic result.

5.4 Summary

The participants' reflections highlighted that while the transition to digital imaging was treated in practice as a technological, transactional process, it was experienced as a more fundamental knowledge driven process. Participants suggested the introduction of digital imaging was assumed to be part of medical imaging's natural evolution. This perspective influenced the way in which the change process was managed, as the underlying assumption was it would be a smooth transitional process with minimal impact on the way MITs work.

The focus on the technological aspects of the digital imaging equipment during training seemed to rely heavily on practical rather than underlying system functions, and could have contributed to the technology being experienced as a *"black box".* The participants training ultimately appeared to affect the level of knowledge they could assimilate, with consequences for their clinical practice.

When using this technology, the participants frequently relied on their own problem-solving skills to complete the patient imaging process. While the participants had been able to “get by”, there appeared to be no consideration of how a lack of standardisation may influence patient care or the diagnostic utility of the images.

It was evident the participants recognised digital imaging offered opportunities to both reduce and increase patient radiation dose. As such it was one of a number of dichotomies which had been revealed through the introduction of FPDR. While some of these have always existed as tensions within medical imaging practice, such as the risk versus benefit of patient radiation dose, it appeared that digital technology had the potential to increase their level of complexity. When these tensions were combined with the transactional nature of the transition process, they created a shift in practice with unintended consequences for both patients and MITs. Specifically, FPDR had unexpected repercussions on the quality of patient care provision and was also deemed to present a risk of deskilling and retrogression for the MIT profession.

In the following chapter, I discuss the Phase One findings.

Chapter 6 Phase One Discussion

6.1 Introduction

This chapter discusses the main findings from the qualitative aspect of this research with reference to the research questions (specified in Chapters 1 and 4) and in the context of existing literature. The thematic analysis of the interview data revealed that the significance of the transition to digital technology was undervalued. The speed of the transition and the task driven training process exemplified ways in which the transition was underestimated. Consequently, there were unforeseen consequences for medical imaging practice. For some participants, the technology became a "black box" where fundamental operations were not understood, which seems to have resulted in transactional approach to equipment use, with implications for medical imaging practice and patient safety. The most important finding related to clinical practice was that the introduction of technology, appeared to prompt a shift in medical imaging practice affecting the level of patient centred care, MITs were able to deliver. Tensions and complexities that exist in medical imaging, particularly in relation to radiation dose optimisation and image quality, were exacerbated through the introduction of digital technology.

6.1.1 The transition was underestimated

My findings suggested the transition to digital technology was considered to simply be another change in an ever-changing field and therefore its significance was underestimated. The fast changeover to digital technology influenced MIT training provision, and impacted the way in which MITs engaged with the equipment. Furthermore, while many of the promoted benefits of digital imaging were realised, these were frequently accompanied with unforeseen drawbacks. Disadvantages included the potential to increase patient dose through poor radiation protection or work flow errors.

The view that medical imaging technology is constantly developing is well supported in the literature (Laal, 2013; Margulis, 2010; Munn et al., 2020). Despite this, the significance of the change to digital imaging on medical imaging practice has been previously identified. For example, the IAEA commented in 2015 the transition from film-screen to digital systems would be a radical change and as such needed careful and effective oversight. Earlier research findings, such as those of Vano (2007) and Fridell (2011), also indicated this development should not be underestimated. Fridell asserted it could take up to six years to fully implement and integrate new information technologies within the work environment. He added that due to the wide-ranging impact on the entire work organisation, the integration of digital technologies should encompass a flexible approach which recognises unpredictable events may occur and therefore the adoption of an effective change management process was critical.

Change management

It appeared that the transitions experienced by the participants may not have incorporated a formal change management approach, particularly given the speed at which the technology was introduced into their departments and the level of training they received. Poor change management processes (due in part to a fast transition period) have been shown to impact on MITs' engagement with, and knowledge of, digital imaging systems (Campbell et al., 2019).

Change management processes are essential in the facilitation and acceptance of changes to the workplace (Rajiah & Bhargava, 2017) and the IAEA (2015) recommended the adoption of effective change management philosophies to support the digital transition process in medical imaging. The need for a change management process where the focus extended beyond the technological aspects of the system and included human and organisational factors was also identified by Tzeng et al. (2013). This also supports Bridge's theory that the internal transition required to make change successful, requires the affected individual to navigate through three distinct phases i.e. "letting go", "explorations" and "moving forward" (Bridges & Mitchell, 2000). These phases align to Schein's (2002) "unfreeze", "move" and "refreeze" stages of change management as described in section 2.5.1. Successful navigation through the phases takes time and can be supported through appropriate management. Effective support is particularly important in the final phase, as new ways of working can threaten individuals' self-perceived competency (Bridges & Mitchell, 2000).

The participants reflected that shift working and workload negatively impacted the degree of training they were able to access, and the training they received varied in length and quality. Further, the transition happened over a very short period, reducing their ability to adjust to a new way of working. Schein's model of transformative change indicates implementation failure may arise when there is a lack of vision, time, or training (Rajiah & Bhargava, 2017). Indeed, sufficient time to learn the technology, staff workload, and staff training have been identified as key factors in the successful adoption of new technology by nurses (Ashtari & Bellamy, 2019). Unfortunately, my participants identified that for them the opposite had occurred.

Bramson & Bramson (2005) propose that staff participation in the implementation process is recommended for successful integration of new technology into medical imaging and is considered to be part of a sound change management process. Staff engagement has also been shown to be important in the adoption of technology in other healthcare settings such as nursing (Joseph et al., 2019). However, participation in the transition process from CR to FPDR seemed to be limited to those participants who were trained as superusers.

My findings suggest that previously reported risks associated with ineffective change management processes, such as reduced knowledge and reduced engagement with technology, plus decreased feelings of competency, were evident in my participants.

Training provision

The training process was described as a predominantly task driven or transactional process. This was indicated by the speed in which the transition took place, whether moving from F-S to CR or from CR-FPDR. Participants identified the key factor driving this fast transition was cost. Cost was seen as influencing equipment purchase and the level of applications training provided by the vendor, which was part of the tender process. The risks of saving money through reduced or minimal training, have been previously identified, with reliance on the "cursory" nature of vendor training at the time of equipment installation cited as counter intuitive (Bramson & Bramson, 2005, p. 1729). Cost savings were discussed predominantly by my participants who worked in private practice and may reflect the focus on cost in the private sector (Hagland, 2017). Nevertheless, the need for cost efficiencies is not restricted to the private sector but has also been seen in public health systems globally, due to periods of financial austerity accompanying a focus on increased productivity coupled with decreased financial outlay (Hyde & Hardy, 2020).

One way in which cost savings can be achieved is through the use of a cascade training process rather than using external providers (Hayes, 2000). Cascade training was experienced by many of my participants, although it seemed to be most prevalent within the DHB sector rather than in private practice. This could be because within the private sector, a staged approach to transitioning took place i.e. one branch at a time. Whereas within the DHB environment the transition affected an entire site and all personnel at the same time. Nevertheless, all sites underwent "crash conversion" processes i.e. one in which the old system is shut down and the new one becomes operational on the same day. When installing new IT systems, it is generally recommended that a parallel conversion process is undertaken i.e. the old system runs alongside the new for a period of time and acts as a backup. However, in the healthcare environment this is not practical and therefore the benefit of a gradual introduction to a new system is not available. A "crash conversion" process can lead to increased anxiety and concern for the user and in these situations the training approach becomes critical (Karuppan, 2000). For my participants training was undertaken predominantly through a cascade process or by applications specialists (appointed by the vendor). However, both approaches were identified as problematic by the participants.

Cascade training

In medical imaging, cascade training is achieved by a nominated superuser receiving training from an applications specialist. The superuser then undertakes training of other staff in how to use the equipment. Jacobs (2002) defined the goal of cascade training as "critical change-related information [that] will flow through the organization in a planned way to facilitate subsequent parts of the institutionalization process" (p. 180). There is a clear expectation the process will ensure all requisite content will be accurately delivered to the staff who need it. A cascade model of training is beneficial as it reduces training costs by using existing staff to undertake the training (Ono & Ferreira, 2010). Plus as it is in-house, it reduces the amount of time staff are away from their duties (Hayes, 2000). Moreover, cascade training allows for a large number of staff to be trained in a short space of time (Suzuki, 2008). Disadvantages of cascade training relate to the dilution of information or the transmission of incorrect content (Bax, 2002). These can lead to misunderstandings which may be replicated and become engrained within medical imaging practice

(Westbrook, 2017). The cascade process is therefore reliant on the superuser being provided with sufficient training themselves to feel confident and capable of teaching the next member of staff in the chain (Suzuki, 2008).

Cascade training: the superuser perspective

Effective superuser training is even more critical during a "crash conversion process" and superuser selection is ideally based on their "potential competencies" (Karuppan, 2000, p. 22). If this is not feasible, then an advanced level of training, including an awareness of learning theory, is necessary for them to be able to carry out their role (Karuppan). It was interesting to note in my study, the superusers identified the importance of their own training (in terms of being able to carry out their role effectively) and yet they felt the training they received was insufficient. They recognised the importance of understanding how digital systems function, due to their very different nature compared to F-S systems. However, their training was limited to a task driven approach rather than content related to the software, such as the function of algorithms. They suggested this was due to time constraints, specifically linking this to the number of training hours available to them which was governed by the very short transition process. This is contrary to recommendations that training and support should be ongoing after the first few weeks post equipment installation (Bramson & Bramson, 2005; Hayre et al., 2017). Ongoing support can be achieved through the use of a cascade training model (Bramson & Bramson). However, my superusers implied they were unable to provide ongoing training and support, due to their own insufficient training and individual work rosters (theirs and the staff's). Reduced training allocation was also discussed when departments transitioned from a CR system to a FPDR system. My participants suggested this was due to an underlying assumption that this move was considered less significant in comparison to the initial transition to CR. This supposition again reflects an undervaluing of the transition as it does not consider the differences between CR and FPDR technology and image production.

The impact of time constraints in a cascade training process has been previously identified as a factor which causes the training to become task driven rather than knowledge or values based (Kennedy, 2005). Knowledge of the subject material, as well as the ability to train, have been identified as critical factors when selecting cascade trainers (Suzuki, 2008). This is consistent with the findings of Karuppan (2000), who specified knowledge of individual learning styles is key to the success of a cascade training system coupled with effective interpersonal and communication skills. The superusers in my study identified they frequently felt ill equipped to train staff as their knowledge of the equipment was limited. Additionally, they revealed superuser selection was made based on current position rather than an ability to educate others. While it could be suggested that an individual in a more senior role would demonstrate effective communication skills and be expected to train more junior staff, this assumption does not consider whether the superusers had any knowledge about adult education or learning theories, nor indeed whether they possessed effective inter-personal skills.

Learning theory or teaching pedagogy did not seem to have been considered through the delivery approach, as none of the superusers referred to individual learning styles and how to meet them when discussing their training approach. When considering MITs' learning styles, some research studies have suggested MITs use experiential learning on which to base their learning, reflecting Kolb's experiential learning theory, learning "both through experience at work and through a more theoretical approach" (Thingnes & Lewis, 2011, p.12). The ability to experience hands on teaching was identified as beneficial by my participants and also reflects the recommendations of the cascade teaching approach. However, there was no consideration of how the theory of digital imaging should be covered, nor was there time for the superusers to reflect on their learnings before being expected to put this into practice. Rather, the focus seemed to be on how to convey the required information in a succinct and timely manner to train as many staff as possible. Therefore, the training approach was influenced by the speed of the transition, coupled with a seeming lack of knowledge of learning theory; once again supporting the notion that the significance of the transition to digital imaging was underestimated.

Cascade training: the staff perspective

It seemed as if a "one-size-fits-all" standardised approach to training was undertaken which inevitably affected the way in which the participants subsequently viewed and utilised the equipment. For example, the training experienced through the cascade process was considered sufficient by the participants to operate the equipment and achieve an image, but more detailed theory was absent. This influenced staff capability for tasks related to image processing (via algorithms) and troubleshooting equipment faults. Their knowledge gap occurred despite the fact that a limited number of superusers undertook training of all staff, reducing the number of transmission processes and therefore the likely spread of misinformation, as identified by Suzuki (2008).

The success of cascade training requires time for the trainees and the trainers to reflect on their learnings, and for the trainer to adapt their teaching approach to reflect the context of the learners and their environment (Hayes, 2000; Turner et al., 2017). My findings illustrated that the staff (and the superusers) did not feel they had enough time to absorb, reflect and act on the content they had received prior to being expected to teach their peers or use the equipment. This is in contrast to the recommended approach identified by Wedell (2005) and also Hayes, who specified that successful cascade training is “experiential and reflective rather than transmissive” (Hayes, 2000, p.138).

Application specialist training

The participants seemed to feel more confident when MITs were training them rather than applications specialists who may have had a different professional background. Being trained by an MIT allowed the trainees to feel that there was a shared knowledge and understanding of medical imaging practice, which when absent led to obstacles in the training process.

As previously indicated, my findings suggest that the training process relied on the trainer to provide the correct information at the appropriate level, to support safe practice. However, some participants identified that the applications specialists did not seem to have the pre-requisite knowledge and understanding to explain how the equipment worked. Rather, their expertise was primarily related to how to use the equipment.

Developing knowledge and creating attitudinal change is dependent on the way in which information is presented (Schiavo, 2014). One area consistently highlighted in my study was issues with the terminology used by the applications specialist when teaching the participants. It suggested differences in the use of language caused confusion for MITs and contributed to their discomfort. Other research indicates that the inappropriate application of F-S radiographic terminology to FPDR systems has the potential to cause both frustration and confusion for operators (Carroll & Vealé, 2020).

Ambiguity and oversimplification of terminology were two areas the participants associated with applications specialist training. The participants revealed the specialists used words (e.g. dose) in a different way to that routinely used in MIT practice. Plus, the seemingly dumbing down of terminology, for example, "kV hungry" caused irritation and confusion. As effective change is predicated on people having a shared understanding built on common meanings, it is clear that the use of a set of standardised terms as proposed by Carroll & Vealé (2020), may have aided the transition process. Conversely a lack of shared understanding can produce communication issues and will influence how knowledge is acquired (Schiavo, 2014). That is, the way in which new information is absorbed and reflected on, is governed by the communication approach taken.

Effective communication requires the "sender" to respond effectively to specific social cues and requirements (Schiavo, 2014) Namely, it was important the applications trainer had the ability to respond to individual contexts. If this response is achieved, open communication based on mutual trust, helps create an environment in which new information may be viewed as valid and reliable (Schiavo). Furthermore, communication theories reflect an individual's pre-existing knowledge, experience and biases influence the way in which information is received and understood. Communication is a process in which meaning is co-created through dialogue (Blythe, 2009). A common or shared language also enhances collaboration, which is key to educative outcomes (Hayes, 2000; Thomas & McDonagh, 2013). These factors could account for the participants' appreciation when the trainer had an MIT background and was cognisant of the complexities and nuances of medical imaging practice.

In summary, my findings demonstrated that there seemed to be several training issues experienced by my participants. While these were considered to have differing levels of significance, they appeared to create a transactional approach to learning which could have played a role as to why the technology was perceived as a "black box". While supporting the literature identifying MITs' knowledge of digital imaging systems warrants improvement (Hayre, 2016; Hayre et al., 2017; McFadden et al., 2018; Moolman et al., 2020), my findings contribute to an increased understanding of some of the underlying factors as to why this may be the case.

6.1.2 The shift in MI practice

The radiography profession has been criticised previously for failing to give enough attention to the possible impact of new radiological technology, not only on the profession but also on society (F. J. Murphy, 2006). This was supported by Squibb (2013) who commented that the focus on the technology associated with medical imaging could be detrimental to patient care. As the impact of imaging technology and the outcome of any patient examination is dependent on the operator rather than the equipment design (F. J. Murphy), the ability of the MIT to utilise the equipment effectively is critical. My findings suggested that my participants' experiences had also focused on the technology itself while minimising the significance of the change. In so doing, there was a failure to appreciate how medical imaging practice might change and subsequently an under-appreciation of the potential for negative outcomes for both patients and staff.

The risk to professional status

The speed of the transition and the transactional training approach seemed to create a situation where the MITs did not fully understand the complexities and underpinning theories of digital technology. As such it influenced the way the staff utilised the equipment and supports previous research findings (Alsleem et al., 2019; Moolman et al., 2020; Seeram et al., 2015; Valentin, 2004). Furthermore, it resulted in several participants reflecting on the danger of becoming "button pushers" i.e. their role being minimised or reduced to "non-intelligent operation" of imaging equipment (Ritchie, 1958 p. 94). This was due in part to the perception that the equipment could be operated with a decreased level of knowledge and precision, particularly in relation to exposure factor choice and image processing. For example, previously MITs used their knowledge of anatomy, radiographic positioning, and the needs of the patient to try and ensure the initial image was correct first time. However, my participants implied that the ease of taking repeat digital images created less impetus to get images right first time. Consequently, they expressed concern that MITs could opt to rely on the resultant images for feedback on their technique, simply retaking an image to correct any mistakes. This seemed to demonstrate a risk of unconscious practice associated with the introduction of this technology, which was compounded when coupled with reduced precision and accuracy in patient positioning. Specifically, deliberate choices related to radiographic technique (e.g. patient positioning and exposure factor selection), could be replaced with habitual behaviours requiring less "cognitive effort" (Potthoff et al., 2019, p. 74).

The participants reflected a process of de-professionalisation which left them feeling a loss of personal power and reduced autonomy. De-professionalisation is multifaceted with one definition characterising it as:

> To cause to appear unprofessional, discredit or deprive of professional status, also privately experienced as a weakening of status, respect or tendency away from a position of strength or equal status; associated with measures for lessening the need for specialist knowledge and expertise (Malin, 2017, p. 77).

The deskilling of MITs following the introduction of FPDR was previously identified by Mothiram et al., (2014) and specifically linked to a lack of technical factor knowledge when utilising FPDR (Walker et al., 2011). This can be linked to "practice drift", a term defined by Snaith (2016, p. 267) as a loss of knowledge at either a professional or individual level which can be created through the introduction of technology in a resource poor environment, which reflects the training environment described by my participants. A loss of MIT autonomy associated with the introduction of new technology, through reduced decision making and problem solving processes, was previously identified by Ferris (2009). In her study this was due to equipment that was more user friendly which resulted in radiologists utilising specialist equipment that had previously sat within the domain of the MIT.

A lack of professional autonomy through not adjusting pre-set exposures on the control panel was also identified by Hayre (2016) as an issue specifically related to the use of FPDR. This also links to nursing research which found that de-professionalisation occurs when practitioners utilise pre-set protocols rather than using their own judgement in decision making (Nilsen et al., 2017). Given that expert or specialised knowledge is considered to be an essential component in the defining of a profession (Hashimoto, 2006; Ruitenberg, 2016; Sim & Radloff, 2009) and therefore an individual holding “professional status”, it is perhaps unsurprising that the diminution of knowledge required to operate imaging equipment gave rise to concerns about the risk of de-professionalisation.

Conversely, concerns about the impact of digital technology on individual status and that of the medical imaging profession, were not found in two Swedish studies which both described increased MIT responsibility as a result of its introduction (Fridell et al., 2008; Larsson et al., 2007). This was predominantly due to MITs undertaking roles previously completed by radiologists e.g. image review prior to patients being released from the imaging department. This is a very different context to the one experienced by my participants, who had always taken responsibility for reviewing their images and determining whether to confer with a radiologist in that decision process. This contextual difference could explain why Swedish MITs did not experience a feeling of professional loss. Overall, my findings align with and provide additional insight to previous research relating to the potential for a de-skilled, de-professionalised MIT workforce following the introduction of digital technology.

Lost opportunities

Losses were also identified in areas which had been previously taken for granted prior to the introduction of digital technology, specifically the interaction between MITs and radiologists. For example, the change in communication processes between MITs and radiologists as a result of the introduction of digital systems, links to findings previously reported in the literature (Fridell et al., 2007; Larsson et al., 2007). This created a sense of isolation for many participants, which was exacerbated by the removal of a communal viewing area. These losses created a cultural shift within MI practice, given staff felt removed from the radiologists, from their MIT colleagues, and from other health professions. The solitary nature of MIT work, resulting in staff working alone or in small isolated teams has been previously identified (Strudwick, 2011) and was evidenced by my participants and particularly pronounced for those in private practice. While this could be related to working in small or even solo practices, the introduction of digital technology compounded the issue. This reflects the findings of other researchers investigating the nature of MIT work such as Larsson et al. (2007) who identified the introduction of CR had resulted in MITs predominantly working solely within the x-ray room. Plus, Fridell et al. (2008) who described reduced opportunities for inter and intra-professional communication following the introduction of digital imaging systems.

Access to the educational role radiologists had previously routinely adopted, was another loss linked to the change in MIT-radiologist communication. Educational practices previously experienced included providing insight into radiological appearances of disease and normal variants, as well as supporting future decision making regarding repeat or additional imaging requirements. The advent of tele-reporting reduced ad hoc teaching opportunities that arise when working in a collective space. While MITs in Aotearoa NZ do not report radiological findings, they must provide patient care to the appropriate level (New Zealand Medical Radiation Technologists Board, 2018). This includes an expectation that MITs are able to differentiate between normal and abnormal radiological appearances to be able to take appropriate further action (The New Zealand Medical Radiation Technologists Board, 2018). It could be argued this competency is met as a requirement of registration and ongoing recertification with the NZMRTB, and can be supported through CPD activities. However, my study suggested that my participants had seen these opportunistic teaching moments with radiologists as beneficial to their own learning and professional practice, a finding not previously reported in the literature.

It is clear the transition to, and ongoing use of, digital technology had contributed to a number of perceived losses for my participants. These were directly related to a loss of knowledge and individual confidence. Increased feelings of isolation and reduced opportunities for meaningful professional interactions were due to changes in the physical nature of the medical imaging department required by the change to CR and FPDR. Although change is frequently accompanied by feelings of loss (Bridges & Mitchell, 2000) and the changed radiologist-MIT communication process has been previously identified (Larsson, 2009), my findings suggested that some of the professional and educational losses described by my participants were individually significant and do not seem to have evaluated previously.

6.1.3 The health and safety balancing act

My participants conveyed concerns that the change in MIT practice, coupled with unforeseen drawbacks associated with the cited benefits of digital technology, had the potential to adversely impact on patient care. MITs' knowledge and understanding supports the provision of safe practice, a key aspect of which is in relation to radiation dose. As previously discussed, a widely held assumption was that digital imaging would reduce patient exposures, due to the reduced number of repeats required (Nol et al., 2006). However, my findings suggest that the introduction of digital technology may have inadvertently created a situation where patients could receive a higher radiation dose than necessary due to issues such as exposure creep (Don et al., 2013; Gibson & Davidson, 2012; Hayre, 2016) and collimation creep (Tsalafoutas, 2018).

Collimation creep was found to have resulted in a significant increase in the irradiated field in some studies following the transition to digital imaging technology (Satharasinghe et al., 2020; Zetterberg & Espeland, 2011). It therefore appeared that patient safety relied heavily on the individual MITs operating the equipment rather than the safety features of the imaging systems. While it could be argued this has always been a fundamental aspect of MIT practice, it would seem that the introduction of new technology had created additional tensions within this area rather than minimising them e.g. ease of repeat imaging; exposure and collimation creep. Although my findings supported the existing literature in this respect, my participants considered one of the underlying causes of increased patient radiation dose was due to the way in which the technology had been introduced. Specifically, for some participants this resulted in a lack of understanding of what EI values related to and as such, a decision to ignore them and revert to image evaluation to determine effective exposure factor settings. This approach had two potential impacts on patient safety.

First, is the inability to assess correct exposure choice on digital images through visual inspection. This creates an opportunity for inadvertent and continued overexposure of patients. As EIs are designed for the operator to determine whether the exposure to the patient is correct (Erenstein et al., 2020; Mothiram et al., 2013), failure to use them correctly may lead to exposure creep. Much of the literature on the use of EIs has focused on the accuracy of EI values (Butler et al., 2010; Mothiram et al., 2014), whether MITs were achieving the correct EI values (Lewis et al., 2019a; Mothiram, 2014) and the adoption of a standardised EI value (Seeram, 2014; Seibert & Morin, 2011), Nevertheless, some studies have shown that the level and quality of training MIT practitioners received during the change to digital imaging underpin why EI values may not be used effectively (Lewis et al., 2019b; Seeram et al., 2015). My findings reflect those of Seeram et al. who identified that key theoretical components such as image processing, optimisation of image quality and radiation dose, and EI standardisation were not included in CR training.

Second, is the difference in the quality of the monitors used by MITs and radiologists for image review. My participants identified how their monitors made it difficult for them to accurately assess the quality of their images and made some of them unsure whether an image would be deemed diagnostic by a radiologist. The need for the correct monitor for the correct purpose has been identified in the literature previously (Papathanasiou et al., 2020) and is supported by my findings. Much of the existing research on this aspect has focused on monitor quality for image interpretation (Kagadis et al., 2013) and it is not clear whether the impact of work station monitors on MIT image evaluation has been investigated previously. As the production of high-quality diagnostic images is the underpinning goal of MIT practice, it is not unreasonable to suggest MITs should be provided with the appropriate tools to complete this task. Furthermore, it would seem logical to suggest uncertainty about whether an image is acceptable or not may lead to unnecessary repeat imaging (and increased patient radiation dose) or potentially patient recall for additional imaging leading to increased costs and patient anxiety (Bredal et al., 2013; Gutzeit et al., 2019; Lee et al., 2013).

In pursuit of perfection

Although not specifically related to exposure or collimation creep, the pursuit of the perfect image through repeat imaging was another way in which patient radiation dose could be increased and was identified as being made easier with digital technology. While this may be linked to providing the best possible care to the patient through the provision of excellent quality images (Morrison et al., 2011), my participants suggested unnecessary repeat imaging was undertaken to make the MIT "look good". It has been previously determined that there can be a clear discrepancy between MIT and radiologist assessment of whether an image needs to be repeated (Mount, 2016). Namely, images an MIT may reject for technical reasons, may be deemed sufficient to make a diagnosis by radiologists. Mount suggested this could be due to differences in the evaluation criteria employed by radiologists (diagnostic criteria) and MITs (technical criteria) (p. e116). This reflects a dichotomy that has long existed in medical imaging practice, i.e. MITs are expected to consider whether the increased dose to the patient (through a repeat image) will improve image quality to such an extent that it is likely to change the patient management or affect the diagnostic utility of the film. However, similar to other researchers, my findings indicate that MITs may repeat images as they feel evaluated against the quality of their images (Decker & Iphofen, 2005; Strudwick, 2014) and criticism of their images may be taken personally (Strudwick, 2014). Radiologist preferences influence MIT decision making (Morrison et al., 2011) and technical expertise is used as the principal way to define MIT knowledge (Thingnes & Lewis, 2011). Therefore, the anticipation of personal judgement could be a contributory factor when determining whether to repeat an examination. This adds another dimension to the existing literature.

It is all about the speed

Increased speed and productivity had been cited as positive outcomes associated with the transition to digital imaging (Korner et al., 2007). The speed of digital imaging was recognised as beneficial to patients in terms of diagnosis and treatment outcomes, consistent with the findings of Andriole (2002), Reiner et al. (2002), and Moodley & Moodley (2015). My participants also noted system speed had led to increased productivity, but that this in turn reflected an increased staff workload, which subsequently introduced communication issues and impacted their ability to provide quality patient care.

Communication issues were principally due to the way workflow was organised through the Radiology Information System and Picture Archiving and Communication System, causing incorrect patient identification. Modification and revision to the Radiology Information Systems, and in one instance reverting to paper request forms, were remedial actions discussed by my participants to resolve patient identification errors. As such they reflected partial changes to the patient verification processes. The strategies were deemed to be effective in improving patient identification and correct examination selection and allowed increased MIT-patient communication, which is also crucial in building trust and rapport between the patient and the MIT (Pollard et al., 2019).

Communication errors within healthcare have been shown to cause a reduction in quality of care and much of the research associated with radiology based communication errors focuses on failures in communication between the radiologist and the referring clinician i.e. provision of a radiological diagnosis (Brady, 2017; Pinto, 2010; Waite et al., 2018). However, communication errors are also linked to “wrong-patient or wrong-study events” within imaging departments (D. N. Jones et al., 2010; Rubio & Hogan, 2015). Furthermore, D. N. Jones et al. stated that 29% of adverse patient incidents occurred in plain film imaging, with a similar figure of 27.6% reported by Tarkiainen et al. (2020). Given that Hayre et al (2016) identified that in the UK, 90% of all imaging procedures are undertaken within general or planar radiography, there is the potential for significant numbers of adverse events to occur. The risk for patients is not only from an increased radiation burden but the possibility of a missed diagnosis if the mistake is not rectified (Rubio & Hogan, 2015).

While errors can occur at any stage of the imaging process, areas specifically linked to MIT practice predominantly occur in the patient preparation or technical performance segments of the cycle (D. N. Jones et al., 2010). Issues include communication errors, incorrect patient identification, and incorrect examinations undertaken (D. N. Jones et al.). Factors which have also been identified as influencing errors in medical imaging by other researchers (Brady et al., 2012; Larson et al., 2015), resulting in a number of suggested approaches to reduce the likelihood of mistakes occurring, such as the introduction of additional verification processes (C. Field, 2018; Rubio & Hogan, 2015).

Speed brought an increased potential for patient examination errors due to the reduced opportunities for MIT-patient communication. To minimise errors, my participants described individual approaches or workarounds to artificially slow the imaging process and enable them to have enough time to focus on the patient and the imaging examination. Workarounds[20] are frequently created by individuals rather than adopted as a universal approach (Debono et al., 2010) and are utilised as an approach to achieve the desired end result in a timely manner (Westphal et al., 2014). Workarounds exist within healthcare, tending to occur when there is a mismatch between work practices and technology (Ejnefjäll & Ågerfalk, 2019) and are often

[20] Defined as a plan or method to circumvent a problem

considered by the initiator to be of benefit to the patient (Debono et al.). Additionally they may be used by workers to modify the way in which a task is completed to reduce demands which are perceived as unrealistic (Schoville, 2009). My findings imply that MITs recognised that the reduced patient interactions could increase the risk of errors and adopted workarounds to help reduce this risk. Although my findings support previous research on workarounds in healthcare, they add another dimension by revealing the idiosyncratic approaches specific to the introduction of digital imaging technology.

Productivity

The introduction of digital technology required a high financial outlay and therefore an expectation that increased productivity would offset some of these costs. Increased productivity is feasible due to the speed of digital imaging systems (Andriole, 2002; Moodley & Moodley, 2015; Reiner et al., 2002). Reiner et al. found that after an initial drop in productivity (due to adjusting to the new technology) MIT productivity rose by "27.8%" (p. 135). Other research has indicated that while productivity increases, cost savings can only be achieved through increasing MIT workload (Redfern et al., 2002). MIT workload has also been increased through non-replacement of staff (Moodley & Moodley, 2015). Although the focus of Reiner et al.'s study was on cost savings and increased productivity, based on a previous study (Reiner et al., 1998), there was some discussion on the impact of technology on MIT stress and fatigue levels. Reiner et al. (2002) specified MIT stress levels reduced following the introduction of digital technology. This seems to counter the expectation that increased workload results in increased stress. A number of more recent studies have found that high MIT workload is clearly identified as a significant stress factor (Lehmann et al., 2014; Lohikoski et al., 2019; Verrier & Harvey-Lloyd, 2010). These align with my findings which suggested increased workload created feelings of increased pressure and an added expectation to work more quickly. This resulted in my participants describing feelings of stress and recognising they were more prone to make mistakes. The increased likelihood of radiology errors due to workload has also been discussed previously (Itri et al., 2018).

The faster patient turnaround associated with the digitisation of medical imaging has also been linked to a risk of burnout and reduced MIT morale (Hardy & Harvey, 2020). Burnout as an unintended consequence of the introduction of new healthcare technology has been identified in other studies (Colicchio et al., 2019; Kroth et al., 2019). While my participants did not discuss burnout specifically, they did reflect that their workloads were high and that they felt ongoing pressure to work quickly. This reflects the findings of Singh et al. (2017) who identified high levels of demands placed on the MIT workforce are due in part to the fact that the "'value' of these professionals is often determined by the number of patients they can successfully image…" (p. 308). Employers have been blamed for increased MIT workload and staff burnout for failing to fully anticipate the changes that would result following the introduction of digital technology (Hardy & Harvey, 2020), thus supporting my assertion that this transition was underestimated on many levels.

6.2 Summary

My research question for this phase asked **"What are the experiences and perceptions of MITs regarding the introduction and ongoing use of digital imaging technology?"** My findings demonstrated some resonance with the existing literature including for example, the potential for increased patient radiation dose with digital imaging systems and the need for more effective approaches to training to build MIT knowledge in the use of this technology. However, importantly, when these issues are considered together they may represent an undervaluing of the significance of the move to digital imaging and highlight the importance of a carefully thought out implementation process underpinned by change management practices. It is clear there were unforeseen consequences arising as a result of this change to digital technology prompting a shift in MI practice.

In the following chapter I present the findings from Phase Two of the research i.e. the cross-sectional survey.

Chapter 7 Phase Two Quantitative findings.

7.1 Introduction

In this chapter I will address the following research questions, using results from the statistical analysis of survey data including sample characteristics; bivariate and multivariate analyses; and regression modelling:

1. **"What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application?"**
2. **"What factors are related MITs' knowledge of and perceived competence in the use of digital technology?"**

As described in Chapters 1 and 4, the research questions were broken down in to specific objectives to support answering the research questions.

7.2 Sample characteristics

In total, 49 participants completed the survey and were grouped according to the number of years qualified, reflecting Andersson, Christensson, Jakobsson, et al. (2012). The full breakdown of the sample characteristics are provided in Table 9 below.

7.2.1 Demographics

Of the total sample, 81.6% (n = 40) were women. The majority of participants fell within the 25-40 year age bracket (n = 22, 44.9%); the minority were under 25 years (n = 6, 12.2%); with the remaining evenly distributed across the other age ranges: 41-54 years (n = 10, 20.4%) and >54 years (n = 11, 22.4%).

7.2.2 Education

More than half of the sample (n = 30; 61.2%) had been qualified less than 15 years. Most participants had an undergraduate degree (n = 28; 57.1%). While 16.3% (n = 8) had a postgraduate certificate or postgraduate diploma.

7.2.3 Work context

Of the 30 participants who had been qualified under 15 years, the majority were employed as Staff MITs (n = 26, 86.7%). The majority of participants worked full-time (n = 31, 63.3%) and were employed in a DHB (n = 30, 61.2%).

All participants worked in areas consistent with the general scope of MIT practice in NZ. No one worked with additional scopes of practice such as nuclear medicine; magnetic resonance imaging; or ultrasound. Most participants were working in plain film imaging only (n = 23, 46.9%) with 15 (30.6%) working in general imaging and one modality, and 11 (22.4%) across multiple areas.

Table 9

Sample characteristics

Years qualified	Total	0-5 years	5-15 years	15-25 years	>25 years
n (%)	49 (100)	14 (28.6)	16 (32.7)	7 (14.3)	12 (24.5)
Gender					
Female	40 (81.6)	10 (71.4)	14 (87.5)	5 (71.4)	11 (91.7)
Male	8 (16.3)	4 (28.6)	2 (12.5)	1 (14.3)	1 (8.3)
Prefer not to answer	1 (2.0)	0 (0)	0 (0)	1 (14.3)	0 (0)
Age					
<25	6 (12.2)	6 (42.9)	0 (0)	0 (0)	0 (0)
25-40	22 (44.9)	7 (50.0)	13 (81.3)	2 (28.6)	0 (0)
41-54	10 (20.4)	1 (7.1)	2 (12.5)	4 (57.1)	3 (25.0)
>55	11 (22.4)	0 (0)	1 (14.3)	1 (14.3)	9 (75.0)
Present position					
Staff MIT	37 (75.5)	13 (92.9)	13 (81.3)	3 (42.9)	8 (66.7)
Grade MIT[a]	6 (12.2)	1 (7.1)	1 (6.3)	2 (28.6)	2 (16.7)
Charge MIT[b]	5 (12.2)	0 (0)	2 (12.5)	2 (28.6)	2 (16.7)
Present role/duties					
General Imaging	23 (46.9)	11 (78.6)	7 (43.8)	2 (28.6)	3 (25.0)
General Imaging + 1 additional area	15 (30.6)	3 (21.4)	3 (18.8)	3 (42.9)	6 (50.0)
General Imaging + multiple roles	11 (22.4)	0 (0)	6 (37.5)	2 (28.6)	3 (25.0)

Highest academic level					
Diploma	13 (26.5)	0 (0)	0 (0)	2 (28.6)	11 (91.7)
BSc/BHSc +/- (Hons)	28 (57.1)	14 (100)	11 (68.8)	3 (42.9))	0 (0)
Postgraduate qualification	8 (16.3)	0 (0)	5 (31.3)	2 (28.6)	1 (8.3)
Work place					
DHB	30 (61.2)	12 (85.7)	8 (50.0)	4 (57.1)	6 (50.0)
Private	17 (34.7)	1 (7.1)	8 (50.0)	2 (28.6)	6 (50.0)
DHB and Private	2 (4.1)	1 (7.1)	0 (0)	1 (14.3)	0 (0)
Employment status					
Part-time	18 (36.7)	2 (14.3)	10 (62.5)	3 (42.9)	3 (25.0)
Full-time	31 (63.3)	12 (85.7)	6 (37.5)	4 (57.1)	9 (75.0)

Note.· [a] Includes senior MIT and Clinical Specialist

[b] Includes Team Leader

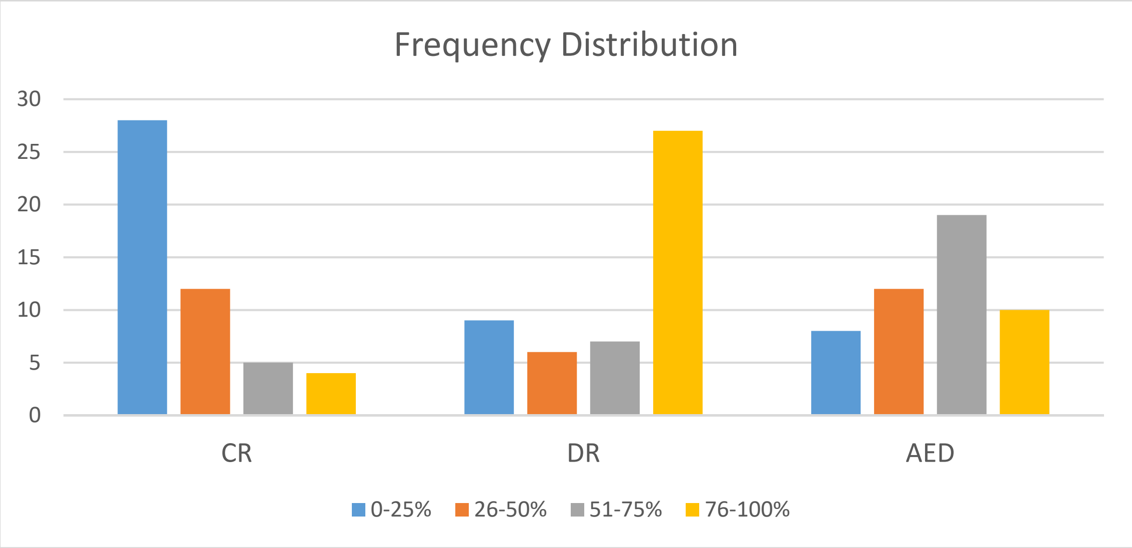
Image Acquisition

Participants were asked to state the amount of time they spent per week using CR equipment, FPDR equipment, and automatic exposure devices (AEDs).

CR was typically used the least (<25%) by 57.1% users (n = 28), compared to FPDR which was used the most frequently (>76%) by 55.1% of users (n = 27). The use of AEDs was moderate (>51%) by 59.2% of users (n = 29). The data is illustrated in Figure 6 as a graph of the frequency distribution relating to the use of CR, FPDR and AED.

Figure 6

Frequency of weekly activities



Quality Control

Participants were asked to provide details about the quality control processes used at their place of work. Questions were asked about the use of electronic post-collimators, frequency of image manipulation and postprocessing at both workstation and high resolution monitors, and whether workstation adjustments affect the EI.

Adjusting the electronic collimators to align with the radiation field was undertaken by 75.5% of participants (n = 37) <50% of the time. Checking collimation, by removing the post-collimators, was undertaken infrequently (<25%) by 67% (n = 33). Image cropping using the post-collimation tool was undertaken less than 25% of the time by just over half the participants (n = 26, 54.2%). The full breakdown of quality control activities is provided in Table 10 below.

Table 10

Proportion of time per week on QC activities at work station monitor

n (%)	0-25%	26-50%	51-75%	76-100%
Manipulate brightness and contrast	31 (63.3)	13 (26.5)	4 (8.2)	1 (2)
Manipulate the Look Up Table	41 (83.7)	5 (10.2)	3 (6.1)	0 (0)
Re-process under another body part or projection	32 (65.3)	14 (28.6)	3 (6.1)	0 (0)
Adjust post-collimators to align with collimation field	20 (41.7)	17 (35.4)	7 (14.6)	4 (8.3)
Remove post-collimators to view collimation borders	33 (67.3)	12 (24.5)	3 (6.1)	1 (2)
Adjust post-collimators to crop image and reduce field of view	26 (54.2)	17 (35.4)	3 (6.1)	2 (4.2)

The use of a high resolution monitor to adjust images was undertaken infrequently, with 24.5% (n = 12) of participants indicating they never do this. Of these, 50% (n = 6) identified this was because there were no high resolution monitors available; 25% (n = 3) stated they would use the work station console only and 16.6% (n = 2) commented their images were always acceptable.

When asked whether adjustments at the work station monitor affected the EI, only 18.4% (n = 9) participants correctly stated that adjusting the image at the quality control workstation does not affect the EI. 12.2% (n = 6) were not sure and the remaining 34 (69.4%) were equally divided between “yes” and “sometimes”.

Quality Assurance

Participants were asked to comment on image repeat/reject rates and could signify multiple responses. 87.8% (n = 43) indicated that they have a way to monitor repeat/reject rates. A small number (n = 3, 6.1%) did not have access to or know how to do this.

Participants were asked to select the most common causes for their repeat imaging. The responses were grouped into: positioning 87.8% (n = 43); patient movement 22.4% (n = 11); exposure 8.2% (n = 4); patient limiting conditions 6.1% (n = 3); equipment faults 4.1% (n = 2) and artefacts 2% (n = 1).

The vast majority of participants (n=45, 91.8%) indicated poor image quality resulted in repeat exposure <25% of the time. The same number of participants specified they always approve their own images. One participant (2%) indicated this was undertaken by another MIT. The remaining three (6.1%) stating they sometimes undertake this, adding image approval may be undertaken by another MIT working at the console, a Charge MIT, or following discussion with a colleague.

Responses varied when the participants were asked which personnel are permitted to adjust the equipment postprocessing parameters: 67.3% (n = 33) indicated a service engineer; 55.1% (n = 27) an applications specialist; 53.1% (n = 26) a superuser; 36.7% (n = 18) a physicist and 14.3% (n = 7) the manufacturer.

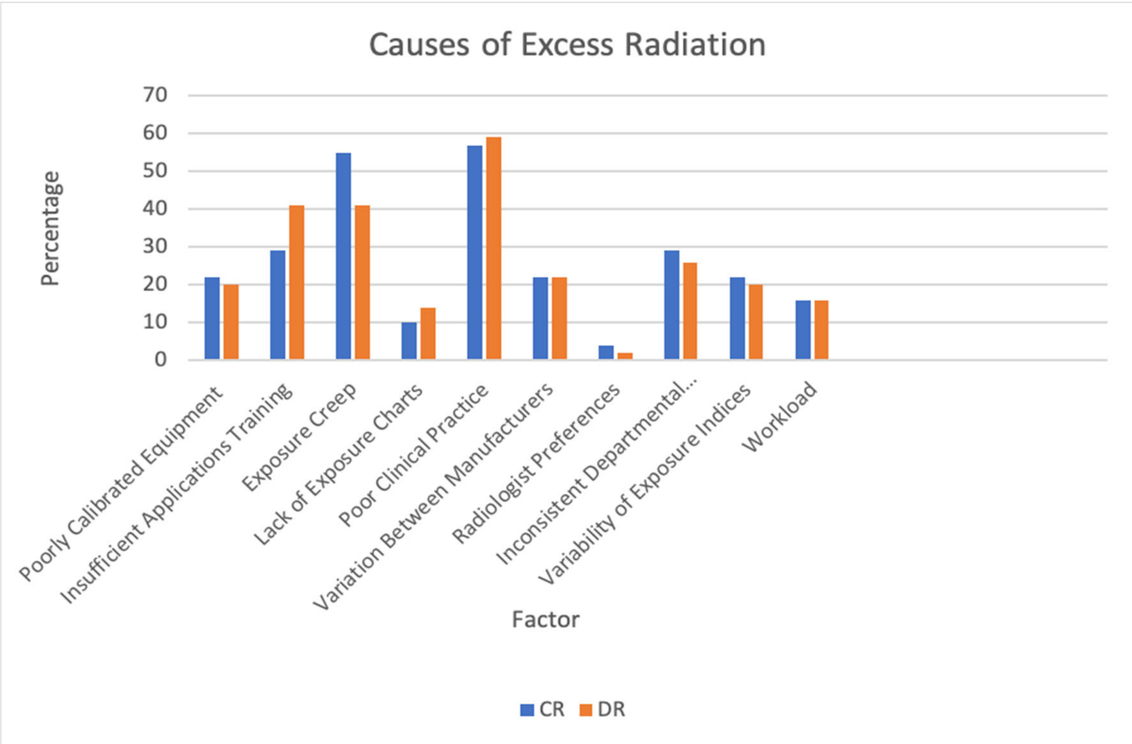
Radiation Exposure

Participants were asked to comment about the management of exposure values, exposure choice and the subsequent evaluation of those factors. In total 87.8% participants (n = 43) indicated there were established exposure values for all equipment at their place of work. When asked whether there was a mechanism in place to determine the percentage of examinations that fall into the acceptable range, a small majority were unsure (n = 20, 40.8%); 18.4% (n = 9) stated no and 38.8% (n = 19) confirmed it was available. Just over half the participants (n = 25, 51%) indicated their institution had adopted a Target Exposure index and Deviation Index against which images were assessed.

The highest ranked factors which contribute to excess radiation exposure in CR and FPDR imaging procedures were: “insufficient applications training”; “exposure creep”; and “poor clinical practice”. “Insufficient applications training” was cited by 14 (28.6%) of participants for CR, this increased to 40.8% (n = 20) for FPDR. “Exposure creep”, i.e. use of increased mAs values to avoid quantum mottle, was specified by 27 participants (55.1%) for CR and 20 (40.8%) for FPDR. “Poor clinical practice” was identified as contributing to excess exposure in CR by 28 participants (57.1%) and 29 (59.2%) for FPDR. The lowest ranked factors were “radiologist preferences”, “lack of exposure charts” and “workload”. The responses are summarised in Figure 7.

Figure 7

Causes of excess radiation exposure



When asked strongly radiation dose reduction was emphasised at their workplace, 53.1% of participants (n = 26) indicated it was either emphasised "all" or "most" of the time.

7.2.4 Training

Participants were asked to indicate the type of training they had received for both CR and FPDR. This included undergraduate and postgraduate education, training from an applications specialist, cascade, training others, and equipment manufacturer training. The most commonly accessed resources for both CR and FPDR were undergraduate education, application specialist or cascade training (i.e. training from another MIT), as illustrated in Table 11 below.

Table 11

Types of education and training

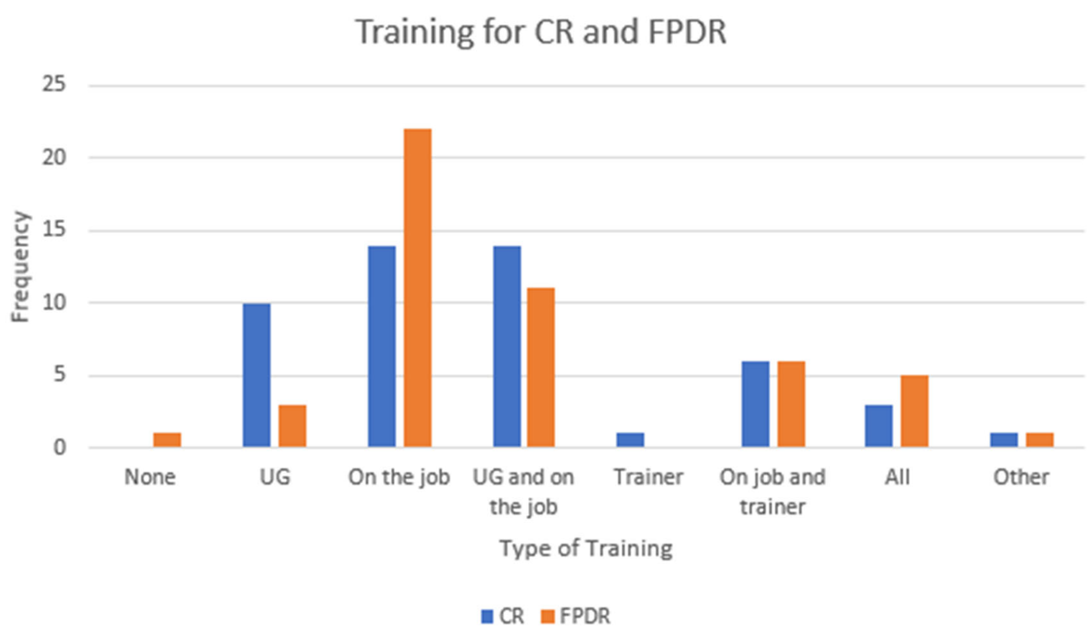
n (%)	CR	FPDR
Undergraduate education	27 (55.1)	22 (44.9)
Postgraduate education	3 (6.1)	1 (2.0)
Applications training	23* (47.9)	34 (69.4)
Cascade training	23 (46.9)	27 (55.1)
Had trained others	9 (18.4)	12 (24.5)
Equipment manufacturer training	7 (14.3)	12 (24.5)
Other e.g. personal CPD	1 (2.0)	1 (2.0)

Note. * 48 responses

When combining applications training, cascade training, and equipment manufacturer training as "on the job" training, the results were as demonstrated in Figure 8.

Figure 8

Training received for CR and FPDR



Participants were asked to indicate the approximate number of hours training they received, excluding undergraduate and postgraduate education. For CR, 40.8% (n = 20) received 3.75 hours or less. For FPDR, 20.4% (n = 10) received 3.75 hours or less. The breakdown of the number of hours is illustrated in Table 12 below.

Table 12

Number of training hours

n (%)	CR	FPDR
None / no response	19 (38.8)	15 (30.6)
< 3.75 hours	20 (40.8)	10 (20.4)
4 – 15 hours	6 (12.2)	18 (36.7)
> 15 hours	4 (8.2)	6 (12.2)

The hours of training received for both modalities were similar and ranged from 0.5 to 32 hours for CR, compared to 0.5 to 36 hours for FPDR.

7.3 Bivariate and multivariate analyses

Statistical significance

An alpha value of <0.005 was considered when reviewing the data and for determining highly statistical significance, a value of < 0.05 was considered to demonstrate conventional statistically significant differences.

7.3.1 Multiple-choice questions: Knowledge and understanding

Multiple-choice questions were asked to determine knowledge and understanding of: common post processing functions, exposure indices, FPDR artefacts and CR and FPDR detectors. These questions were chosen based on the methodological development of the survey described in Chapter 4.

Correct answers to the questions were given a score of one, while incorrect or blank answers were given a score of zero reflecting the approach of Farajollahi et al. (2014). The total potential score was 11, the range of scores achieved was from 0 – 10 (Table 13).

Table 13

MCQ and number (%) of correct answers by MITs

Domain and Question Number	Correct Answer: n	(%)
Postprocessing		
F1	40	(81.6)
F2	18	(36.7)
F3	24	(48.9)
Number of MITs with all answers correct	11	(22.4)
Exposure Indices		
F5	37	(75.5)
F6	6	(12.2)
F8	21	(42.9)
Number of MITs with all answers correct	4	(8.2)
Artefacts		
G1	15	(30.6)
G2	4	(8.2)
Number of MITs with all answers correct	1	(2.0)
Digital Detectors		
F4	25	(51.0)
F7	7	(14.3)
G3	5	(10.2)
Number of MITs with all answers correct	1	(2.0)

Question F6 asked participants to select all factors they believed may cause EI errors. Fully correct answers achieved a score of 1, partially correct or totally incorrect answers achieved a score of 0. Given the importance of EI values to digital image evaluation, a full break down of the results from this question are provided in Figure 9.

The full data range for the MCQ scores is provided in Figure 10.

Figure 9

Responses to EI error MCQ F6

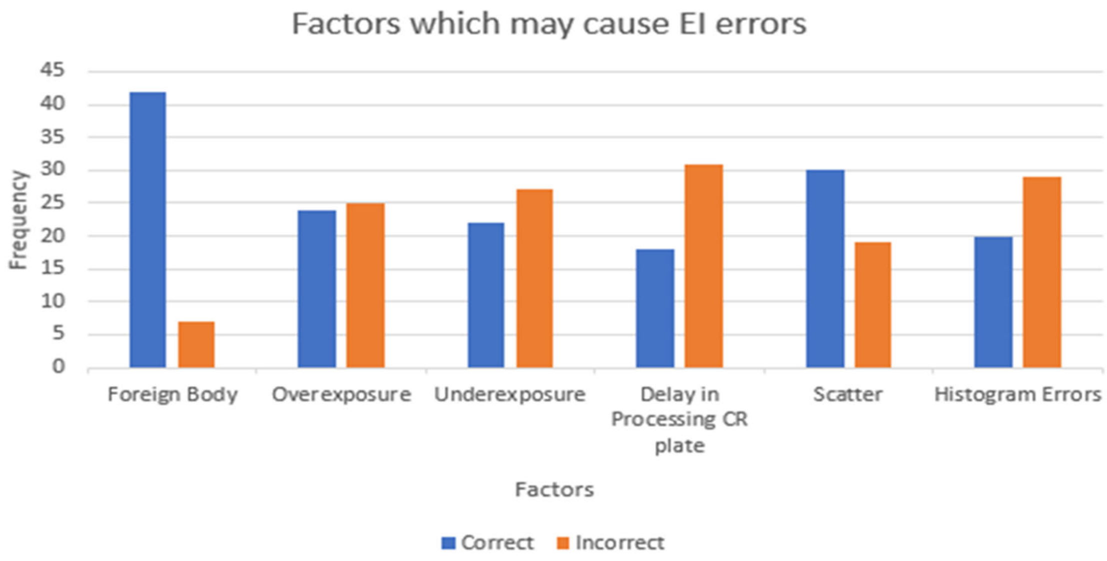
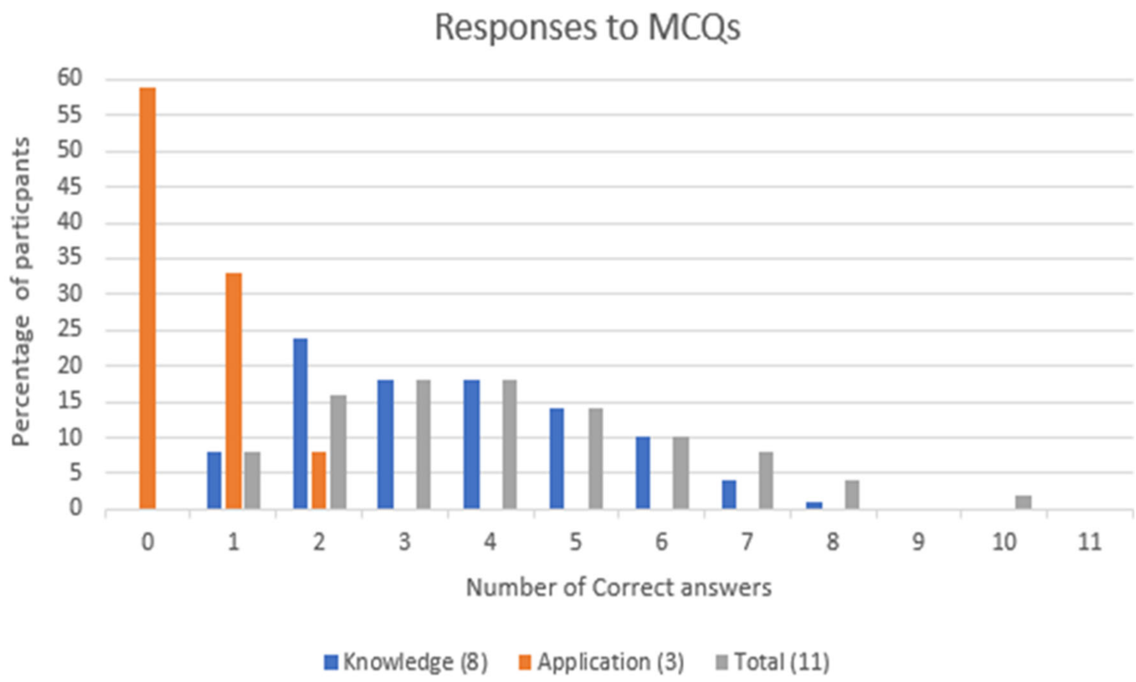


Figure 10

Scores received for MCQs



Qualification time

Statistically significant differences in total MCQ scores by qualification time were seen in those who had been qualified the least amount of time (median 6) compared to those who had been qualified five to fifteen years (median 3, $p = 0.029$).

Employer

Regarding employers, those working in a DHB plus private practice achieved the highest median value (6) and those working in private practice only, the lowest median value (3) for total MCQ scores. Across all employer groups a statistically significant difference of p = 0.009 was demonstrated. Pairwise analyses demonstrated a statistically significant difference between DHB employees and private practice employees of p = 0.036, and borderline significance between those who worked in private practice and those employed in both private practice and a DHB (p = 0.056).

Age

There were statistically significant differences in total MCQ scores by age group with those in the 41-54 year group scores (median 5.5) indicating higher knowledge and understanding than those >55 years (median 3, p = 0.014).

Results for qualification time, employer and age range are given in Table 14.

FPDR Education

Statistically significant differences in total MCQ scores were seen in those participants who had FPDR education as an undergraduate student (p = 0.031) compared to those who had not experienced FPDR as an undergraduate. The results for educational experience and employment status i.e. full-time or part-time are indicated in Table 15.

There were no statistically significant differences in MIT MCQ scores across these variables: level of education; type or hours of training; weekly equipment use; employment; transitions MITs had experienced; educational materials requested; or MITs total perceived competency rating. (A full break-down of these results is in the supplementary data file- Appendix N)

Table 14

Mean MCQ scores achieved: Comparison between groups with different: years since qualification; employer; and age

	MCQ- Knowledge (/8)		**MCQ- Total Score (/11)**	
	Number (Median)	***p*-value**	**Number (Median)**	***p*-value**
Years qualified				
Total	49 (3.00)	**0.017**	49 (4.00)	**0.029**
0-5 years (I)	14 (5.00)		14 (6.00)	
>5-15 years (II)	16 (2.50)		16 (3.00)	
>15-25 years (III)	7 (4.00)		7 (4.00)	
>25 years (IV)	12 (3.00)		12 (3.50)	
Employer				
Total	49 (3.00)	**0.009**	49 (4.00)	**0.009**
DHB	30 (4.00)		30 (4.00)	
Private	17 (2.00)		17 (3.00)	
DHB + Private	2 (5.50)		2 (6.50)	
Age				
Total	49 (3.00)	**0.012**	49 (4.00)	**0.014**
< 25	6 (4.50)		6 (5.00)	
26-40	22 (3.00)		22 (4.00)	
41-54	10 (5.00)		10 (5.50)	
>55	11 (3.00)		11 (3.00)	

Note: Statistical significance indicated in bold when $p < 0.05$.

Table 15

Mean MCQ scores MITs achieved: Comparison between groups with different education experiences and employment status

	MCQ- Knowledge (/8)			MCQ- Total Score (/11)		
	Number	**Mean (SD)**	***p*-value**	**Number**	**Mean (SD)**	***p*-value**
Education & Training						
UG CR education	27	3.78 (1.601)	0.391	27	4.37 (1.904)	0.239
PG CR education	3	3.67 (1.781)	0.882	3	4.00 (2.000)	0.983
CR apps training	23	3.48 (1.904)	0.451	23	3.96 (2.306)	0.460
CR cascade training	23	3.78 (1.833)	0.640	23	4.30 (2.162)	0.631
Trained others in CR	9	4.33 (1.658)	0.157	9	5.00 (1.732)	0.095
UG FPDR education	22	4.00 (1.662)	0.131	22	**4.73 (1.907)**	**0.031**
PG FPDR education	1	3.00	0.774	1	3.00	0.567
FPDR apps training	34	3.32 (1.770)	0.091	34	3.74 (2.709)	0.072
FPDR cascade training	27	3.59 (1.824)	0.775	27	4.07 (2.165)	0.776
Trained others in FPDR	12	4.25 (2.006)	0.182	12	4.75 (2.301)	0.209
Employment Status						
Part-time	18	3.17 (1.886)	0.132	18	3.61 (2.173)	0.187

Note: Statistical significance indicated in bold when $p < 0.05$.

7.3.2 Perceived competencies

Participants were asked to self-rank feelings of competency in four subdomains: "radiation dose", "image evaluation and image quality", the "use of existing equipment", plus, the "use of new equipment". These subdomains were created via twelve survey items, in which participants rated their competency level as either high, good, average, low or none. The values for each subdomain and the participants total competency scores were compared against a number of variables.

Given the non-normal distribution of the data, Kruskal-Wallis tests were undertaken to compare the competency rating scores for groups of more than three e.g. the number of years qualified, age range. Mann-Whitney U tests were undertaken to compare the competency scores for groups of two e.g. males and females.

Competencies were rated highly overall, the highest rated competencies were in these survey items: *"ongoing use of new equipment, six months post training"* (range 4-5, median 5.00); *"evaluating the diagnostic quality of the image in relation to the clinical indications"* (range 3-5, median 5.00); and *"adjusting exposures to suit patient body habitus"* (range 4-5, median 5.00).

The greatest range of perceived competencies were in the *"manipulating exposure factors in computed radiography"* (range 1-5; median 4) and *"manipulating exposure factors in digital radiography"* (range 1-5; median 4) items.

There were no statistically significant differences in competency ratings in MITs across these variables: number of years qualified; highest qualification; number of work areas; seniority/position; requested educational materials from manufacturers or those related to radiation dose management. Similarly, there was no statistical difference for competency scores related to the type of training received or the training role i.e. whether at undergraduate level, cascade, or applications specialist training, or if the participant had undertaken training of their colleagues as a superuser or cascade trainer. The full breakdown of these results are available in the supplementary data file (Appendix N).

Competency ranking and age range

A consistently significant finding was observed for the "new equipment use" sub-domain and age, where older age groups ranked themselves lower than the younger age groups in this domain (p = 0.057) overall, and in the *"use of new equipment one month after training"* survey item (p = 0.060). While these p values demonstrate borderline statistical significance in these competencies, a statistically significant finding was observed for the "*ongoing use of new equipment after 6-months"* (p = 0.020), again showing older participants ranking themselves lower than younger participants (Table 16).

Competency ranking and gender

The level of variability in competency ratings was similar for males and females indicating a level of homogeneity between these groups. There was no significant difference in the scores for either gender in any competency, except for the "*recognising equipment faults from the image artefacts produced"* item. The Mann Whitney U test produced a mean rank of 33.88 for males compared with 22.63 for females, U = 85.00, z = -2.23, p = 0.038 (Table 17).

Competency ranking and training hours

The results demonstrated borderline significance in relation to the number of FPDR training hours participants received (p = 0.051) when "*using new equipment immediately post training"*. In this competency, the group who had received between 4 and 15 hours training (n = 18) had a median score of 3.5, whereas it was 4 for all other groups. In all other competencies, the rankings were not statistically significant (Table 18).

Competency ranking and equipment use

The weekly use of CR and FPDR equipment did not significantly affect the rankings MITs gave themselves for any variable. The sole statistically significant variable was seen in *"manipulating exposure factors in CR"* and frequency of AED use per week (p = 0.016). Pairwise comparisons indicated that there was a highly significant difference (p = 0.003) between the group who used AEDs more than 76% of the time (median = 4) and those that used them 51-75% of the time (median = 5). Similarly, a significant difference (p = 0.011) was also seen between the groups who used AEDs less than 25% of the time (median = 5) and those using them more than 76% of the time per week (median = 4). These results indicate MITs who used AEDs less frequently ranked their competencies more highly than those who used AEDs >75% (Table 19).

Table 16

The level of MIT competencies: Comparison between groups with different age ranges

		Age				
	All	**Under 25**	**26-40**	**41-54**	**>55**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	53.00	51.00	48.00	48.00	0.524
Radiation dose subdomain	16-25 (21.00)	22.00	20.50	21.50	20.00	0.887
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.50	4.50	4.50	4.00	0.908
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.00	5.00	4.00	0.907
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	5.00	4.00	5.00	4.00	0.694
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	5.00	4.00	4.50	4.00	0.712
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.50	4.00	5.00	4.00	0.418
Image evaluation and quality subdomain	11-20 (16.00)	17.00	16.00	16.00	16.00	0.650
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	4.00	0.852
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	5.00	5.00	4.00	4.00	0.819
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	4.00	0.342
Performing post-processing procedures	2-5 (4.00)	5.00	4.00	4.00	4.00	0.241
Existing equipment use subdomain	30-45 (37.00)	40.00	37.50	37.00	37.00	0.790
New equipment use subdomain	9-15 (13.00)	14.00	13.50	12.00	12.00	*0.057*
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	4.00	4.00	0.289
Ongoing use of new equipment, one month post training	3-5 (4.00)	5.00	5.00	4.00	4.00	*0.060*
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	5.00	4.00	4.00	**0.020**

Note: Statistical significance indicated in bold when $p < 0.05$. Borderline statistical significance indicated in italics

*1 missing; 48 responses

Table 17

The level of MIT competencies: Comparison between genders

		Gender*		
	All	**Male**	**Female**	
Competency	**Range (Median)**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	48.50	51.00	0.881
Radiation dose subdomain	16-25 (21.00)	20.50	21.00	0.635
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.50	4.00	0.797
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.00	0.737
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	4.50	4.00	0.776
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.00	0.157
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.50	4.00	0.505
Image evaluation and quality subdomain	11-20 (16.00)	17.00	16.00	0.734
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	5.00	4.00	**0.038**
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	4.50	5.00	0.755
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	0.454
Performing post-processing procedures	2-5 (4.00)	4.00	4.00	0.734
Existing equipment use subdomain	30-45 (37.00)	35.50	37.50	0.776
New equipment use subdomain	9-15 (13.00)	13.00	13.00	0.635
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	0.505
Ongoing use of new equipment, one month post training	3-5 (4.00)	4.50	4.00	0.946
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	5.00	1.000

Note: Statistical significance indicated in bold when $p < 0.05$.

*1 missing; 48 responses

Table 18

The level of MIT competencies: Comparison between groups with different number of FPDR training hours

FPDR Training hours						
	All	**Not specified/0**	**<3.75**	**4-15**	**>15**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	51.00	54.00	47.00	50.50	0.242
Radiation dose subdomain	16-25 (21.00)	21.00	23.50	20.00	20.00	0.236
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.00	5.00	4.00	4.00	0.618
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.50	4.00	4.00	0.846
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	4.00	5.00	4.00	4.00	0.201
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	5.00	4.00	4.00	0.089
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.50	4.00	4.00	0.793
Image evaluation and quality subdomain	11-20 (16.00)	16.00	17.00	16.00	16.50	0.580
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	4.00	0.429
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	5.00	5.00	4.00	4.50	0.227
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	3.50	0.380
Performing post-processing procedures	2-5 (4.00)	4.00	4.50	4.00	5.00	0.214
Existing equipment use subdomain	30-45 (37.00)	38.00	40.50	36.00	36.50	0.239
New equipment use subdomain	9-15 (13.00)	13.00	14.00	12.00	13.50	0.094
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	3.50	4.00	*0.051*
Ongoing use of new equipment, one month post training	3-5 (4.00)	4.00	5.00	4.00	4.50	0.171
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	5.00	4.50	5.00	0.454

Note: Borderline statistical significance indicated in italics

*1 missing; 48 responses

Table 19

The level of MIT competencies: Comparison between groups with different AED use per week

AED use (per week)						
	All	**<25%**	**26-50%**	**51-75%**	**>76%**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	50.50	51.00	51.00	46.50	0.312
Radiation dose subdomain	16-25 (21.00)	22.00	20.00	22.00	20.00	0.066
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.50	4.50	4.00	4.00	0.894
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.50	4.00	5.00	4.00	0.094
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	5.00	4.00	5.00	4.00	**0.016**
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.50	4.50	5.00	4.00	0.208
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.00	4.00	4.00	0.333
Image evaluation and quality subdomain	11-20 (16.00)	16.00	18.00	16.00	16.00	0.254
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	4.00	0.739
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	4.00	5.00	5.00	4.00	0.213
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	4.00	0.402
Performing post-processing procedures	2-5 (4.00)	4.00	4.50	5.00	4.00	0.166
Existing equipment use subdomain	30-45 (37.00)	37.50	38.00	38.00	35.50	0.229
New equipment use subdomain	9-15 (13.00)	12.00	12.50	14.00	12.50	0.408
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	4.00	3.50	0.414
Ongoing use of new equipment, one month post training	3-5 (4.00)	4.00	4.00	5.00	4.00	0.520
Ongoing use of new equipment, six months post training	4-5 (5.00)	4.50	4.50	5.00	5.00	0.321

Note: Statistical significance indicated in bold when p < 0.05.

*1 missing; 48 response

7.4 Linear regression modelling

As described in Chapter 4 (section 4.9) regression modelling was undertaken to determine whether there was a predictive relationship between the independent variables and specific dependent variables, reflecting the approach of Andersson, Christensson, Jakobsson, et al. (2012).

The dependent variables were selected from different sections of the survey to explore the topic areas of MIT knowledge, understanding and perceived competency (Table 2). Independent variables were selected from the cross-sectional survey items. As described in Chapter 4, a forward stepwise approach was adopted, with each independent variable added to the model one at a time. The independent variables were ranked ordered according to their clinical relevance, based on existing literature and clinical experience (Appendix K)

The predictors for the MCQ scores are presented in Table 20, and those for perceived competency rankings in Table 21 below.

7.4.1 Total MCQ

Participants who experienced UG education in FPDR compared to those who did not, had a statistically significant higher total MCQ score (beta = 0.32, p = 0.025).

Borderline statistical significance was seen in the scores of those MITs who had trained staff in the use of CR (beta = 0.27, p = 0.058) compared to those who had not.

MCQ subdomain- knowledge

Highly statistically significant results were seen for two independent variables:

Participants who identified that radiation dose reduction was emphasised all of the time at their place of work, scored significantly higher on the MCQ knowledge subdomain, compared to those who selected most, some of the time or never (beta = 0.55, p = <0.001).

Those who indicated there was a mechanism in place to identify the percentage of examinations that fall within an acceptable range, achieved lower scores compared to those who stated this was not available (beta = - 0.39, p = 0.003).

Statistically significant results were identified for participants who had received applications training in FPDR, who scored significantly lower (beta = - 0.34, $p = 0.008$) than those who had not received this type of training.

Table 20

Results of linear regression analysis for detecting independent determinants of knowledge score of MITs

Dimension/scales of the dependent variable	Model/Independent Variable	β	p-value	95% Confidence Interval Lower	Upper
Total MCQ score	Received undergraduate education in FPDR	0.32	**0.025**	0.18	2.51
	Trained others in CR	0.27	*0.058*	-0.05	2.94
MCQ knowledge subdomain	Indicated that dose reduction is emphasised all of the time	0.55	**< 0.001**	1.17	3.17
	Applications training in FPDR received	-0.34	**0.008**	-2.15	-0.35
	Indicated a mechanism was in place to identify the percentage of examinations that fall within an acceptable range	-0.39	**0.003**	-2.127	-0.51

Note: Statistical significance indicated in bold when $p < 0.05$. Borderline statistical significance indicated in italics.

7.4.2 Total competency

Individuals who had trained others in CR had significantly higher competency ratings compared to those who had not (beta = 0.40, p = 0.002). This result was statistically highly significant.

Those who indicated exposure values were established for all equipment at their place of work also scored themselves significantly higher (beta = 0.32, p = 0.008), compared to those who did not.

Significant negative predictors of competency ratings were evidenced in three variables including those who had received CR training from a manufacturer (beta = -0.29, p = 0.025); those who indicated “inconsistent standards increase dose in CR” (beta = -0.32, p = 0.010); and for those who specified that artefacts are the most common cause for repeating their images (beta = - 2.56, p = 0.014) compared to those that had not.

Radiation dose subdomain

A statistically significant result was seen in participants who had received applications training in FPDR, ranking their competencies more highly than those who had not had this training (beta = 0.37, p = 0.003). In addition, those who had trained others in CR ranked their competencies more highly compared to those who had not (beta = 0.35, p = 0.008).

Endorsing the item “radiologists preferences influence radiation dose in FPDR” was a negative predictor of ranked competencies in this subdomain (beta = - 0.38, p = 0.005).

Participants who indicated “inconsistent standards increase dose in CR” ranked their competencies lower (beta = - 0.25, p = 0.040) compared to those who did not.

Borderline statistical significance was seen in two other groups of participants: those who had received manufacturer training in CR (beta = - 0.24, p = 0.061); and those who specified “patient limiting conditions cause the most repeats” (beta = - 0.22, p = 0.074) compared to those who did not.

Image evaluation and quality subdomain

Endorsing the item “a lack of exposure charts increases radiation dose in FPDR” was a negative predictor of ranked competencies in this subdomain ranking (beta = - 0.38, p = 0.002). This result was highly statistically significant.

Participants who had trained others in CR ranked their competencies higher when compared to those who had not (beta = 0.30, p = 0.017). Participants who had received manufacturer training in CR was a negative predictor of ranked competencies in this subdomain (beta = -2.30, p = 0.027).

Borderline statistical significance was seen in two other groups of participants: those who post-collimate their images less than 25% of the time (beta = - 0.22, p = 0.072); and those who indicated “workload increases radiation dose in CR” (beta = - 0.21, p = 0.090).

Using existing equipment subdomain

A highly significant result was seen in participants who had received manufacturer training in CR, ranking their competencies lower (beta = - 0.043, p = 0.004) than those who had not had this training.

Participants who trained others in the use of CR, ranked their competencies higher when compared to those who had not (beta = 0.36, p = 0.010).

Borderline statistical significance was seen in participants who received manufacturer training in FPDR compared to those who did not (beta = 0.25, p = 0.078).

Using new equipment subdomain

A highly significant result was seen in participant rankings for those who reprocess their images 26-50% of the time (beta = - 0.45, p = 0.001).

Participants who received manufacturer training in CR, ranked their competencies lower (beta = - 0.32, p =0.016) than those who had not had this training.

Those participants aged > 55 years, ranked their competencies lower (beta = - 0.26, p = 0.043) than those aged < 25 years and those aged 26-40 years.

Table 21

Results of linear regression analysis for detecting independent determinants of MITs self-ranked competencies

Dimension/scales of the dependent variable	**Model/Independent Variable**	**β**	**p-value**	**95% Confidence Interval**	
				Lower	**Upper**
Total competency domain	Received manufacturer training in CR	-0.29	**0.025**	-8.22	-0.58
	Trained others in CR	0.40	**0.002**	2.06	8.85
	Indicated inconsistent standards increase dose in CR	-0.32	**0.010**	-6.48	-0.96
	Indicated that artefacts are the most common cause of repeats	-2.56	**0.014**	-21.91	-2.59
	Indicated that exposure values were established for all equipment	0.32	**0.008**	1.56	9.03
Radiation dose subdomain	Applications training in FPDR received	0.37	**0.003**	0.73	3.43
	Received manufacturer training in CR	-0.24	*0.061*	-3.75	0.09
	Stated patient limiting conditions cause the most repeats	-0.22	*0.074*	-5.02	0.24
	Trained others in CR	0.35	**0.008**	0.66	4.06
	Indicated inconsistent standards increase dose in CR	-0.25	**0.040**	-2.80	-0.07
	Indicated radiologist preferences increase dose in FPDR	-0.38	**0.005**	-11.85	-2.28
Image evaluation and quality subdomain	Received manufacturer training in CR	-2.30	**0.027**	-3.21	-0.21
	Trained others in CR	0.30	**0.017**	0.32	3.00
	Indicated that a lack of exposure charts increases radiation dose in FPDR	-0.38	**0.002**	-3.77	-0.88
	Stated that they post-collimate images less than 25% of the time	-0.22	*0.072*	-0.09	1.97
	Stated workload increased radiation dose in CR	-0.21	*0.090*	-2.63	0.20

Dimension/scales of the dependent variable	Model/Independent Variable	β	p-value	95% Confidence Interval	
				Lower	Upper
Using existing equipment subdomain	Manufacturer training in CR	-0.43	**0.004**	-8.44	-1.73
	Manufacturer training in FPDR	0.25	*0.078*	-0.28	5.03
	Trained others in CR	0.36	**0.010**	0.99	6.79
Using new equipment subdomain	Reprocess their images under another body part 26-50% of the time	-0.45	**0.001**	-2.52	-0.76
	Received manufacturer training in CR	-0.32	**0.016**	-2.70	-0.30
	Aged over 55 years	-0.26	**0.043**	-2.05	-0.03

Note: Statistical significance indicated in bold when $p < 0.05$. Borderline statistical significance indicated in italics.

7.5 Summary

The purpose of Phase Two of the research was to describe and identify factors relating to MITs' knowledge and understanding of digital imaging and its application, as well as their perceived competence in using digital technology. The relationship between MIT knowledge, understanding and perceived competencies was explored through key variables. These included: training and education in the use of different technologies, experienced technological transitions in the clinical environment, number of years post qualification and percentage of time using the equipment.

The development, piloting, and distribution of a self-administered survey with a set of pre-defined questions was used in an attempt to answer the following questions:

1. **What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application?**
2. **What factors are related to MITs knowledge of and perceived competence in the use of digital technology?**

The bivariate and multivariate analyses indicated that having experienced FPDR education as an undergraduate significantly increased the total MCQ scores achieved. There was no evidence that the type or hours of other training in these technologies significantly influenced the MCQ scores. Similarly, the amount of time using the equipment did not significantly affect the MCQ scores.

The survey demonstrated that this group of MITs ranked their competencies in the use of digital imaging equipment highly. The results demonstrated borderline significance in relation to the number of FPDR training hours participants received. Competency scores were not significantly affected by any other training or education variables nor by the amount of time the participants used the equipment each week, with the exception of the use of AED equipment and the "manipulation of exposure factors in CR" item.

The regression modelling demonstrated the variables significant in predicting an increase in the total MCQ scores, were undergraduate education in FPDR, and to a lesser extent training other in CR. Where employers consistently emphasised the need for radiation dose reduction, a highly significant increase in the MCQ knowledge subdomain score was also seen. Applications training in FPDR resulted in a significantly lower score in the MCQ knowledge subdomain of the survey.

Predictors that significantly increased the competency rankings included training others in CR. This was evidenced in the total competency rating and all of the subdomains with the exception of using new equipment.

Conversely, receiving manufacturer training in CR was seen as a variable that was significant in predicting a lower ranking across all domains and subdomains. Applications training in FPDR increased the rankings in the radiation dose subdomain compared to those participants who had not had this training. Similarly, manufacturer training in FPDR was borderline significant in predicting an increase in the 'using existing equipment' subdomain.

While the percentage of time participants spent using the equipment did not significantly affect the rankings, in departments where exposure values were established for all equipment, the participants ranked themselves significantly higher than those participants who indicated this was not the case. Finally, there was no evidence that the MCQ scores were a predictor of competency rankings or vice versa for this group of MITs.

In the following chapter, I discuss the Phase Two cross-sectional survey findings.

Chapter 8 Phase Two Discussion

8.1 Introduction

In this chapter I discuss the results from the descriptive, bivariate, multivariate, and inferential statistical analyses undertaken in Chapter 7. I then compare and discuss my findings in the context of existing published literature and my own professional knowledge and experience. Synthesised findings from both phases will be discussed in-depth in Chapter 9.

The overarching aim of this phase was to describe and identify factors influencing MITs' knowledge and understanding of digital imaging and its application, as well as their perceived competence in using digital technology.

Two research questions were used to guide my approach:

1. **"What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application?"**
2. **"What factors are related to MITs knowledge of and perceived competence in the use of digital technology?"**

As identified in Chapters 1 and 4, specific objectives were used to support answering these questions as follows:

1. In relation to clinical practice, do MITs understand:
    a) How digital systems respond to different levels of radiation exposure?
    b) How different functionalities of the equipment influence best practice?
    c) Whether their practice is meeting the ALARA principle?

2. What factors are related to MITs' knowledge and understanding of the practical application of digital technology? It was hypothesised that:
    a) MITs who learnt about FPDR or CR in their undergraduate programme would demonstrate higher levels of digital technology knowledge.
    b) MITs who had received training in FPDR or CR technologies would demonstrate higher levels of digital technology knowledge.
    c) MITs who spend more time using FPDR or CR equipment on a weekly basis would demonstrate higher levels of digital technology knowledge.

3. What factors are related to NZ MITs' perceived competence using digital technology? This was assessed using a self-ranked competency scale relating to MIT clinical practice and utilisation of digital technology. A competency scale was selected as it reflects an individual's self-rated feelings of ability and is linked to feelings of self-confidence (Takase et al., 2015).

In accordance with the research design, this phase of the study was used to build on the key concepts that had been identified in the Phase One interviews, through the creation and utilisation of a cross-sectional survey. Quantitative data exploring MIT knowledge and perceived competencies in the use of digital imaging technology and factors which influence them were gathered. The use of descriptive analyses supporting my understanding of the MITs' experiences and the inferential analyses allowed me to identify predictor variables which were related to MIT knowledge or perceived feelings of competency regarding digital imaging technology (Onwuegbuzie & Combs, 2015). Actions to ensure validity, reliability and rigour in this research phase have been discussed in detail in Chapter 4.

In this section, I discuss the representativeness of study sample in relation to the broader NZ MIT population. Overall, the sample characteristics of the participants seemed to reflect the NZ MIT population. There was a higher percentage of female participants (81.6%), reflecting similar proportions in the NZ MIT workforce, i.e. 87.5% (New Zealand Health Information Service, 2007) and NZ 2018 census of 86% (Stats NZ Tatauranga Aotearoa, 2018). A higher proportion of females (40%) compared to males (25%) had "long term" or the "longest levels" of experience (i.e. qualified more than 15 years). The increased number of males in the groups with short or medium term experience suggests that although historically more females trained as MITs, there is now a similar increase in males and females in the NZ MIT workforce. This is supported by statistics from the NZ censuses of 2013 and 2018 which show similar changes in numbers in the NZ MIT population between males (6.5% increase) and females (7% increase). Although males were less well established in the workforce, there was no statistical difference in the number of years since qualification ($p = 0.526$), supporting the findings of Andersson, Christensson, Jakobsson, et al. (2012) who found, in their study in Sweden, that gender was not statistically significant between groups with different levels of experience.

There was a higher proportion of more junior staff (such as Staff MITs) in the groups who had been qualified under fifteen years (54%). Seniority was determined by the participants' indicated position i.e. Staff, Grade or Charge MIT. All participants worked in areas consistent with general scope of practice in NZ. There was no observed association between length of time since qualification and working in a DHB or private practice ($p = 0.115$).

With regard to employment status, 63% were working full-time and 37% part-time, exactly mirroring UK MIT workforce statistics (Careersmart.org.uk, 2020). There was a significant difference between time since qualification and whether the participants were working full-time or part-time ($p = 0.038$). Full-time workers had either the least amount of experience (0-5 years) or most experience (>25 years), compared to those working part-time who were in the 5-15 years' experience group.

Those who had been qualified over 15 years had diplomas in medical imaging, whereas those who qualified more recently were most likely to have Bachelor degrees, reflecting the change to a degree-based profession in NZ in 1994. Regarding higher education qualifications, 16% held a postgraduate certificate or diploma. While the number of NZ MITs with postgraduate qualifications working in the general scope of practice is unknown my figures, although higher than the 7% indicated in Andersson, Christensson, Jakobsson, et al.'s (2012) study, are very similar to the 17% indicated by McFadden et al. (2018) in their review of MIT digital imaging knowledge and practice in 12 countries across Europe.

8.2 Research Question 1: What knowledge, understanding and perceived competence do MITs have regarding digital technology and its application?

The total MCQ scores, indicated the level of knowledge displayed by participants was low i.e. only 24.5% participants ($n = 12$) achieved > 54.5%, i.e. six or more correct answers out of eleven. This finding supports Hayre et al. (2017) findings that MITs sometimes lacked requisite underpinning knowledge when operating FPDR systems. Moolman et al. (2020) similarly identified a need for increased MIT education and training to support digital imaging practice. Their survey demonstrated MITs in Gauteng did not understand the link between EI and image quality, potentially leading to patient overexposure in paediatric patients. Specifically, my results demonstrated that there were knowledge gaps associated with the theory of digital technology for both CR and FPDR systems which were supported by Seeram et al. (2015), who reviewed MIT knowledge of CR and determined CR education and training had been insufficient. The variables which significantly affected levels of MIT knowledge, are discussed further in relation to my second research question.

Participants ranked their perceived competencies highly, with median competency ratings of 5 (“high”) for two variables and 4 (“good”) for the remainder. They considered themselves highly competent in two of the survey items: “*ongoing use of new equipment, six months post training”;* and “*evaluating the diagnostic quality of the image in relation to the clinical indications”*. High feelings of competence with regard to evaluating the diagnostic quality of the image, would align with this skill being a key competency for NZ MIT practice. The submission of a CPD portfolio (on request) when renewing annual practising certificates, provides documentary evidence that NZ MITs are meeting the required competencies for practice (The New Zealand Medical Radiation Technologists Board, 2018).

Despite most statements having a median rating of “good”, some variables had a wide range of scores, suggesting some participants felt less competent in these areas. For example, a range of “none” to “high” (1-5) was identified for “*manipulating exposure factors in CR”* and replicated in “*manipulating exposure factors in FPDR”*. This could reflect confusion pertaining to the way CR and FPDR systems respond to radiation (Alsleem et al., 2019; Seeram, 2019; Uffmann & Schaefer-Prokop, 2009). Being able to adjust patient radiation exposures appropriately, relates to the ALARA principle and is especially important when using digital imaging systems (Herrmann et al., 2012; Moore, 2016; Seibert & Morin, 2011).

That participants reported a perceived competency range of “low” to “high” (2-5) for the“*optimising image quality through increasing the contrast to noise ratio”* item, is concerning. The ability to understand the factors that underly image production (including how noise, contrast and patient radiation dose influence image quality) is an essential MIT competency (Andria et al., 2016; Huda & Abrahams, 2015; The New Zealand Medical Radiation Technologists Board, 2018). The CNR has been identified as a way in which image quality can be quantatively determined (Schaefer-Prokop et al., 2008). The CNR influences the quality of the image as it affects the contrast resolution i.e. an increase in the CNR will increase the visibility of anatomical structures and vice versa (Fauber, 2016).

As discussed peviously, an increase in CNR can be achieved through reducing noise and/or increasing the contrast in the image (Huda & Abrahams, 2015). Noise can be reduced by increasing the number of photons (intensity of the beam) reaching the detector, through increasing the mAs for example, however it also increases patient radiation dose. Although image contrast can be manipulated post-exposure (Uffmann & Schaefer-Prokop, 2009), it is primarily affected by the tube voltage (kV) selected by the MIT (Fauber, 2016). MIT exposure factor selection influences the intensity and quality of the beam, whether using a digital or film-screen system (Huda & Abrahams, 2015). Therefore, the exposure choices MITs make, and the protocols adopted within imaging departments, affect the CNR and ultimately impact on the optimisation of the imaging procedure (Freitas et al., 2020; A. K. Jones, Ansell, et al., 2015).

The differing levels of perceived competence identified in relation to the CNR and exposure manipulation compared to image quality evaluation, could suggest my participants had not appreciated how these are linked and related to the principle of optimisation. Research has previously identified MITs' knowledge of optimisation processes for digital imaging systems seemed lacking (Alsleem et al., 2019; Hayre, 2016; McFadden et al., 2018; Moolman et al., 2020). However, there appears to be limited literature with regard to MIT competencies linked to the use of quantifiable digital image quality measures such as CNR. For example, although Farajollahi et al., (2014) reviewed MIT technical competencies, their study focused on F-S systems. Other research used a more generic approach in assessing technical processes (Andersson, Christensson, Jakobsson, et al., 2012; Vanckavičiene et al., 2017), which suggests that further research into MITs knowledge and understanding of key digital imaging concepts, such as the CNR, may be beneficial.

Overall, the generally high competency scores seem to suggest that MITs have high levels of self-belief, despite the low knowledge scores, as demonstrated in their MCQ responses. One influencing factor on the competency ratings may have been the placement of the MCQ questions in the cross-sectional survey. Had they been placed before the competency section, the rankings the MITs gave themselves may have been different. However, as indicated in the methods section, this sequencing was a deliberate choice.

High levels of perceived self-competency supports previous research outcomes (Andersson, Christensson, Jakobsson, et al., 2012; Chigunta et al., 2020; Vanckavičiene et al., 2017). For example, survey respondents in studies by Andersson, Christensson, Jakobsson et al. and Vanckavičiene et al., rated themselves highly on the Radiographer Competence scale. Whereas, Chigunta et al.'s mixed methods study, which compared the differences between junior MITs' self-ranked competencies versus the ratings awarded to them by their supervisors, identified supervisor ratings of technical competence were lower than the junior staff's self-ranked scores. Chigunta et al.'s findings imply there are inherent flaws with using self-ranking as a measure of competency. This aligns with Katowa-Mukwato & Banda (2016), who compared self-ranked clinical competencies versus those achieved in an Objective Structured Clinical Examination (OSCE). They identifed significant disparity between self-perceived and objectively measured competencies namely, high or moderate self-rankings were not evidenced by the OSCE results. They suggested participants' inaccurate self-rankings were because they were afraid of revealing gaps in their knowledge to others. While this seems appropriate within the context of their study reviewing final year medical students, Anderssson et. al, Vanckavičiene et al., and I used anonymous surveys, making Katowa-Mukwato & Banda's suggestion less plausible in the context of my research. Rather, my findings suggest that self-assessment may not be effective in identifying learning needs, thus supporting and building on Baxter & Norman's (2011) findings that self-assessment is ineffective in evaluating clinical competencies.

8.2.1 In relation to clinical practice: Do MITs understand how digital systems respond to different levels of radiation exposure?

Digital imaging utilises a detector to capture and convert attenuated x-ray photons emitted from the patient into electronic (analogue) signals. These are subsequently converted into digital data to be processed by a digital computer. Processing creates a "viewable image" for the MIT, radiologist or requesting clinician (Seeram, 2019).

As described previously, determining the level of radiation exposure on digital images is achieved through evaluation of the EI. EI review takes place at the work station monitor and is considered essential in determining whether the correct exposure has reached the detector and supported the production of a diagnostic image (Mothiram et al., 2014). My participants' responses to the EI MCQs, showed variable awareness as to how it functions. For example, the majority of participants (75.5%) correctly identified EI is calculated from the exposure incident on the detector. However, only 12% of participants correctly identified all of the technical factors which may affect EI values, potentially leading to incorrect exposure factor selection and an increased likelihood of increased radiation dose to the patient (Mothiram et al., 2013).

Due to variability in EI calculation between manufacturers (Mothiram et al., 2013), the use of a target EI (EI_T) and exposure deviation index (DI) is recommended (International Electrotechnical Commission [IEC], 2008), to produce more uniform feedback on exposure factor selection to MITs and radiologists (Don et al., 2012; Seibert & Morin, 2011). There is an expectation that the IEC recommendations are adopted by manufacturers and imaging departments alike. More recently, guidelines from the American Association of Physicists in Medicine have concluded that modification and regular review of the EI_T and DI should be undertaken by departments, as part of a continuous quality improvement programme (Dave et al., 2018). Despite this, 51% of my participants identified that their departments utilised EI_T and DI. An inconsistent approach to the use of EI_T has been previously identified in the literature (Guðjónsdóttir et al., 2021), who identified marked differences in EI_T values and usage across 10 x-ray units in Iceland. Non-availability of EI_T and DI values were linked to applications training provision from equipment vendors, with Guðjónsdóttir et al. suggesting manufacturers may be impeding the use of EI_T and DI values through using outdated training content.

MITs are also supported in their exposure factor decision making through the availability of equipment exposure values and a process to determine the number of examinations which fall within the required range (Morrison et al., 2011). The majority of participants (88%) specified that values exist for all equipment, while a much fewer number (39%) confirmed there was a process in place to determine the percentage of examinations which have the correct, too high or too little exposure. Some participants did not know whether this process existed (41%), which would seem to support Morrison et. al's (2011) assertion that this could be due to a lack of knowledge, or the way the FPDR system has been set-up.

Understanding and reviewing EI values supports MITs in meeting the ALARA principle and determining the quality of their images (Moore, 2016). Without this knowledge MITs may come to an incorrect conclusion about the level of radiation the patient has received, or whether a repeat examination is required. My results align with other studies that have indicated MITs' theoretical knowledge of EIs is lacking and a consistent approach to training in this area is required (Guðjónsdóttir et al., 2021; S. Lewis et al., 2019a; Seeram et al., 2015).

8.2.2 In relation to clinical practice: Do MITs understand how different functionalities of the equipment influence best practice?

The methods used by the participants to evaluate the quality of their images is captured in this subsection and primarily considers quality control activities undertaken at the work station monitor. MITs are responsible for creating images which support clinical diagnosis and thus clinical decision making. Overall, my descriptive statistics suggested there was a disconnection between best practice recommendations and clinical practice. Very few participants indicated they regularly undertook image post-processing activities such as: manipulating the brightness and contrast of their images; manipulating the Look Up Table (LUT); or re-processing under another body part. This may reflect concerns MITs may manipulate an image such that false positive diagnoses may result (McHugh, 2020). However, McHugh argued this is only problematic if a lossy compression[21] process is used, as in lossy compression original data would not be stored in PACS and would be unavailable for subsequent retrieval. The ability to post-process an image to enhance diagnostic interpretation is considered an important component of MIT work (DeAngelis, 2007; McHugh, 2020; Seeram, 2019). Post-processing allows the MIT to improve image appearance through adjusting the contrast and brightness, or to reduce the level of noise evident in the image (Seeram). This process may prevent any unnecessary repeat imaging and therefore reduce patient radiation dose (McHugh). Patient dose can be further

[21] Data compression is used to facilitate image transmission and storage. Methods including lossy (irreversible, some information lost) and lossless (reversible, no information lost) compression.

reduced by using lower mAs values coupled with image manipulation via the LUT (Al Khalifah & Brindhaban, 2004).

LUTs utilise manufacturer pre-set reference histograms during the automated transformation of the raw data into the final image (McFadden et al., 2018). However, the automated process may be adversely affected by a number of factors, such as the presence of a metal hip prosthesis within the patient. These create an image which has very poor contrast or brightness and therefore require the MIT to manipulate the LUT to rectify the issue (DeAngelis, 2007). This problem is less common in FPDR compared to CR, due to the different way in which the raw data is read (DeAngelis, 2007). Nevertheless, image manipulation through the LUT provides MITs the opportunity to ensure image display supports diagnostic interpretation.

To undertake post-processing effectively, MITs need to be aware that the option exists and understand how and when to use it. However, as previously mentioned, my participants indicated they spent very little time each week undertaking this activity. While this could suggest that their imaging systems were appropriately configured and therefore post-processing was not required, that would be contrary to research indicating that digital imaging system set up frequently requires modification (Peters & Brennan, 2002; Seeram et al., 2016). Issues with complexity and the numerous software options available, have been previously highlighted as a barrier to the use of post-processing controls (Precht et al., 2019). This could account for the lack of image manipulation undertaken by the participants. Alternatively, it could be due to a lack of high-resolution (medical grade) monitors available to them, reducing the opportunity to manipulate images appropriately.

When reviewing the quality of their images, MITs determine whether repeat or additional images would support diagnosis. Furthermore, MITs must be able to recognise and communicate any significant appearances to the relevant clinician (New Zealand Medical Radiation Technologists Board, 2018,). The ability to undertake this effectively is predicated on the assumption that they are given the tools to do this. The use of a high-resolution monitor to review and manipulate images before sending to PACS was very limited for my participants. Thirty one (63%) either never did this or undertook it less than a quarter of the time. For those who never undertook this, 50%

stated this was because they did not have access to a high-resolution monitor. While it is accepted that the cost of these monitors is higher than work station monitors (Moodley & Moodley, 2015), it could be argued that MIT access to at least one high-resolution monitor within the imaging department would be beneficial, especially as the use of a sub optimal monitor may inhibit correct image evaluation by the MIT (Seeram, 2019). This would seem to be of increased importance in situations where radiologists are working remotely, have no interaction with the patient and therefore have increased reliance on the MIT's judgement (Fridell et al., 2008).

MIT image review and quality processes ultimately influence the radiation dose received by the patient. Maintaining or improving quality in medical imaging also requires the monitoring of examination repeat rates. The majority of my participants (88%) stated they were able to access their own repeat rate data. However, three participants stated they did not know how to do this. While this is only a small number of individuals (and much lower than the 30% quoted by Morrison et al. (2011)), it is concerning a key feedback process relating to personal and professional development requirements and potential equipment faults, was not available or not used by those three participants. Several other radiation protection issues have been highlighted as specifically related to the use of digital imaging systems such as exposure creep and collimation creep. In general, my findings were consistent with the literature and are discussed in more detail in the following section.

8.2.3 In relation to clinical practice: Do MITs understand whether their practice is meeting the ALARA principle?

Findings related to AED use, image collimation checks and electronic post-collimation image cropping have informed this section.

AED utilisation was reviewed, as these devices govern the amount of radiation reaching the receptor, determining the correct signal to noise ratio, exposure index value and resultant image quality (Scott et al., 2016; Seeram, 2019). As such, they are key in supporting patient dose optimisation through avoiding exposure creep, while maintaining image quality (American College of Radiology, 2017; Herrmann et al., 2012; Sung & Choi, 2014). Given the known risk of exposure creep in digital imaging, it was expected AED use would be widespread in NZ MI practice. However, I found that while AEDs were used by the majority of participants at least some of the time, they were not used consistently, with only 20% of my sample using AEDs more than 76% of the time. This shows variability in practice, consistent with Morrison et al. (2011).

Inconsistent AED use has been linked to participants working in a children’s hospital, (Morrison et al., 2011). This is because AED use is not recommended in paediatric patients, whose body parts are smaller than the size of the ionisation chambers (Herrmann et al., 2012). Nonetheless, Morrison et al. also indicated that adults were the predominate patient group their participants encountered. Although my participants were not asked about paediatric imaging specifically, it could be argued that adults were also likely to be their main client group. Therefore, there was an expectation regular use of AEDs would be identified by the participants (Gibson & Davidson, 2012)

Irregular AED use has been linked to those clinical environments in which their utilisation would be problematic, such as mobile imaging (Fauber, 2016; Herrmann et al., 2012). However, alternative explanations include MITs not opting to use AEDs due to issues following the implementation of digital technology. For example, AED and APR calibration not reflecting individual digital detector responses (Bowden et al., 2011; Moore, 2016). It is also possible that the wide exposure latitude afforded by digital systems (Seeram et al., 2015), coupled with the lower doses required to produce an image compared to F-S systems (Marsh, 2020), has created a perspective that AED use is less relevant than it used to be.

While a reduction in AED use has not been reported in the literature, Hayre et al. (2018) specified that MITs consider patient radiation dose associated with planar imaging to be insignificant compared to CT imaging. Furthermore, previously entrenched radiation protection measures were being ignored. My findings reflect a potentially similar attitude towards the use of AEDS and could indicate MITs were applying their own standards, rather than using evidence-based practice in relation to radiation protection. My findings are supported by Hayre et al.’s assertions and a previously identified concern that variations in MIT clinical practice are linked to increased patient radiation dose (Bijwaard et al., 2017; McFadden et al., 2018).

The removal of electronic collimation (to view collimation borders) also relates to patient radiation protection. However, the participants identified this was not consistently undertaken. Checking the collimation borders allows an MIT to confirm whether anatomy outside of the region of interest has been irradiated. It gives feedback on whether MIT practice is adhering to the ALARA principle (Bomer et al., 2013). Furthermore, effective collimation reduces the amount of scatter reaching the detector and improves image quality (Herrmann et al., 2012). The risk of poor collimation practices following the introduction of digital technology has been previously highlighted in the literature (Zetterberg & Espeland, 2011) who, in their retrospective study of F-S and digital lumbar spine images, found the irradiated area significantly larger in the digital images, leading to an unnecessary increase in patient radiation doses.

The lack of evaluating the irradiated field size, could be because digital systems require MITs to consciously check their collimation borders, rather than having immediate visual feedback, as in F-S systems. Nevertheless, it was concerning that my participants were not checking this aspect of their practice, especially when considered in conjunction with the practice of electronic cropping of the radiation field. Electronic cropping is a post-processing technique designed to reduce image brightness and improve the viewing conditions (Herrmann et al., 2012) and should not be used as a means to obscure poor collimation practice (Guðjónsdóttir & Hannesdóttir, 2019). Post-collimation or cropping of the image indicates the MIT has irradiated an area outside of the region of interest and has increased the radiation dose to the patient (Alsleem et al., 2019; Tsalafoutas, 2018). The subsequent use of post-collimation to mask over-irradiation is not supported as appropriate clinical practice, as it may exclude potentially useful information from the image (Eaton, 2018). In the linear regression model, participants who post-collimated less than 25% of the time ($n = 26$), demonstrated borderline reduced perceived competence in the "image quality and image evaluation" subdomain ($p = 0.072$, $\beta = - 0.22$).

While the number of my participants who were frequently undertaking post-collimation is considerably lower than those indicated by Morrison et. al (2011), the potential to overexpose the patient remains an issue for radiographic practice (Guðjónsdóttir & Hannesdóttir, 2019; Uffmann & Schaefer-Prokop, 2009). Alsleem &

Almohiy (2018) identified, in their quantitative study of MIT paediatric digital imaging knowledge, that overexposure occurs when MITs opt to use electronic collimation processes in preference to primary beam collimation. Due to this risk, refresher training and the subsequent auditing of collimation practice have been recommended to support the ICRP tenet of optimisation (Tsalafoutas, 2018).

The linear regression model demonstrated statistically significant results in the MCQ knowledge subdomain in relation to radiation protection issues. Specifically, increased scores were achieved by participants who indicated "*dose reduction is emphasised all of the time"* in their workplace ($p = < 0.001$, $\beta = 0.55$), compared to departments where this was less frequent. Consistent repetition of such a key message is likely to encourage staff to maintain or improve knowledge levels. This would align with the findings of Boyd (2013) who, in her theory of planned behaviour study, identified that social pressures positively influence MITs radiation protection practice when using digital technology.

MITs who worked in an environment where there was a "*process to confirm whether their images fell within an accepted exposure range"* were statistically more likely to achieve lower scores in the knowledge MCQ subdomain ($p = 0.003$, $\beta = -0.39$). One potential explanation is an overreliance on technology to provide information without understanding the background processes (Hayre et al., 2017). Furthermore, a study on MRI technologists identified that a lack of "formal" educational opportunities can result in over-reliance on manufacturer-based equipment settings, subsequently negatively influencing the technologists' ability to recognise and problem solve image quality issues (Alsharif et al., 2017). Alternatively, a decreased score could also reflect the participants' misunderstanding of the way these systems work (such as EI values) and how the information can be utilised to inform practice. Morrison et al. (2011) concluded MITs and their managers may have insufficient knowledge in this area. Overall the reduced knowledge subdomain score, suggested that the presence of a feedback mechanism may not automatically improve clinical practice without an underlying foundational understanding of key theoretical concepts

These results reveal some variability in medical imaging practice across participants. When coupled with the frequency of post-processing activities undertaken, it suggests that the ALARA principle is not being strictly adhered to.

8.3 Research Question 2: What factors are related to MITs' knowledge of and perceived competence in the use of digital technology?

This question looked to identify the variables which seemed to be linked to MITs' knowledge and perceived competency levels. The use of two specific objectives assisted in answering this question.

8.3.1 What factors are related to MITs' knowledge and understanding of the practical application of digital technology?

To address this question, the aim was to determine whether there was a link between MIT digital technology knowledge and the training approaches they had experienced or weekly levels of digital equipment use.
It was hypothesised that:

a) MITs who learnt about FPDR or CR in their undergraduate programme would demonstrate higher levels of digital technology knowledge

44.9% of the participants learnt about FPDR as undergraduates, with 55.1% taught about CR in their undergraduate programmes. The bivariate results indicated that undergraduate education in FPDR significantly improved ($p = 0.031$) the total MCQ score participants achieved. After adjusting for potential covariates, the linear regression model results indicated a higher level of significance relating to undergraduate education in FPDR and total MCQ scores ($p = 0.025$; $\beta = 0.32$). These results support the hypothesis.

These results indicate a formal education process incorporating relevant pedagogical theories may have contributed to an improved knowledge base for this group of MITs. It is likely that the structured nature of an undergraduate degree curriculum with specific learning outcomes would also support learning. The increased MCQ score is consistent with existing literature, which has reported MRI practitioner knowledge learned in a formal educational setting to be higher than in those individuals who learned experientially (Westbrook, 2017).

CR undergraduate education was not found to be statistically significant and could reflect the higher rates of FPDR use compared to CR. This result is consistent with changes in the use of different digital technologies more generally in the medical imaging field (Korner et al., 2007). My results specifically related to FPDR and CR education during undergraduate programmes. I found no statistical link between the type of qualifying degree and level of knowledge, unlike Farajollahi et al. (2014). In their study, participants with a Bachelor's degree demonstrated higher levels of knowledge, compared to those with a Higher National Diploma. Higher levels of knowledge were also seen in their participants with higher grade point averages.

Johnston et al. (2010) identified medical imaging undergraduate education should enable graduates to utilise equipment safely. Updates through in-service training are required to maintain competencies and are essential when new technology is introduced. However, the relationship between undergraduate education and different training approaches to MITs' knowledge of digital imaging systems does not seem to have been previously explored.

b) *MIT's who had received training in FPDR or CR technologies would demonstrate higher levels of digital technology knowledge*

69.4% of participants had applications training in FPDR and 47.9% in CR systems. Cascade training in FPDR was received by 55.1% of participants, with 46.9% in CR. The linear regression model indicated applications training in FPDR systems significantly reduced the participants MCQ score in the knowledge subdomain ($p = 0.008$; $\beta = -0.34$). Factors previously identified as influencing the effectiveness of applications training have included time spent with and knowledge level of the trainer (Morrison et al., 2011). A low level of applications' training time was reflected in my study and was further reduced in the transition to FPDR compared to CR. It appeared as though the transition to CR from F-S systems was seen as more significant compared to transitioning from one digital system to another.

Another possible explanation for the negative relationship between applications training and knowledge scores, could be that the applications training may not have covered the areas assessed by the MCQs (Seeram et al., 2015). The MCQ section covered questions relating to image evaluation, the exposure index, processing protocols and artefact identification. This reflected Herrmann et al.'s (2012) recommendations that applications training should incorporate these topics, as well as image acquisition and radiation protection measures. I did not ascertain from my participants whether these areas were covered in their training process. Nevertheless, this would not explain why participants who had not received applications training achieved a higher score. The lower scores seen in those participants who had applications training may indicate this type of training was task-focused rather than theory-based. Furthermore, the variation in the number of training hours my participants received reflects an inconsistent approach to training. Additionally, there do not seem to be any quality standards associated with in-house or applications-based training, unlike formal education programmes. This is of concern, as a lack of quality processes may also result in inconsistent training and potential disparity in patient care provision.

Linked to the hypothesis, borderline statistical significance in the linear regression model identified an increase in the total MCQ scores for those MITs who had trained staff in the use of CR ($p = 0.058$, $\beta = 0.27$). As a CR trainer it is possible they had been CR superusers and had increased training to support this role. While increased CR knowledge may have been acquired through training, it does not entirely explain why their total scores were higher. It is possible that trainers were initially selected based on the level of knowledge or expertise they had already or those who expressed the desire to undertake this role, potentially resulting in increased motivation to expand their knowledge of digital technology to prepare for the trainer role. As CR trainers, these individuals were likely to have been using digital equipment for a longer period of time and as such may have developed increased knowledge and expertise over time.

The role and significance of applications training does not seem to have been considered in the literature previously. It would be beneficial to explore this in greater depth in future research, for example to determine whether set standards would create a more consistent training process.

c) *MITs who spent more time using FPDR or CR equipment on a weekly basis would demonstrate higher levels of digital technology knowledge.*

Participants were asked about image acquisition processes to identify rates of CR and FPDR usage. Over half (55.1%) the participants identified using FPDR more than 75% of the time, the same percentage of participants used CR less than 25% of the time. This supported the expectation that the results would show higher rates of FPDR compared to CR use, and again is consistent with recent changes in the use of different digital technologies in planar imaging. There was no statistically significant correlation between equipment use and knowledge levels.

8.3.2 What factors are related NZ MITs' perceived competence using digital technology?

Although the impact of PACS on MIT work practice has been described in the literature (Fridell et al., 2008; Larsson et al., 2006), MIT self-ranked competencies regarding the use of digital equipment does not seem to have been evaluated previously. As such this aspect of my study provides a new and novel insight.

As described in research question one, the descriptive statistics indicated that the MITs ranked their competencies highly. The outcomes of the linear regression analysis, identified factors which were demonstrated to be statistically significant. These were predominantly linked to training and education processes and statements relating to patient radiation dose.

Training and education

Training and education were found to be the statistically significant influences on MIT feelings of competence. However, this varied according to whether the MIT had been a trainer, the type of training/education received and the imaging modality.

Highly significant results for those individuals who had trained others in CR compared to those had not, were seen in the total competency domain ($p = 0.002$, $\beta = 0.40$) and all of the competency subdomains. Again, this indicates that training others had a positive impact for those individuals. Learning theories have previously identified the positive impact learning may have on feelings of competency (Illeris, 2009; Nilsen et al., 2017). This would support the notion that the trainer role and individual approaches taken to fulfil it, increased overall feelings of competence.

Undergraduate education in FPDR did not affect perceived competency rankings, unlike its impact on the MCQ scores, suggesting knowledge is not the only factor influencing feelings of competence. Rather, competence is a highly complex concept which incorporates technical skills, knowledge, values and attributes when considered from a holistic perspective (Takase et al., 2015). This may well account for the fact that the MCQ scores did not significantly predict competency scores.

Training from an applications specialist (applications training) in FPDR, significantly affected the competency rankings in the "radiation dose" subdomain. Participants indicated higher perceived competency if they had received this type of training ($p = 0.003$, $\beta = 0.37$). This may reflect the fact that FPDR allows for reduced levels of radiation exposure compared to CR and F-S systems. As such the participants may have felt that the training supported their ability to keep doses as low as reasonably achievable. Similarly, manufacturer training in FPDR demonstrated borderline significance in the "using existing equipment" subdomain ($p = 0.078$, $\beta = 0.25$) Conversely, manufacturer training in CR was seen as a negative predictor of perceived competency in the "total competency" domain ($p = 0.025$, $\beta = -0.29$) and all the competency subdomains. My results suggest that MITs who had received this type of training, were aware that their knowledge of CR systems would not fully translate to the FPDR technology they were predominantly using, given that FPDR is being used to replace CR equipment over time (Korner et al., 2007; Lehnert et al., 2011).

The number of training hours was only seen to have borderline significance in the bivariate analyses i.e. $p = 0.051$, for those participants who had 4-15 hours training in FPDR. This group achieved a lower median score in the *"using new equipment immediately post training"* survey item.

Factors linked to radiation dose

A number of statements relating to radiation dose were seen to be negative predictors of competency in the "total competency" domain, "radiation dose" and "image quality and image evaluation" subdomains.

Participants identifying *"inconsistent departmental standards increase dose in CR"* was a negative predictor of perceived competency in the "total competency" domain ($p = 0.010$, $\beta = -0.32$) and the "radiation dose subdomain" ($p = 0.040$, $\beta = -0.25$). This may reflect the issues which have been previously identified in regard to EI variability in CR and FPDR systems, most notably between different manufacturers or in equipment retrofitted with a CR system (Erenstein et al., 2020; Jamil et al., 2018; Mothiram et al., 2014; Scott et al., 2016). Compounding factors also include hybrid departments which utilise both CR and DR systems (Tonkopi et al., 2012) or inconsistent feedback from radiologists (American College of Radiology, 2017; Morrison et al., 2011). However, the broad framing of the statement did not allow me to fully explore what these inconsistences were. For example, they could be related to MIT practice and exposure factor selection (Darcy et al., 2015), image acquisition (Snaith et al., 2019), variable decision making when determining whether to repeat or reject a film (Atkinson et al., 2019), or variation in departmental protocols (Al-Murshedi et al., 2020).

In future research, as well as providing the ability to include more detailed answers, consideration should be given to the fact that very few of the participants (18%) were utilising CR more than half of the time. Additionally, the use of CR in imaging departments is continuing to decrease over time. Therefore, if the cross-sectional survey were to be repeated it might be beneficial to only ask questions relating to CR for those participants who were using the equipment more frequently, as feelings of competency and levels of knowledge may diminish over time.

The influence of radiologists on radiation dose was seen as significant. Indicating *"radiologist preferences increase dose in FPDR",* was a negative predictor in the "radiation dose" subdomain ($p = 0.005$, $\beta = -0.38$). The influence of radiologists on the setting of exposure factors by MITs, has been previously identified as a cause of increased radiation dose (Morrison et al., 2011). Morrison et al. identified that this was due to some radiologists focussing on noise levels in images rather than patient dose, making it more difficult for MITs to reduce exposure settings. Additionally, it was linked to inexperienced radiologists requiring "textbook images" which encouraged the taking of repeat images and therefore increased patient dose. Morrison et al. also identified that receiving timely feedback about image quality and radiation dose was important from an MIT perspective. However, opportunities to receive this have diminished due to radiologists working off-site. It is likely that my participants had experienced similar issues to those identified by Morrison et al., and this adversely affected their perceived competency in the "radiation dose" subdomain.

In the "image evaluation and quality" subdomain indicating a *"lack of exposure charts increases dose in FPDR"* was statistically significant (p = 0.002, β = -0.38). When using digital technology, MITs need to be fully aware of the impact of exposure factor choices (Mothiram et al., 2014), not only on patient dose, but also in relation to image quality. MITs use exposure charts to determine the most appropriate exposure settings for their patients and have been identified as one way in which to reduce exposure creep. They can be used in conjunction with EI values to determine whether an image is effectively exposed (Andriole et al., 2013). Effective exposure not only ensures minimal radiation dose to the patient but underpins the diagnostic quality of the image. The statistical significance of this statement on feelings of competency was not surprising given that best practice guidelines in digital imaging indicate exposure charts should be available, regularly updated and applicable to a wide range of patients (Herrmann et al., 2012). Furthermore, the provision of standardised protocols, as well as exposure charts, has been recommended to support MITs to adhere to the ALARA principle (A. K. Jones, Ansell, et al., 2015; McFadden et al., 2018).

Given that the level of education and training hours were not significantly associated with self-competency rankings in the linear regression model, it is interesting to consider what MITs draw on to evaluate their competency. It is possible that clinical practice and personal experience (i.e. experiential learning) is more formative to self-evaluation of perceived competency levels, than underpinning theoretical knowledge. Indeed, the highest competency rankings were noted for clinical skills that are used in daily radiographic practice such as "*reviewing the image in relation to the patients' clinical indications*" and "*adjusting exposure factors to suit the patients' body habitus"*. This supports and builds on previous assertions that high levels of MIT confidence are associated with activities "embedded within the daily routine practices" (Seeram et al., 2015, p.9).

The significance of accurate self-review can be related to the renewal of annual practising certificates. Renewal is dependent on NZ MITs supplying evidence of clinical hours, CPD activities and self-reflective practice (The New Zealand Medical Radiation Technologists Board, 2020). MITs are advised to use a planning cycle to help identify training needs, two components being a "contextual analysis" and a "needs and goals analysis" (The New Zealand Medical Radiation Technologists Board, p. 14). The "needs and goals analysis" supports Eva & Regehr's (2005) assertion that utilising external feedback is more effective at determining knowledge gaps, than an individual's self-evaluation. However, the "contextual analysis" relies on the practitioner's ability to ascertain their CPD requirements to ensure their practice is current. The high rankings of perceived competency the participants identified, implies that their assessment of relevant CPD activities may not be accurate. My findings suggest that MITs may need additional methods to determine their knowledge gaps, particularly as these gaps may impact on both competency and patient service provision. It would be beneficial for future research to explore how MITs determine their competency levels, the factors which may lead to inaccurate self-evaluation, and whether competency can be determined through alternative approaches.

My findings indicated there were multiple factors which affected the participants' knowledge and perceived competence in the use of digital technology. Training others increased feelings of perceived competency in all areas, and applications training in FPDR was a positive predictor for the "radiation dose" subdomain. Conversely, manufacturer training in CR was a negative indicator of perceived competencies in the total competency and all subdomains. Some statements linked to medical imaging departmental processes and protocols were negative predictors for perceived competency. These outcomes suggest the critical nature of effective training on feelings of competency, while indicating multifactorial influences on perceived competencies, some of which may not have been identified previously. These findings build on the findings of Seeram et al., (2015), who in their non-interventional quantitative survey on MIT knowledge and confidence in using CR systems, found no correlation between "*age", "education level", "years since qualification", "type and hours of CR training and education",* and feelings of confidence using CR technology.

8.4 Summary

This phase of the research demonstrated a disconnection between MITs' knowledge of digital imaging systems and their perceived competency levels. The participants ranked their competencies highly although this was not supported by the level of knowledge demonstrated. This is concerning because it is essential for MITs to maintain competency through ongoing education or training (Moolman et al., 2020). In NZ, this is evidenced through practitioners identifying their individual learning needs and undertaking relevant CPD to maintain an annual practising certificate (The New Zealand Medical Radiation Technologists Board, 2020). The high levels of competence selected could suggest that the participants overestimated their abilities and may not have considered their practice needed additional underpinning theory. Alternatively, MITs may be using other aspects of their practice, such as previously taught theories and routine clinical decision making, when ranking their competency levels. While this in itself would not necessarily be problematic, the different nature of digital imaging systems in terms of image capture, response to radiation and image display is known to have led to increased patient dose (Hayre et al., 2017; Honey & Hogg, 2012; Johnston et al., 2010). Therefore, having a good foundational knowledge of digital imaging systems is key to ensuring MITs are able to meet the ALARA principle. Overall, it was evident there were multifactorial influences in the way the participants perceived their competencies, which aligns with previous research (Andersson et al., 2012b; Vanckavičiene et al., 2017). However, my study explored this in relation to imaging technology use and has therefore added a new perspective.

A lack of MIT knowledge about digital technologies has been previously identified in the research (Hayre et al., 2017; S. Lewis et al., 2019a; Seeram et al., 2015). My study has provided findings which support this but have added another dimension. I had hypothesised that those MIT's who learnt about FPDR or CR in their undergraduate programme, received training in these technologies, and spent more time using this equipment on a weekly basis, would demonstrate higher levels of digital technology knowledge. My findings have highlighted that undergraduate education in FPDR technologies supported MIT knowledge, whereas applications training in FPDR had a negative effect on MIT knowledge. This suggests that the pedagogical approach used may not be effective. It may be beneficial to review the learning theories that manufacturers and their application specialists utilise to support the introduction of new technology in the future. While it could be argued that other factors such as the number of available training hours would also influence MIT knowledge, this was not demonstrated in my study.

The results of this phase reveal some variability in medical imaging practice across participants. The findings suggest best practice guidelines were not always adhered to, which may have additionally influenced the radiation protection measures the participants adopted. Overall it emphasises the need for undergraduate curricula to review their content to remain current and reflect new technologies. There is also a significant requirement for manufacturers and imaging departments to ensure that new technology training is pedagogically sound, reflects the needs of the learners, incorporates underpinning theory as well as practical applications, and is offered on an ongoing basis.

In the following chapter, I present a synthesised discussion of my findings, together with: strengths and limitations of my research study; recommendations; and my conclusion.

Chapter 9 Synthesised Discussion and Conclusion

9.1 Introduction

In this chapter I consider how the integrated findings of my doctoral research contribute to knowledge and practice. This sequential exploratory mixed methods study, exploring MITs' experiences of the introduction and ongoing use of new technology contributes a) new knowledge supporting MIT clinical practice; b) key insights regarding the introduction of new technology into practice. These insights have practical utility and the potential to meaningfully impact on the introduction of new technology in the future. This is the first study to explore the experiences of MITs regarding the introduction and ongoing use of new technology in Aotearoa New Zealand.

The introduction of digital technology has provided some benefits, such as making tele- radiology possible, increased speed in image acquisition and diagnosis, plus the ability to manipulate and enhance images to improve their diagnostic quality (Gibson & Davidson, 2012; Goske et al., 2011; Moodley & Moodley, 2015; Wani et al., 2019). MITs are also less likely to repeat images due to incorrect exposure choice (Nol et al., 2006). However, my findings demonstrated that the introduction of digital technology has also had some unintended effects. It has affected participating MITs' clinical practice and the provision of effective patient care. Underlying the introduction of the new technology, was an apparent undervaluing of the significance of the transition, which appeared to influence the educative processes adopted. This, in turn, led to a theory-practice gap. Despite the cited benefits of digital imaging technology, some of the underlying complexities and tensions that exist within medical imaging practice were exacerbated through its introduction. Consequently, this appeared to have a negative impact on quality care provision.

The apparent influences on patient centred care are considered in more depth in the section below in relation to: quality of care; the theory-practice gap; the potential to increase patient radiation dose; and communication challenges. The impact digital technology seems to have had on MIT professional identity is also reviewed in this chapter.

9.2 Patient centred care

Patient centred care can be described as a model which recognises patients as individuals, provides individual tailored care plans and engages them in their treatment decision making process (Calisi et al., 2016; Hyde & Hardy, 2020). Patient centred care may therefore lead to improved quality and safety; better patient health outcomes; and higher levels of patient satisfaction (Calisi et al., 2016; Itri, 2015; Lathoura et al., 2020).

Medical radiation technology is identified as “a patient centred profession” incorporating medical imaging and radiotherapy (The New Zealand Medical Radiation Technologists Board, 2018, p. 36). It is therefore unsurprising that current research and regulatory boards continue to promote the need to adopt patient centred care in medical imaging both in NZ and overseas (Harding et al., 2020; Hyde & Hardy, 2021b; The New Zealand Medical Radiation Technologists Board, 2018). MITs may demonstrate patient centred care through placing the patient at the centre of their practice, practising safely, while exhibiting compassion and empathy (Calisi et al., 2016).

Patient centred care should encourage MITs to reflect that any and every imaging examination is one step in a patient’s health journey, as patients try to make sense of that journey and what it means to them (Makanjee et al., 2020). My findings indicated the introduction of digital technology had compounded known difficulties in providing patient centred care in medical imaging. These issues have been previously linked to MITs focussing on the resultant image rather than the patient (Reeves & Decker, 2012), or an emphasis on meeting targets in a cost driven market (Hendry, 2019). Furthermore, Hayre et al.'s (2016) study on person-centred care and the use of FPDR, identified that digital technology had resulted in a time pressured environment for staff, with fast patient turnaround times and some patients ranking their experience according to the speed of the process. The concept of “speed” was reflected in my study, not only through increased MIT workload, but also in the transition process itself and through reduced patient-MIT communication. These all had the potential to adversely affect the provision of safe patient centred care.

Technology has not been identified as a barrier per se to the provision of high-quality patient centred care in medical imaging. Rather, technological advances in imaging have made, and are continuing to make, significant contributions to patient diagnosis, prognosis and treatment options such as theragnostics[22] (Bercovich & Javitt, 2018; Huang et al., 2020). Nevertheless, technology is more likely to adversely affect patient care in the context of a business driven focus on improved efficiency and throughput (Hyde & Hardy, 2021a). This aligns to previous commentary that new health IT technology needs to support a patient focused rather than task-focused approach (Ashtari & Bellamy, 2019). Accordingly, technology design and subsequent implementation need to consider and adapt to the roles and tasks of the end users (Ashtari & Bellamy). My participant narratives suggest this was not consistent with their experience. For example, many identified negative implementation processes and several revealed they had less time available to spend with their patients, due to increased workload as a direct result of the introduction of FPDR. Although increased efficiency was identified as a benefit of digital imaging, the implications for MIT workload have been only partially explored in the literature (Hardy & Harvey, 2020; Hutton et al., 2014; Price, 2009b), despite evidence indicating that MIT workload is a significant cause of stress (Lohikoski et al., 2019; Reingold, 2015; Verrier & Harvey-Lloyd, 2010). High workloads experienced by healthcare practitioners have been linked to a reduction in quality care with an increased likelihood of errors occurring and staff adopting shortcuts to complete tasks (Brady, 2017; Itri et al., 2018; Westphal et al., 2014).

The positive and negative influences of technology on patient centred care is supported by Tunlind et al. (2015), who identified that technology in intensive care wards was seen as facilitating improved patient care. The primary reason offered was that technology allowed for advanced patient monitoring, freeing nurses to focus more of their time on patient care. Impediments to effective care provision were related to physical placement of the technology or equipment failure (Tunlind et al.). Increased time for patient care resulting from the introduction of technology in critical care units, was also identified by Bagherian et al. (2016). Disadvantages were related to nurses' limited knowledge of equipment functionality and equipment reliability issues

[22] A treatment approach that combines diagnosis with therapy.

(Bagherian et al.). Technology has also been reported to improve patient care in gerontology, due to reducing the volume of paperwork nurses needed to complete (Meli et al., 2016). These studies resonate with my findings i.e. new technology has both advantages or disadvantages. My findings appeared to demonstrate alternative perspectives of the potential impact of technology on patient care compared to Meli et al. and Tunlind et al. This may be due to different perceptions about the role of technology in nursing compared to medical imaging. For example, Meli et al. and Tunlind et al. suggested nurses perceive technology as augmenting aspects of their work that would otherwise detract from patient care. In contrast, in medical imaging, the use of technology is inherent and central to MIT clinical practice and therefore plays a different role compared to nursing practice.

9.3 Quality care

Poor knowledge translation into practice, combined with an inability to utilise new technology in a safe and appropriate manner, adversely affect standards of patient care (Institute of Medicine, 2001)[23]. The six predicating factors of a quality healthcare system are:

1. Safe through avoiding patient harm
2. Effective, through the appropriate provision of services
3. Patient centred i.e. care is tailored to individual patient values, requirements, and decisions.
4. Available in a timely manner
5. Efficient
6. Equitable (Institute of Medicine, 2001).

These factors are applied to NZ healthcare systems (Health Navigator NZ, 2018) and are reflected in *Improving Quality,* a document designed to promote and support a systems approach to quality improvement (Minister of Health, 2003). Quality care in NZ is further supported by: legislation (Health Practitioners Competence Assurance Act 2003); guidance from the Health Quality and Safety Commission New Zealand (Health Quality and Safety Commission, 2016); and accreditation bodies (International

[23]The IoM is an American, not for profit independent organisation. Mandated to provide the government and the public with advice on major healthcare topics, improving health through shared knowledge.

Accreditation New Zealand, n.d.; The New Zealand Medical Radiation Technologists Board, 2018).

Quality in medical imaging is often indicated via the production of high-quality diagnostic images which support clinical diagnosis or the review or management of a pathological condition. To accomplish this, MITs must meet specific knowledge outcomes including: "patient care, patient positioning, imaging physics and technology, anatomy and physiology identification and assessment, bioeffects and radiation safety, clinical and organisational responsibility for the examination, and quality assurance" (The New Zealand Medical Radiation Technologists Board, 2018, p. 36).

MIT professional values encompass the provision of safe, high-quality and ethical care (A. Brown, 2004; Nortjé & Hoffmann, 2018). To achieve these, MITs need to have developed the required professional knowledge. Providing the appropriate standard of patient care, required my participants to learn about functionality and safe application of the equipment, during the transition to digital technology. Effective training and knowledge transfer is identified when the recipients demonstrate successful and ongoing application of knowledge and skills attained over a period of time (Gitonga, 2006). The successful acquisition of knowledge is dependent on a number of factors, which include the work environment, the pedagogical approach, plus the time to absorb theoretical and attempt practical components. My participants suggested these factors were overlooked when their departments transitioned to digital technology. This culminated in an apparent theory-practice gap for my participants, which seems to have impacted on patient safety.

9.3.1 The theory-practice gap

Baird (1996) identified that MITs use academic, practical, and experiential knowledge in their clinical practice. The context of the theory-practice gap relates to an apparent lack of academic knowledge related to digital imaging systems.

Both phases of the research indicated limited theoretical knowledge of fundamental concepts in digital imaging such as: the principles of digital image acquisition and processing; digital image characteristics and image manipulation; and EI values. This supports previous research which has indicated MITs have less knowledge than is required or desirable in this area (Alsleem et al., 2019; S. Lewis et al., 2019a; Morrison et al., 2011; Seeram et al., 2015). For example, the study by Seeram et al. identified MIT training and education in CR systems was lacking and had created specific knowledge gaps. They identified the training method and hours of education and training, did not influence feelings of competency. Conversely my participants' narratives implied that the training method and time spent on the training process did affect them. Furthermore, the participants perceived competency in both CR and FPDR systems was affected by the type of training received. My findings build on those of Seeram et al. by providing additional insights and encompassing both CR and FPDR imaging systems.

The theory-practice gap in my research seemed to be linked to the participants' experiences of: the implementation process during transition; pedagogy; a shared language during training; their perceived competence.

The implementation process

My research demonstrated the knowledge MITs gained was potentially affected by the implementation process, which participants perceived underestimated the significance of the transition. This, combined with workplace culture and the resource constraints facing the health care sector, was perceived to influence the training experienced by participants. This was exemplified by the speed of the transition and difficulties accessing training due to shift work for example. These factors have been previously identified as creating feelings of reduced self-efficacy for MITs when new technology is introduced into imaging departments (Watson & Odle, 2013).

Those participants who transitioned from F-S to CR, and subsequently CR to FPDR, identified a reduction in total training hours for the second transition (as highlighted in Chapter 5), also indicating the significance of the changeover was underestimated. The adoption of technology within organisations has been reported as challenging and “a complex socio-technical intervention” which may result in adverse patient events if not implemented effectively (Ingebrigtsen et al., 2014, p.395). The notion that the implementation of clinical healthcare technology is a multi-faceted process which should not be underestimated, is supported by Harvey et al. (2018). Collectively, this highlights an effective and well-structured implementation process is critical for successful integration, as well as patient safety. However, it was not evident that my participants had experienced this type of implementation.

The impact of strategic and organisational decision making throughout the implementation process, from investment to utilisation, determines the success of the adoption process (Avgar et al., 2012). Successful implementation is also dependent on understanding the context in which the technology will be introduced (Khalil, 2016), highlighting the role of leaders at all levels in the process. At a departmental level, leaders need to support implementation through effective communication, sufficient training, and ongoing staff support. Specifically, training requires adequate investment and resourcing, to ensure staff have time to attain and maintain the required skills and that staffing levels permit release for training (Ingebrigtsen et al., 2014). Furthermore, challenges faced by healthcare staff when adapting to the ongoing use of new IT applications have been linked to insufficient training; the need for ongoing technical support; and workload issues; with training identified as the main influence on staff performance (Ashtari & Bellamy, 2019). Although Ingebrigtsen et al. and Ashtari & Bellamy were discussing the implementation of IT healthcare technology, the principles may be applied to other technologies. There was no suggestion from my participants that there was a lack of support from their team leaders. Nevertheless, they recognised their training process was limited due to a lack of time and accessibility. Furthermore, additional training post-implementation was minimal and relied on informal approaches to superusers or applications specialists, which arguably all signal that the leadership did not appear to prioritise these processes. The participants' experiences of the training process are considered in greater depth in the following sections.

The need for effective implementation strategies when introducing technology, has been identified previously, predominantly in relation to health IT (Avgar et al., 2012), or patient equipment i.e. medical technology (Harvey et al., 2018). However, the influence of implementation procedures on the introduction and ongoing use of new medical imaging technology has not been considered previously. Furthermore, my findings suggest that further in-service or professional training regarding FPDR would be of value. As such these are new findings which can be used to support the future introduction of new technology within medical imaging. This is significant given the way in which medical imaging technology systems are continuing to advance (Munn et al., 2020; Žunic, 2019).

Pedagogical approach

The requirement for pedagogically informed approaches to MIT training which encourage and support critical reflection, was identified by Larsson et al. (2009). Different educational approaches are therefore required which consider the individual needs of the learners. While the perspectives of individual trainers, and their knowledge of education theory was not explored, two of the three superusers interviewed identified they had no knowledge of learning theory. The other superuser had previously been a medical imaging lecturer and had acquired this knowledge by virtue of that role.

Overall, the participants' experiences suggested trainers adopted a behaviourism or rote teaching approach which was task-focused, and one which did not support critical thinking or problem solving (Clark, 2018). It is possible that the trainers' lack of formal understanding of educational theories, alongside a "one-size-fits-all" approach, contributed to this teaching technique and therefore knowledge acquisition outcomes. Conversely, it could be argued that the focus of "training" is on results (or task completion), whereas the aim of "education" is the development of knowledge (Vassallo, 2005). In this sense, applications or superuser "training" would not be expected to provide underpinning theory, given the purpose would be to enable trainees to successfully complete tasks, i.e. the provision of practical rather than academic knowledge. My participants' experiences would seem to support this differentiation between training and education. They felt equipped to complete the imaging process, albeit with a lack of underpinning theoretical knowledge. Nevertheless, despite the argument that medical imaging is a task driven process, quality care relies on practitioners having the necessary academic knowledge as previously discussed. Future research evaluating the role, and expected outcomes, of practitioner training in the implementation of new technology, may be beneficial.

The influence of instructors in knowledge translation has been discussed in the literature previously, although not in relation to systems application training in medical imaging. While previous research has tended to focus on clinical or practice educators, similarities may be drawn with my study. For example, the difficulty in undertaking dual roles as a practitioner and an instructor has been identified as impacting on student knowledge (Towns & Ashby, 2014). The superusers in my study had dual roles when working as trainers. Although applications specialists are employed by equipment manufacturers to support the integration of technology into imaging departments, they are sometimes considered part of the vendors' sales force. As such they may be viewed as having competing roles i.e. that of a salesperson as well as that of a trainer.

The inability for trainers to effectively articulate their knowledge, and demonstrate how knowledge was embedded within their own practice, are issues associated with undertaking dual roles (Towns & Ashby, 2014). These inabilities may lead to trainees having reduced trust in the instructor. Reduced levels of trust are also experienced if trainers present information which does not seem to be based on underpinning theory. Although Towns and Ashby's study related to the influence of practice educators on occupational therapy students, there are clear links to the experiences described by some of my participants. For example, some of the MITs revealed they did not trust what the trainers were telling them, especially when it contradicted previously learnt theoretical principles. Their distrust was compounded when differences in language were experienced.

Language

The trainers' professional backgrounds impacted the way information was delivered, not only from their own knowledge base but also from a language perspective. My findings indicated that the language used by the applications specialists was not always understood or did not seem related to a priori knowledge. A shared language can increase the integration of information and build knowledge concepts (Tamjidyamcholo et al., 2013). Furthermore, shared language supports meaningful dialogue through a shared context i.e. a shared language allows individuals to access, gain and share information with others (Nahapiet & Ghoshal, 1998). This would seem to support my findings, as my participants indicated they had difficulty comprehending some of the terms the applications specialists used or the meanings they ascribed to them. Not only did this appear to impact on the participants' learning, but it also influenced their perception of the trainer and whether their knowledge was trustworthy.

Participants indicated they felt more at ease with trainers who were MITs, reflecting not only a common language and understanding, but also the influence of professional culture on their level of engagement i.e. whether they viewed the applications specialists as being "one of their own". Korica & Molloy (2010) discussed the influence of inter and intra-professional relationships on the successful integration of new technology within the surgical environment, while Karahanna et al. (2005) recognised the influence of professional culture on task-focused competencies. Professional culture has been shown to influence safe practice within healthcare, especially because clinical practice is affected by enculturation into the accepted behaviours, practices and values of a professional group (Machen et al., 2019). The findings of Korica & Molloy and Karahanna et al. would seem to support the suggestion that my participants' experience of the transition was predominantly managed through relationships.

Evaluating Perceived Competency

As shown in Chapter 6, there seemed to be a lack of association between theoretical knowledge and perceived competency. This was supported in the survey, with participants reflecting high feelings of competency, despite low levels of knowledge in several areas. Knowledge gaps can only be addressed if MITs identify there is a need for additional understanding. This is generally achieved through self-reflection and feedback (Larsson et al., 2013). Self-reflection is also used as a way to measure and establish competence (Tan et al., 2012). Competency linked to self-reflection has been considered by many researchers including Ruona & Gilley (2009), who identified four types of practitioner, ranging from atheoretical to scholar practitioners (p. 441). They identified that a reflective practitioner is one who meets the practitioner requisites (i.e. has the required entry standards to the profession and participates in ongoing learning to update knowledge) and who also critically evaluates their practice, basing decisions on where to improve, from research and evidence-based practice. MITs are one of a number of health professions who are required to undertake self-reflective practice to maintain professional registration status (The New Zealand Medical Radiation Technologists Board, n.d.). Although the benefits of self-reflection have been identified in the literature (Baird, 2008; Sim & Radloff, 2009; White, 2003), there seems to be little evidence identifying barriers to reflective practice. Nevertheless, a lack of training, limited skills and experience, high workload demands, and insufficient time have all been highlighted as impacting on the ability to self-reflect (Cashell, 2010; Miller, 2020). These barriers can create a risk the practitioner will revert to previous practice habits which may not reflect evidence-based theory (Tan et al., 2012). As my participants identified limited training and increased workloads following the introduction of digital technology, it is not unreasonable to suggest these impacted on their ability to self-reflect regarding the application/use of new technologies.

A lack of effectual self-reflection and feedback may result in underlying practice issues remaining undetected and unresolved (Larsson et al., 2009). My findings highlight participants felt their level of knowledge was adequate for them to perform their role. Aside from increased workload negatively influencing self-reflective practice, other reasons for non-identification of knowledge gaps may include:

- Participants determining competency from routine aspects of their work, such as patient positioning, which have not changed significantly following the introduction of digital technology. This supports the idea that MITs adopt a task-focused approach to their work, with their focus primarily on the resultant image (Strudwick, 2011). Task based behaviours and acquired (experiential) informal knowledge may be used by health professionals as a means of self-evaluating competence rather than underlying theoretical knowledge (Castillo et al., 2011). This is also demonstrated through the utilisation of unconscious habitual behaviours within the clinical environment (Andersson, Christensson, Jakobsson, et al., 2012). This is problematic as it reduces competence to simply representing an individual’s capability to demonstrate or complete a task. Limiting competency to the successful completion of a task’s technical aspects ignores the humanistic components of care (Castillo et al.). This reductionist approach has been identified in medical imaging practice, where patients may be classified according to the body part under investigation and reflects the process driven nature of medical imaging practice (Strudwick, 2016).
- The participants revealed departmental CPD opportunities were not focused on equipment use. Therefore, they may have remained unaware of any potential

gaps in their knowledge. This would seem to be supported by a known MIT reliance on their own clinical expertise, advice from colleagues, and departmental protocols, rather than research when justifying clinical decision making (Di Michele et al., 2020). My experience presenting my initial study results at an NZIMRT study day resonates with Di Michele et al.'s findings. Following the presentation, several audience members identified my findings had reflected their own personal experiences. They had come to the realisation they needed to undertake CPD to increase their knowledge of digital imaging systems. However, prior to this event they had been unaware of any potential gaps in their knowledge.

- Participants reported increased isolation from peers and radiologists resulting in a reduced level of feedback, consistent with previous findings (Fridell et al., 2008). Feedback supports self-reflection by providing information which the recipient can analyse and draw on to identify learning needs (Embo et al., 2010). Feedback from radiologists has traditionally focused on image quality (Atkinson et al., 2019; Fridell et al., 2008), whereas feedback from peers can be acquired on multiple aspects of practice through informal conversations, role modelling and observation (Takase et al., 2015). As such, peer feedback may provide additional insights into an individual's clinical practice (Takase et al.).

Feelings of competency and associated knowledge of digital imaging systems has not been evaluated previously. Findings from my research, provide new insight into these aspects of MIT practice. My findings show that the task-focused nature of medical imaging, the way in which digital technology has been introduced, plus unforeseen changes this technology has created, may have reduced practitioners' awareness of and the significance of gaps in their knowledge. MITs' perceived high levels of competence which do not correlate to foundational knowledge of digital imaging systems has important implications for clinical practice.

9.3.2 Increased radiation dose

Fundamental responsibilities within medical imaging include knowledge of the radiobiological effects of radiation and the application of radiation protection measures for patients (Frush et al., 2013). Radiation safety in medical imaging is predominantly achieved through the safe use of equipment and applying the ICRP tenets of justification and optimisation (Schultz et al., 2016; Valentin, 2004; Vano, 2007). Optimisation should cover all components of the imaging process to support the ALARA principle (Uffmann & Schaefer-Prokop, 2009).

My research identified that despite the promoted benefits of a reduced patient radiation dose with digital technology, participating MITs did not seem to be strictly adhering to the ALARA principle. This was indicated by several factors, including a lack of understanding and appreciation of EI values, and therefore correct exposure techniques. These, plus the inherent vagaries of EI calculation have been discussed previously in the literature (Erenstein et al., 2020; Moore et al., 2012; Mothiram et al., 2014). The adoption of a standardised EI system was intended to overcome some of the confusion created by manufacturer specific EIs and allow MITs to better appreciate under or overexposure on their images (Mothiram et al., 2014; Seeram, 2014). My participants appeared to be confused about how EIs are calculated and the factors which influence EI values. In some cases, they questioned the relevance of EI values to clinical practice. Concerningly, it resulted in some of the MITs continuing to rely on the visual appearance of their images to determine whether the exposure was correct or not, despite evidence indicating this is neither appropriate nor good practice (Benfield et al., 2020; S. Lewis et al., 2019b; Moore, 2016). The apparent lack of undertaking of EI values and the potential to use higher exposure factors than necessary, support the concept that confusion around correct exposure techniques is a significant factor in increased patient radiation dose following the move to digital imaging systems (Moore, 2016).

My participants identified that “exposure creep” remained a concern associated with the introduction of digital imaging. Furthermore, issues such as “collimation creep” and the ability to easily repeat images, may also contribute to increased patient radiation exposure. Both “exposure creep” and “collimation creep” have been identified in the literature as problematic (Alsleem & Almohiy, 2018; Gibson & Davidson, 2012; Tsalafoutas, 2018). Associated with these, is the risk that accepting small increases in patient dose eventually becomes embedded within MIT practice (Hayre et al., 2017). Digital technology has facilitated repeat imaging (Hayre et al.), however the ease of repeating an image to improve perceptions of competency as described in Chapter 6 does not seem to have been previously reported. This finding supports and builds on Strudwick's (2014) findings that MITs take ownership of their images with resultant criticism taken personally and viewed as a judgement of their ability.

The introduction of digital technology has resulted in reduced patient dose through more efficient detector systems and a wide exposure latitude (Lança & Silva, 2013). However, the issues identified within my research and recent literature were not predicted prior to its introduction.

9.3.3 Communication

The safe use of protocols and equipment is essential in the provision of patient centred care. However, patient centred care also relies on MITs having time to communicate effectively with patients and respond to any queries or fears (Carlsson & Carlsson, 2013; Henwood & Munro, 2013). Effective communication, imaging availability and reduced wait times are associated with patient satisfaction (Hayre et al., 2016; Mount, 2016; Odle, 2019). The introduction of digital imaging systems has been cited as improving patient satisfaction, particularly in relation to accessibility and wait times (Hayre et al.). However, patients have also indicated that the interaction they have with MITs during imaging procedures is a main determinant of quality care provision (Hyde & Hardy, 2020).

Communication skills which engender trust in the patient and their family, is a required competency for MITs working in NZ and Australia (The Medical Radiation Practice Board of Australia, 2014; The New Zealand Medical Radiation Technologists Board, 2018), as well as being necessary to meet legislative requirements such as informed consent (Health and Disability Commissioner (Code of Health and Disability Services) Regulations, 1996; Pollard et al., 2019). Trust between patients and MITs is critical in enabling patient centred care and the provision of professional standards of care (European Society of Radiology & European Federation of Radiographer Societies, 2019; The Medical Radiation Practice Board of Australia, 2014). The need to physically touch and manipulate the patient is necessary to achieve a diagnostic image, and this requires patient trust in the MIT (Reeves & Decker, 2012). The ability to communicate effectively and build trust is inevitably affected by the time available for the event. The term "hit and run carer" has been used to describe MITs and reflects the limited time

MITs interact with their patients, who they are unlikely to meet again (Reeves & Decker, 2012). Time pressured medical imaging environments have been recognised as promoting a culture of parental or practitioner focused communication styles, which do little to promote patient autonomy and the principles of patient-centred care (Bolderston, 2016; Booth & Manning, 2006). Although not specifically identified by my participants, it is possible they were also adopting these types of communication styles due to increased workloads and less time to communicate with patients than previously.

MIT-patient communication is complex within the medical imaging environment due to patient concerns related to the technology and also the outcome of the imaging process i.e. diagnosis and what that may entail (Makanjee et al., 2015; Watson & Odle, 2013). High technology environments can also result in patients' feeling the focus is on the equipment and the data outputs, rather than on them (Tunlind et al., 2015). This is further complicated as MITs have limited time to communicate with patients compared to other healthcare professionals (Strudwick, 2016). The need to reduce costs and waiting lists, has resulted in systems which have become task and results focused and which do not necessarily reflect the complex situations faced by staff (Crawford & Brown, 2011; Lundvall, 2019). This has culminated in staff-patient interactions which are frequently less than five minutes in duration (Crawford & Brown) and reflects the experiences described by my participants following the move to FPDR.

My participants described how digital technology had increased their workload, which coupled with a faster patient turnaround, had amplified the feeling of working on a production line. This supports other research which identified the drive for efficiencies in medical imaging, with an associated focus on reduced waiting times, has reiterated the "factory floor" approach seen in many imaging departments (Hayre et al., 2016). Despite some patients considering speed and minimal waiting times as indicators of good patient care, efficiency driven decision making has been shown to reduce the ability to provide patient centred care (Hayre et al.; Hyde & Hardy, 2021a). Adverse effects on quality care were identified by my participants i.e. increased errors due to reduced time for patient-MIT communication. For example, well-established patient safety protocols, such as patient identification, had become more prone to failure or had failed. My participants also discussed how their increased workloads had created an additional barrier to effective communication with their patients.

Communication barriers have always existed in medical imaging and may be classified as physical or time related. For example, the use of ionising radiation requires MITs to physically distance themselves from their patients. Challenges in communication may be created when physical distancing is coupled with the short period of time to interact with patients compared to other healthcare professionals (Strudwick et al., 2011). Furthermore, from a patient perspective the level of patient care provided may seem less than that of other healthcare providers, as the MIT-patient interaction is focused on the task of creating a diagnostic image (Strudwick et al.). This notion is supported by the suggestion that humanistic interactions in a medical imaging procedure are viewed by MITs as a short term goal, merely supporting the end term objective i.e. the production of an image (Reeves & Decker, 2012). These factors inevitably influence the level of rapport and trust that can be established between the MIT and the patient (Pollard et al., 2019).

Although principally based on the impact on patient communication, my participants also recognised changes in communication between MITs and radiologists had safety implications. This has been cited in the research previously, especially in relation to reduced levels of radiologist feedback on image quality due to the physical distance that frequently exists between MITs and radiologists (Nol et al., 2006). In addition, radiologists are less likely to contact MITs in this regard, due to the ability to digitally manipulate images to improve their appearance (Nagy et al., 2008; Nol et al., 2006). My participants suggested that with limited, or no feedback, there was an assumption that the processes they were adopting must be acceptable, despite their lack of underpinning theoretical knowledge. This aligns with the suggestion that when radiologists are off site, complacency may encroach into MIT clinical practice with the potential for adverse patient outcomes (Nagy et al.). Furthermore, my participants indicated that the change to digital technology presented communication challenges to effective intra and inter-professional working, which had not been evident previously. These included less opportunity for peer feedback and support and reduced opportunities for informal education from radiologists.

9.4 Professional identity

The participants suggested that the transition to digital technology had affected their professional identity, specifically relating this to MITs becoming “button pushers”. While MITs are required to press buttons during image acquisition, MITs have argued the label “button pusher” is unjustified (Collins & Nolen, 2002; Ritchie, 1958), because of its negative connotations i.e. a button pusher is defined as someone who performs menial tasks mindlessly with no or limited skills (Oxford Dictionary, n.d.). The production of radiographic images is a key component of an MITs’ professional identity. However, MITs have a unique body of knowledge which goes beyond just image acquisition (Cowling, 2008; Yielder, 2006). Therefore MITs consider themselves to have expert knowledge which allows them to take on dual roles as operators of complex technology and carers (Niemi & Paasivaara, 2007). My participants alluded to the caring aspects of their role when: a) recognising benefits to patients following the introduction of technology; and b) describing the issues they encountered relating to changes in communication and radiation protection practices. In both contexts there was an appreciation these areas had changed as a result of the transition.

The participants highlighted concerns that digital technology design created the opportunity to produce images simply though pressing a series of buttons, without the level of skill previously required. Previously, an MIT’s skill repertoire incorporated correct and accurate exposure selection and patient positioning. MITs’ professional identity is partially based on a sound understanding of imaging technology (Niemi & Paasivaara, 2007). However, my findings implied the participants' knowledge of digital technology was limited. Furthermore, the nature of the transition appeared to result in the technology being viewed as a “black box”. Consequently, some participants seemed to feel their knowledge base had been eroded and may no longer be defined as “expert knowledge”. One specific attribute associated with the classification of a profession is that the practitioners have a specialised body of discipline knowledge. However, my participants suggested this knowledge is being diminished following the introduction of new technology, which may present difficulties in classifying medical imaging as a profession. This is an issue that has been previously identified in the literature (Sim & Radloff, 2009). Furthermore, as Andersson et al. (2017) highlighted concerns that the MIT role is under threat from other health care professions, it could be posited these concerns may be amplified through simplifying the way MITs operate their technology.

New technology provides health care professionals opportunities to re-envision and redefine professional identity (Korica & Molloy, 2010). Korica & Molloy in their exploratory study, considered how senior surgeons evaluated the impact of new technology on their professional identity, and found that "insider/outsider dynamics" (p. 1884) can negatively or positively affect the ever evolving nature of professional identity. Specifically, success in new technology adoption was partially attributed to the level of engagement surgeons had in "innovation, development, and promotion of new technology" (p. 1881). Conversely, MITs work with technology which is generated and introduced into medical imaging departments, with seemingly little input from the MIT profession. As such MITs are frequently seen as "passive technicians, implementing the designs of others" (Nixon, 2001, p. 5), thus reiterating the likelihood that the transition to digital technology had a negative influence on my participants' professional identity.

MIT professional identity is not only influenced by how MITs perceive their role (Crawford et al., 2008) but also by professionalism (Sim & Radloff, 2009). The change to the working environment described by my participants may have impacted on some aspects of professionalism, two key aspects of which are self-reflection and critical thinking. Self-reflection allows MITs to review and provide new insights, into their practice while identifying areas for learning and development (Sim & Radloff). Critical thinking is a necessary attribute of medical imaging as it allows MITS to apply their knowledge to problem solve the situational challenges they may face in clinical practice (Whiting, 2009). Unfortunately, both self-reflection and critical thinking are adversely affected in the process-driven, fast-paced work environments, which were described by my participants following the introduction of digital technology. Furthermore, this technology seemed to have increased the likelihood of my participants taking a task-based approach to clinical practice, a process which is a known detractor to adopting evidence and research based practice (Whiting). These findings are concerning, considering the literature identifies the difficulties medical imaging faces in demonstrating it is an evidence-based profession (Ahonen & Liikanen, 2010; Brettle, 2020; Snaith, 2016; Yielder & Davis, 2009). All of which suggests my research findings may have wider implications for the profession.

Overall, my participants appeared to consider the transition and ongoing use of digital technology perpetuated the myth that medical imaging is merely dependent on the ability to operate the equipment. This ultimately makes the profession more vulnerable to take-over by individuals with basic skills and a limited knowledge base (Smith, 2006), and indicates the potential for adverse effects on the medical imaging profession as a whole, as well as MITs' professional identity.

In summary, my findings make visible the impact digital technology has had on MIT knowledge, workload and effective patient communication (Hayre et al., 2016; Hyde & Hardy, 2020). However, my research also revealed the impact of the transition process on MIT practice and patient centred care, that has not been explicitly discussed in previous research.

9.5 Strengths and limitations of the study

9.5.1 Limitations

There are several limitations to the research design, for example:

- It considered the experiences of MITs within a context bound environment i.e. at a specific point in time and location, indicating data differences or variability in findings, may occur if the design is replicated in the future.
- The data in Phase One and some of the data in Phase Two represents a retrospective account of the transition to digital technology and as such is potentially subject to recall bias (Althubaiti, 2016).

Nevertheless, the findings may resonate with and prove useful for other MIT practitioners, education and training providers. Limitations for specific phases of the research are considered next.

Phase One

Purposive sampling and theoretical sampling were used for this phase. Purposive sampling is considered by some researchers as being less credible than other forms of sampling due to the findings not being generalisable to the wider population.

However, Interpretive Description studies do not aim to produce generalisable findings, rather the expectation is that they will deepen the understanding of a clinical phenomenon. Although theoretical sampling has its origins in grounded theory, it can be used utilised for other qualitative methodologies (Thorne, 2016). An associated drawback with theoretical sampling is that the researcher may draw premature conclusions about their findings and consequently stop the recruitment process too soon (Thorne). Effective theoretical sampling therefore relies on the ability of the researcher to make a situated judgement on who to recruit and when to stop. I believe that my sampling strategy allowed ease of access to potential participants and enabled me to select participants who had specific experience and knowledge of the phenomenon being investigated i.e. the introduction and ongoing use of digital technology in planar imaging.

My findings for Phase One are based on a small sample of practitioners, predominantly based in the Auckland region (and an urban centre). As such they may not reflect the views of other MI practitioners in NZ, nor international MIT experiences of clinical practice. Despite the sample being predominantly from an urban environment, different perspectives were achieved through participants exhibiting variation in age, qualification, levels of experience, clinical settings, and roles. For example:

- Three MITs had worked in Aotearoa New Zealand and overseas;
- Some had worked and experienced the transition to digital technology in other NZ urban environments;
- Half the participants were working with DHBs, while others were working in private practice or both private practice and DHBS;
- Those working in DHBs had different roles and therefore their clinical context differed e.g. superuser.
- There was a mix of full and part-time workers.

Therefore, it could be suggested that the experiences described by my participants and my interpretation of that data, may resonate with other MIT practitioners.

Another limitation is that I have only considered the perspectives of MITs in my study and did not interview other professionals such as clinical managers or applications specialists. As such, while appropriate to my research question, capturing the perspectives of a more diverse range of professionals may have resulted in new or different interpretations.

It is important to note that interview data is time and context-bound and as such are inherently partial. Further, how people talk about their practice is not always reflective of what actually happens in practice. As such, these findings could be expanded by using participant observational studies (Creswell & Creswell, 2018; P. Williams et al., 2010).

Phase Two

Several limitations can be identified in Phase Two. One is related to creating a new instrument rather than using an existing pre-validated survey. This issue is principally due to the need to ensure reliability and validity. Validity of a survey can be evaluated through face, content, and construct validity. Reliability is related to the internal consistency or repeatability of the survey. Internal consistency is typically assessed through the use of Cronbach's alpha (Rattray & Jones, 2007).

The development of the cross-sectional survey was aligned to a mixed methods sequential exploratory design (Creswell & Plano Clark, 2017) and followed a sequence suggested by Rattray & Jones (2007). As described in Chapter 4, face and content validity were assessed during the design and piloting of the questionnaire, and internal consistency was reviewed through calculation of Cronbach's alpha. Although construct validity was not formally assessed, face validity is able to provide an indication as to how participants may interpret and respond to survey items. As such face validity is considered a way in which to determine construct validity (Devon et al., 2007; Drost, 2011). The processes I have described provided initial validation, although utilising the survey for different cohorts, such as international MITs, would determine whether the survey could discriminate between cohorts and add another layer of validation (Tsang et al., 2017).

Non-specificity of questions can be problematic in survey design (Pederson, 1992). While this was reviewed during the design and pilot stages, the competency statement "*evaluating the diagnostic quality of the image in relation to the clinical indications*", is rather broad and could also incorporate other aspects such as patient positioning and including the entire region of interest. Ambiguity can also prove problematic in survey design (Pederson). This was evident in my survey through the lack of a clear distinction between “education” and “training” and the inclusion of an incorrectly worded competency statement.

The sampling strategy was limited as I was unable to construct an accurate sampling frame capturing all NZ MITs who would meet the inclusion criteria, therefore probability sampling was not feasible. In quantitative research, probability sampling is generally the preferred sampling strategy, as it is considered to capture participants representative of the selected population (Creswell & Plano Clark, 2017; Ragab & Arisha, 2018). In comparison, the use of convenience (non-probability) sampling is often considered to have low credibility in quantitative research due to the arbitrary nature of participant selection (Creswell & Creswell, 2018; Flinton & Owens, 2010). As such it limits the generalisability of my findings. Despite the issues of convenience sampling, it’s use in my study also reflects the approach taken in other surveys evaluating MIT knowledge, for example Farajollahi et al. (2014); Foley et al. (2013); and Vikestad et al. (2017).

Another limitation in this phase of the research was the low response rate which resulted in a small sample size. It was not possible to accurately determine the response rate, as the number of NZ MITs who work in planar imaging 50% of the time and are members of the NZIMRT, is not specified. Therefore, the response could only be estimated. Low response rates are linked to the use of questionnaires and may be as low as 20% (R. Kumar, 2014). My approaches to improve the response rate are described in Chapter 4. The low response rate did not necessarily result in non-response bias (Sax et al., 2003), as the sample characteristics of the participants seemed to reflect the NZ MIT population and general assumptions that could have been made about them.

Risks associated with small sample size are that the sampling error may be increased; and Type II errors may be inflated due to insufficient power (Pallant, 2016). My cross-sectional survey had a dataset of 49 participants, and the power value of a study with 50 participants is calculated to be 0.70 (Cohen, 1977, as cited in Stevens, 2009). Lomax (2013) indicates that while many disciplines use a power value of 0.80, a value of 0.70 is also acceptable. Further, Stevens (2009) indicates that setting the alpha value to

0.10 is reasonable in cases where sample sizes are low. Therefore, results which were seen to be between 0.05 and 0.10 were classified as having borderline significance. Although the sample size was limited it was felt that the number would provide sufficient data for this second phase of the study (Nulty, 2008), particularly in a mixed-methods study, which provides opportunities for quantitative results to support the qualitative findings and vice versa (Creswell & Plano Clark, 2017). Nevertheless, generalisation of my research findings is limited due to the small sample size. Further, my participants were practitioners based in NZ and members of the NZIMRT. As such, they may not reflect other MI practitioners both in NZ and overseas.

Although high ranking competency scores were evidenced in my survey, I feel that some variability could have been missed at the high end of the scale, indicating potential ceiling effects, due to using a five scale rather than a ten scale rating. My approach was validated by my expert panel (as indicated in Chapter 4) and reflects other studies which have used a five point competency ranking scale (Huenges et al., 2017; Seeram et al., 2015). Nevertheless, a ten point scale may have allowed the participants to make more subtle distinctions between high and good levels of competency for example (Krosnick & Presser, 2010).

9.5.2 Strengths

I utilised a mixed methods exploratory sequential design, which was congruent with the pragmatic paradigm and the research question. Initially the approach allowed me to consider the experiences of the transition to digital technology from the MITs' perspective. I was then able to use this data to support the development of a survey. A sequential exploratory design is particularly suited to support the creation of an instrument where none is available, as was the case for my research (Creswell & Plano Clark, 2017).

In Phase One, a small number of participants were selected through purposeful and theoretical sampling, to provide rich and detailed information about their experiences. Interpretive Description allowed me to focus the research question and subsequent process on clinical practise (Thorne, 2016) and created findings which are pertinent to clinical practice (Hunt, 2009). The potential for naturalistic generalisability may be seen through feedback from the study day audience members (as described earlier in this chapter) and through conversations with colleagues during the research process, in which they identified similar experiences to those identified (B. Smith, 2018).

In Phase Two, the use of a cross-sectional survey allowed me to identify the key variables which influenced NZ MITs knowledge and self-ranked competencies relating to CR and FPDR technology.

This research has contributed to a wider understanding of how the transition to digital technology has influenced medical imaging practice in NZ. It has provided new insights and expanded the body of knowledge relating to the introduction and use of digital medical imaging technology.

9.5.3 Implications for clinical practice

The potential impact of new technology on medical imaging practice has not been considered from the MIT perspective previously. Research has focused on failings in MIT practice post-transition to the digital environment, but not evaluated some of the reasoning behind this. I have identified that underestimating the significance of this change was a major contributing factor in a theory-practice gap. This gap is not necessarily apparent to MITs, although they recognise it has some impact on clinical practice. The provision of high-quality patient centred medical imaging requires practitioners to be adequately trained to use technology safely. It is clear the issues and concerns I have identified have implications for patient safety, and reveal a need for further MIT education in the area of digital imaging. As the protection of the health and safety of the New Zealand population is the primary function of the NZMRTB, I will be seeking the opportunity to present my findings to them, and to best determine how to support the professional development of the NZ MIT workforce.

Furthermore, the introduction of new technologies in the future need to consider the way in which the transition to new technology is managed and effectively resourced:

- clinical managers may need to consider incorporating staff release into their business plans;
- trainers, whether applications specialists or superusers, need a grounding in educational theories and learner requirements, as well as having a good understanding of the technology.

It was clear from my study that learning theory as well as a planned change management process would be beneficial in supporting successful transition. While it is not possible to predict every eventuality post-transition, utilising an evidence-based approach prior to integration, coupled with regular post-transition service reviews may allow for action to be taken to remediate any issues.

9.5.4 Implications for education

Linked to the implications for clinical practice, recommendations for education relate to overcoming the theory-practice gap. The areas that are key to supporting MITs in their understanding of digital technology, relate to the physics of digital detectors in regard to: image acquisition, formation, and display. This is coupled with exposure and image quality control in digital imaging. The provision of micro-credentialled short courses may be a way to support this. However, as previously stated it is important that any training provision is delivered by individuals who comprehend digital imaging technology and who have a shared understanding of medical imaging practice with their trainees. Knowledge of a range of adult learning theories, such as transformative and social theories of learning, including their application and limitations is important, as it will allow instructors to adopt the most relevant educational approach to meet their learners' needs (Mukhalalati & Taylor, 2019).

The future introduction of new technology, needs to be resourced appropriately to enable effective training to be provided. While education providers may support future graduates by ensuring their curricula are current, technological expansion in the more specialised modalities, such as hybrid imaging, may rely on in-house training provision from superusers or applications specialists.

9.5.5 Implications for research

As indicated previously, expanding the research to include other perspectives such as those of clinical managers and applications specialists, would allow for increased understanding of how the transition was perceived by other professionals. Repetition of the survey with a larger sample size, perhaps including Australian MITs, would provide an International perspective, and potentially capture different imaging systems and clinical environments. This would provide an opportunity to expand my study. Similarly, utilising participant observational studies would provide an opportunity to expand my study within the Aotearoa NZ context.

My research determined that MITs ranked their competencies highly despite an apparent theory-practice gap. Research investigating how MITs evaluate their competency levels and whether this is linked to self-reflection would be beneficial, particularly as the self-reflection process is often key in determining the need for additional learning and professional development requirements.

Other research activities could incorporate an evaluation of the effectiveness of an educational intervention designed to support MITs' knowledge of digital imaging systems.

9.6 Conclusion

The overall aim of this thesis was to answer the following research question: **"How has the introduction and ongoing use of digital imaging technology affected MITs in Aotearoa NZ?"** The aim was subdivided into two phases, each with a specific objective, to:

1. Explore MITs' personal experiences of the introduction and ongoing use of digital technology, and its perceived impact on practice.
2. Describe and identify factors relating to MITs' knowledge and understanding of digital imaging and its application, as well as their perceived competence in using digital technology.

Phase One revealed the transition to digital imaging had been undervalued, and had created several unforeseen consequences. These exacerbated some of the existing tensions and complexities of medical imaging technology and ultimately resulted in a shift in medical imaging practice.

Phase Two determined that undergraduate training in FPDR positively influenced MIT knowledge scores in the survey. However, overall the knowledge MITs demonstrated regarding digital imaging technologies was limited and suggested a theory-practice gap, despite this MITs ranked their competencies highly.

With reference to my overarching research question, my research has added to the body of knowledge of how digital technology has influenced radiographic practice.

Notably, my findings provide new insight, identifying above all the significance of the transition to digital technology was not fully appreciated. This was evidenced in part by the speed of the transition and training provision. Ultimately a task driven process was adopted which influenced the knowledge MITs received and absorbed, and I suggest, may continue to be utilised in clinical practice. The transition to digital technology has created a significant shift in MI practice which has important implications for patient care, as well as the medical imaging profession.

It was apparent that during a technology focused transition process, MITs may "lose sight" of their patients. These findings may also be applicable to the successful implementation of new technology in other health professions. Successful integration of new technology needs to encompass multiple perspectives, not least of which is the adoption of a patient centric approach. As such, transition goes further than implementation science or knowledge translation. Furthermore, training provision is key and needs to do more than purely focus on the functionality of the equipment. The responsibility in ensuring a successful transition process lies with the equipment manufacturers, employers, employees, and education providers, all of whom will engage in the training process albeit within slightly different contexts. This will require adequate resourcing not only from a financial perspective but also time to support staff training whether that be to train the trainers or the staff.

The risk is that without adopting these approaches, as the implementation of new technology increases, the ability to use it for the benefit of patients may become overshadowed and the provision of patient centred care may suffer.

Overall, my findings highlight that despite the realisation of many of the benefits associated with digital medical imaging technology, there remain significant drawbacks. These drawbacks appear to be created through the transition process and arise as a consequence of other unintended effects, such as through the impact on workflow and patient care. These findings have important implications for the future introduction and ongoing use of new technology in MIT practice, and more generally.

References

Aarts, S., Cornelis, F., Zevenboom, Y., Brokken, P., van de Griend, N., Spoorenberg, M., ten Bokum, W., & Wouters, E. (2017). The opinions of radiographers, nuclear medicine technologists and radiation therapists regarding technology in health care: a qualitative study. *Journal of Medical Radiation Sciences*, *64*, 3–9. https://doi.org/10.1002/jmrs.207

Abdekhoda, M., & Salih, K. M. (2017). Determinant factors in applying Picture Archiving and Communication Systems (PACS) in healthcare. *Perspectives in Health Information Management*, *14*, 1–16.

Ahonen, S.-M., & Liikanen, E. (2010). Radiographers' preconditions for evidence-based radiography. *Radiography*, *16*(3), 217–222. https://doi.org/10.1016/j.radi.2010.01.005

Al-Murshedi, S., Hogg, P., & England, A. (2020). Neonatal chest radiography: influence of standard clinical protocols and radiographic equipment on pathology visibility and radiation dose using a neonatal chest phantom. *Radiography*, *26*(4), 282–287. https://doi.org/https://doi.org/10.1016/j.radi.2020.02.005

Al Khalifah, K., & Brindhaban, A. (2004). Comparison between conventional radiography and digital radiography for various kVp and mAs settings using a pelvic phantom. *Radiography*, *10*(2), 119–125. https://doi.org/10.1016/j.radi.2004.02.006

Alsharif, W., Davis, M., McGee, A., & Rainford, L. (2017). An investigation of Saudi Arabian MR radiographers' knowledge and confidence in relation to MR image-quality-related errors. *Radiography*, *23*(2), e27–e33. https://doi.org/10.1016/j.radi.2016.11.002

Alsleem, H., & Almohiy, H. M. (2018). Radiographers' conception and perspectives regarding optimization of the quality of the image in pediatric digital radiography. *Jouf University Medical Journal*, *5*(3), 15–24.

Alsleem, H., & Davidson, R. (2015). Radiographers' ability to detect low-contrast detail in digital radiography systems. *Radiologic Technology*, *87*(1), 29–37. http://www.ncbi.nlm.nih.gov/pubmed/26377266

Alsleem, H., Davidson, R., Al-Dhafiri, B., Alsleem, R., & Ameer, H. (2019). Evaluation of radiographers' knowledge and attitudes of image quality optimisation in paediatric digital radiography in Saudi Arabia and Australia: a survey-based study. *Journal of Medical Radiation Sciences*, *66*(4), 229–237. https://doi.org/10.1002/jmrs.366

Althubaiti, A. (2016). Information bias in health research: Definition, pitfalls, and adjustment methods. *Journal of Multidisciplinary Healthcare*, *9*, 211–217. https://doi.org/10.2147/JMDH.S104807

Altolub, M., Batarfi, M., & Alshulayyil, M. (2018). Assessment of clinical competences and self-confidence of radiologist and technologist at Asir Region Hospitals, Saudi Arabia. *The Egyptian Journal of Hospital Medicine*, *71*(2), 2544–2552. https://doi.org/10.12816/0045654

American College of Radiology. (2017). *ACR-AAPM-SIIM-SPR practice parameter for digital radiography* (pp. 1–16).

Andersson, B. T. (2012). *Radiographers' professional competence: Development of a context-specific instrument*. Hälsohögskolan.

Andersson, B. T., Christensson, L., Fridlund, B., & Broström, A. (2012). Development and psychometric evaluation of the radiographers' competence scale. *Open Journal of Nursing*, *2*, 85–96. https://doi.org/10.4236/ojn.2012.22014

Andersson, B. T., Christensson, L., Jakobsson, U., Fridlund, B., & Broström, A. (2012). Radiographers' self-assessed level and use of competencies - a national survey. *Insights into Imaging*, *3*(6), 635–645. https://doi.org/10.1007/s13244-012-0194-8

Andersson, B. T., Lundgren, S. M., & Lundén, M. (2017). Trends that have influenced the Swedish radiography profession over the last four decades. *Radiography*, *23*, 292–297. https://doi.org/10.1016/j.radi.2017.07.012

Andria, G., Attivissimo, F., Guglielmi, G., Lanzolla, A. M. L., Maiorana, A., & Mangiantini, M. (2016). Towards patient dose optimization in digital radiography. *Measurement: Journal of the International Measurement Confederation*, *79*, 331–338. https://doi.org/10.1016/j.measurement.2015.08.015

Andriole, K. P. (2002). Productivity and cost assessment of computed radiography, digital radiography, and screen-film for outpatient chest examinations. *Journal of*

Digital Imaging, *15*(3), 161–169. https://doi.org/10.1007/s10278-002-0026-3

Andriole, K. P., Ruckdeschel, T. G., Flynn, M. J., Hangiandreou, N. J., Jones, A. K., Krupinski, E. A., Seibert, J. A., Shepard, S. J., Walz-Flannigan, A., Mian, T. A., & Pollack, M. S. (2013). ACR–AAPM–SIIM Practice guideline for digital radiography. *Journal of Digital Imaging*, *26*, 26–37. https://doi.org/10.1007/s10278-012-9523-1

Ashtari, S., & Bellamy, A. (2019). Factors impacting use of health IT applications: Predicting nurses' perception of performance. *International Journal of Healthcare Information Systems and Informatics*, *14*(4), 33–55. https://doi.org/10.4018/IJHISI.2019100103

Atkinson, S., Neep, M. J., & Starkey, D. (2019). Reject rate analysis in digital radiography: An Australian emergency imaging department case study. *Journal of Medical Radiation Sciences*. https://doi.org/10.1002/jmrs.343

Austin, P. C., & Steyerberg, E. W. (2015). The number of subjects per variable required in linear regression analyses. *Journal of Clinical Epidemiology*, *68*(6), 627–636. https://doi.org/10.1016/j.jclinepi.2014.12.014

Avgar, A. C., Litwin, A. S., & Pronovost, P. J. (2012). Drivers and barriers in health IT adoption: A proposed framework. *Applied Clinical Informatics*, *3*(4), 488–500. https://doi.org/10.4338/ACI-2012-07-R-0029

Bagherian, B., Mirzaei, T., Sabzevari, S., & Ravari, A. (2016). Caring within a web of paradoxes: The critical care nurses' experiences of beneficial and harmful effects of technology on nursing care. *British Journal of Medicine and Medical Research*, *15*(9), 1–14. https://doi.org/10.9734/BJMMR/2016/25820

Baird, M. (1995). Postpositivist methodology and clinical education. *Radiologic Technology*, *67*(1), 15–23.

Baird, M. (1996). The idea of a reflective practicum*: Overcoming the dichotomy between academia and the practice setting. *Radiography*, *2*, 119–138.

Baird, M. (2008). Towards the development of a reflective radiographer: Challenges and constraints. *Biomedical Imaging and Intervention Journal*, *4*(1), 10–14. https://doi.org/10.2349/biij.4.1.e9

Balogun, S. O. (2021). Benefits and Limitations of Portable Chest Radiography.

Radiologic Technology, *92*(3), 301–304.

Barton, B., & Peat, J. (2014). *Medical statistics : A guide to SPSS, data analysis and critical appraisal.* (2nd ed.). John Wiley & Sons Ltd.

Bax, S. (2002). The social and cultural dimensions of trainer training. *Journal of Education for Teaching*, *28*(2), 165–178. https://doi.org/10.1080/0260747021000005592

Baxter, P., & Norman, G. (2011). Self-assessment or self deception? A lack of association between nursing students' self-assessment and performance. *Journal of Advanced Nursing*, *67*(11), 2406–2413. https://doi.org/10.1111/j.1365-2648.2011.05658.x

Beaudin, B. P., & Quick, D. (1995). Experiential learning: Theoretical underpinnings. In *Report No. ETT-95-02*. High Plains Intermountain, Center for Agricultural Health and Safety.

Benfield, S., Hewis, J. D., & Hayre, C. M. (2020). Investigating perceptions of 'dose creep' amongst student radiographers: A grounded theory study. *Radiography*, *27*(2), 605–601. https://doi.org/10.1016/j.radi.2020.11.023

Bercovich, E., & Javitt, M. C. (2018). Medical imaging: From Roentgen to the digital revolution, and beyond. *Rambam Maimonides Medical Journal*, *9*(4). https://doi.org/10.5041/rmmj.10355

Bethlehem, J. (1999). Cross-sectional research. In H. J. Ader & G. J. Mellenbergh (Eds.), *Research methodology in the social, behavioural and life sciences: Designs, models and methods* (pp. 110–142). SAGE Publications Ltd.

Bettany-Saltikov, J. (2016). *How to do a systematic literature review in nursing: A step-by-step guide*. McGraw-Hill Education.

Bevan, H., & Fairman, S. (2014). The new era of thinking and practice in change and transformation. In *NHS Improving quality*. https://doi.org/10.13140/RG.2.2.10237.77289

Biesta, G. (2010). Pragmatism and the philosophical foundations of mixed methods research1. In A. Tashakkori & C. Teddlie (Eds.), *The SAGE handbook of mixed methods in social & behavioral research* (2nd ed., pp. 95–118). SAGE Publications

Inc. https://doi.org/https://dx.doi.org/10.4135/9781506335193.n4

Bijwaard, H., de Vries, G., Scheurleer, J., Roding, T., Erenstein, H., Ravensbergen, W., Haarmans-Jonkman, S., & van Welie, F. (2017). Compliance to Diagnostic Reference Levels for radiation exposure in common radiological procedures in Dutch hospitals: A nation-wide survey carried out by medical imaging students. *Radiography*, *23*(3), 197–201. https://doi.org/10.1016/j.radi.2017.03.005

Bishop, F. L. (2015). Using mixed methods research designs in health psychology: An illustrated discussion from a pragmatist perspective. *British Journal of Health Psychology*, *20*, 5–20. https://doi.org/10.1111/bjhp.12122

Blythe, J. (2009). *Key concepts in marketing*. SAGE Publications Ltd. https://doi.org/doi.org/10.4135/9781446221617

Bolderston, A. (2008). Writing an effective literature review. *Journal of Medical Imaging and Radiation Sciences*, *39*(2), 86–92. https://doi.org/10.1016/j.jmir.2008.04.009

Bolderston, A. (2016). Patient experience in Medical Imaging and Radiation Therapy. *Journal of Medical Imaging and Radiation Sciences*, *47*(4), 356–361. https://doi.org/10.1016/j.jmir.2016.09.002

Bomer, J., Wiersma-Deijl, L., & Holscher, H. C. (2013). Electronic collimation and radiation protection in paediatric digital radiography: Revival of the silver lining. *Insights into Imaging*, *4*(5), 723–727. https://doi.org/10.1007/s13244-013-0281-5

Booth, L., & Manning, D. J. (2006). Observations of radiographer communication: An exploratory study using Transactional Analysis. *Radiography*, *12*(4), 276–282. https://doi.org/10.1016/j.radi.2005.09.005

Bowden, L., Faulkner, R., Clancy, C., Gallagher, A., Devine, M., Gorman, D., O'Reilly, G., & Dowling, A. (2011). Doses under automatic exposure control (AEC) for direct digital radiographic (DDR) X-ray systems. *Radiation Protection Dosimetry*, *147*(1–2), 210–214. https://doi.org/10.1093/rpd/ncr301

Bowman, S. (1997). Technical evaluation of radiographs: A case study in radiographic judgement and decision-making. In A. Paterson & R. Price (Eds.), *Current topics in radiography* (1st ed., Issue 3, pp. 69–86). W.B. Saunders Company Ltd.

Boyd, B. L. (2013). *Using the theory of planned behavior as a predictor of radiologic technologists' use of patient radiation protection best practices: A regional study* [Andrews University]. https://doi.org/10.1017/CBO9781107415324.004

Brady, A. P. (2017). Error and discrepancy in radiology: inevitable or avoidable? *Insights into Imaging*, *8*, 171–182. https://doi.org/10.1007/s13244-016-0534-1

Brady, A. P. (2021). The vanishing radiologist — an unseen danger, and a danger of being unseen. *European Radiology*, *31*(8), 5998–6000.

Brady, A. P., Ó Laoide, R., McCarthy, P., & McDermott, R. (2012). Discrepancy and error in radiology: Concepts, causes and consequences. *Ulster Medical Journal*, *81*(1), 3–9.

Bragg, S., Craig, J., Cunningham, I., Eraut, M., Fielding, M., Gillinson, S., Horne, M., Robinson, C., & Thorp, J. (2005). *Factors influencing the transfer of good practice*.

Bramson, R. T., & Bramson, R. A. (2005). Overcoming obstacles to work-changing technology such as PACS and voice recognition. *American Journal of Roentgenology*, *184*(6), 1727–1730. https://doi.org/10.2214/ajr.184.6.01841727

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Braun, V., & Clarke, V. (2020). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, 1–25. https://doi.org/10.1080/14780887.2020.1769238

Braun, V., & Clarke, V. (2021). Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis with other pattern-based qualitative analytic approaches. *Counselling and Psychotherapy Research*, *21*, 37–47. https://doi.org/10.1002/capr.12360

Bredal, I. S., Kåresen, R., Skaane, P., Engelstad, K. S., & Ekeberg, Ø. (2013). Recall mammography and psychological distress. *European Journal of Cancer*, *49*(4), 805–811. https://doi.org/10.1016/j.ejca.2012.09.001

Bree, R., & Gallagher, G. (2016). Using Microsoft Excel to code and thematically analyse qualitative data: a simple, cost-effective approach. *All Ireland Journal of Higher Education*, *8*(2), 28111–28114.

Brettle, A. (2020). Implementing evidence-based practice: A guide for radiographers. *Radiography*, *26*(Supplement 2), S37–S41. https://doi.org/10.1016/j.radi.2020.05.013

Bridges, W., & Mitchell, S. (2000). Leading transition: A new model for change. *Leader to Leader*, *16*, 1–8.

Brown, A. (2004). Professionals under pressure: Contextual influences on learning and development of radiographers in England. *Learning in Health and Social Care*, *3*(4), 213–222. https://doi.org/10.1111/j.1473-6861.2004.00078.x

Brown, C. A., Belfield, C. R., & Field, S. J. (2002). Cost effectiveness of continuing professional development in health care: a critical review of the evidence. *British Medical Journal*, *324*(652–655). https://doi.org/10.1136/bmj.325.7366.693

Brown, K. M., Elliott, S. J., Leatherdale, S. T., & Robertson-Wilson, J. (2015). Searching for rigour in the reporting of mixed methods population health research: A methodological review. *Health Education Research*, *30*(6), 811–839. https://doi.org/10.1093/her/cyv046

Brown, M. E. L., & Dueñas, A. N. (2020). A Medical Science educator's guide to selecting a research paradigm: Building a basis for better research. *Medical Science Educator*, *30*(1), 545–553. https://doi.org/10.1007/s40670-019-00898-9

Bryman, A., Becker, S., & Sempik, J. (2008). Quality criteria for quantitative, qualitative and mixed methods research: A view from social policy. *International Journal of Social Research Methodology*, *11*(4), 261–276. https://doi.org/10.1080/13645570701401644

Buckle, C. E., Udawatta, V., & Straus, C. M. (2013). Now you see it, now you don't: Visual illusions in radiology. *RadioGraphics*, *33*, 2087–2102. https://doi.org/10.1148/rg.337125204

Bunniss, S., & Kelly, D. R. (2010). Research paradigms in medical education research.

Medical Education, *44*(4), 358–366. https://doi.org/10.1111/j.1365-2923.2009.03611.x

Busby, L. P., Courtier, J. L., & Glastonbury, C. M. (2018). Bias in radiology: The how and why of misses and misinterpretations. *Radiographics*, *38*(1), 236–247. https://doi.org/10.1148/rg.2018170107

Bushong, S. (2017). *Radiologic science for technologists E-Book: Physics, biology, and protection* (11th ed.). Elsevier.

Butler, M. L., Rainford, L., Last, J., & Brennan, P. C. (2010). Are exposure index values consistent in clinical practice? A multi-manufacturer investigation. *Radiation Protection Dosimetry*, *139*(1–3), 371–374. https://doi.org/10.1093/rpd/ncq094

Butt, A., Mahoney, M., & Savage, N. W. (2012). The impact of computer display performance on the quality of digital radiographs: A review. *Australian Dental Journal*, *57*, 16–23. https://doi.org/10.1111/j.1834-7819.2011.01660.x

Bwanga, O. (2020). Barriers to continuing professional development (CPD) in radiography: A review of literature from Africa. *Health Professions Education*. https://doi.org/https://doi.org/10.1016/ j.hpe.2020.09.002.

Calisi, R., Boyko, S., Vendette, A., & Zagar, A. (2016). What is person-centred care? A qualitative inquiry into oncology staff and patient and family experience of person-centred care. *Journal of Medical Imaging and Radiation Sciences*, *47*(4), 309–314. https://doi.org/10.1016/j.jmir.2016.08.007

Cameron, E., & Green, M. (2004). *Making sense of change management: A complete guide to the models, tools & techniques of organizational change*. Kogan Page.

Campbell, S. S., Morton, D., & Grobler, A. D. (2019). Transitioning from analogue to digital imaging: Challenges of South African analogue-trained radiographers. *Radiography*, *25*(2), e39–e44. https://doi.org/10.1016/j.radi.2018.10.001

Capper, C. (2012). Key concepts in nursing. In E. Mason-Whitehead, A. Mcintosh, A. Bryan, & T. Mason (Eds.), *Key concepts in nursing* (pp. 79–83). SAGE Publications Ltd. https://doi.org/10.4135/9781446216064

Careersmart.org.uk. (2020). *Medical Radiographers*. https://careersmart.org.uk/occupations/medical-radiographers

Carlsson, S., & Carlsson, E. (2013). “The situation and the uncertainty about the coming result scared me but interaction with the radiographers helped me through”: A qualitative study on patients’ experiences of magnetic resonance imaging examinations. *Journal of Clinical Nursing*, *22*(21–22), 3225–3234. https://doi.org/10.1111/jocn.12416

Carroll, Q. B., & Bowman, D. (2014). *Adaptive radiography with trauma, image critique and critical thinking*. Delmar, Cengage Learning.

Carroll, Q. B., & Vealé, B. L. (2020). Standardizing digital radiography terminology. *Radiologic Technology*, *92*(2), 186–195.

Cashell, A. (2010). Radiation therapists perspectives of the role of reflection in clinical practice. *Journal of Radiotherapy in Practice*, *9*(3), 131–141. https://doi.org/10.1017/S1460396910000014

Castillo, J., Caruana, C. J., & Wainwright, D. (2011). The changing concept of competence and categorisation of learning outcomes in Europe: Implications for the design of higher education radiography curricula at the European level. *Radiography*, *17*(3), 230–234. https://doi.org/10.1016/j.radi.2010.12.008

Cherryholmes, C. H. (1992). Notes on pragmatism and scientific realism. *Educational Researcher*, *21*(6), 13–17. http://www.jstor.org/stable/1176502

Chetley, A., & Vincent, R. (2003). Learning to share learning: an exploration of methods to improve and share learning. In *Exchange* (Issue March).

Chigunta, M., Kalungia, A., Nankonde, P., Kaonga, P., Chongwe, G., Banda, S., & Sichone, J. M. (2020). Self-perceived versus supervisor-rated technical competence in plain film x-ray evaluation by newly graduated radiographers: Implications for curriculum development and practice in Zambia. *Health Professions Education*. https://doi.org/10.1016/j.hpe.2020.04.007

Ching, W., Robinson, J., & McEntee, M. (2014). Patient-based radiographic exposure factor selection: A systematic review. *Journal of Medical Radiation Sciences*, *61*(3), 176–190. https://doi.org/10.1002/jmrs.66

Christensen, I. (2005a). Pattern recognition. In J. McConnell, R. Eyres, & J. Nightingale (Eds.), *Interpreting trauma radiographs.* (pp. 47–62). Blackwell Publishing.

Christensen, I. (2005b). Uncertainty and bias in decision making. In J. McConnell, R. Eyres, & J. Nightingale (Eds.), *Interpreting trauma radiographs.* (pp. 32–46). Blackwell Publishing.

Clark, K. R. (2018). Learning Theories: Behaviorism. *Radiologic Technology*, *90*(2), 172–175. https://doi.org/10.1002/piq.21143

Colicchio, T. K., Cimino, J. J., & Del Fiol, G. (2019). Unintended consequences of nationwide electronic health record adoption: Challenges and opportunities in the post-meaningful use era. *Journal of Medical Internet Research*, *21*(6). https://doi.org/10.2196/13313

Collins, K. S., & Nolen, K. (2002). Enhancing your professional image. *Radiologic Technology*, *73*(3), 265–267. https://doi.org/10.5040/9781718209763.ch-026

Cooke, A., Smith, D., & Booth, A. (2012). Beyond PICO: The SPIDER tool for qualitative evidence synthesis. *Qualitative Health Research*, *22*(10), 1435–1443. https://doi.org/10.1177/1049732312452938

Cowling, C. (2008). A global overview of the changing roles of radiographers. *Radiography*, *14*(Supplement 1), 28–32. https://doi.org/10.1016/j.radi.2008.06.001

Crawford, P., & Brown, B. (2011). Fast healthcare: Brief communication, traps and opportunities. *Patient Education and Counseling*, *82*(1), 3–10. https://doi.org/10.1016/j.pec.2010.02.016

Crawford, P., Brown, B., & Majomi, P. (2008). Professional identity in community mental health nursing: A thematic analysis. *International Journal of Nursing Studies*, *45*(7), 1055–1063. https://doi.org/10.1016/j.ijnurstu.2007.05.005

Creswell, J. W. (2007). *Qualitative inquiry & research design. Choosing among five approaches* (2nd ed.). SAGE Publications Inc.

Creswell, J. W. (2009). The selection of a research design. In *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd Ed., pp. 3–21). SAGE Publicatons Inc.

Creswell, J. W. (2013). *Qualitative inquiry & research design. Choosing among five approaches* (3rd ed.). SAGE Publications Inc.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). SAGE Publications Inc.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications Inc.

Creswell, J. W., Klassen, A. C., Plano Clark, V. L., & Clegg Smith, K. (2011). Best practices for mixed methods research in the health sciences. In *Office of Behavioral and Social Sciences Research*. https://doi.org/10.1002/cdq.12009.

Creswell, J. W., & Plano Clark, V. L. (2007). Choosing a mixed methods design. In *Designing and conducting mixed methods research* (1st ed., pp. 58–89). SAGE Publications Inc.

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications Inc.

Crotty, M. (1998). Introduction: The research process. In *The foundations of social research. Meaning and perspective in the research process* (pp. 1–17). SAGE Publicatons, Inc.

Culpan, G., Culpan, A. M., Docherty, P., & Denton, E. (2019). Radiographer reporting: A literature review to support cancer workforce planning in England. *Radiography*, *25*(2), 155–163. https://doi.org/10.1016/j.radi.2019.02.010

Dalah, E. Z. (2020). Quantifying dose-creep for skull and chest radiography using dose area product and entrance surface dose: Phantom study. *Radiation Physics and Chemistry*, *167*, 1–5. https://doi.org/10.1016/j.radphyschem.2019.03.035

Darcy, S., Rainford, L., Kelly, B., & Toomey, R. (2015). Decision making and variation in radiation exposure factor selection by radiologic technologists. *Journal of Medical Imaging and Radiation Sciences*, *46*(4), 372–379. https://doi.org/10.1016/j.jmir.2015.09.003

Dave, J., Jones, A. K., Fisher, R., Hulme, K., Rill, L., Zamora, D., Woodward, A., Brady, S., MacDougall, R., Goldman, L., Lang, S., Peck, D., Apgar, B., Shepard, S. J., Uzenoff, R., & Willis, C. E. (2018). Current state of practice regarding digital radiography exposure indicators and deviation indices: Report of AAPM Imaging Physics Committee Task Group 232. *Medical Physics*, *45*(11), e1146–e1160. https://doi.org/10.1002/mp.13212

Davidson, R., & Sim, J. (2008). Computed radiography and dosimetry: Some practical tips for dose optimization procedures. *Journal of Medical Imaging and Radiation Sciences*, *39*, 109–114. https://doi.org/10.1016/j.jmir.2008.07.002

Davis, J., & Lovegrove, M. (2016). *Inclusion health: Education and training for health professionals*.

DeAngelis, R. (2007). Digital processing applications. Comparing CR and DR. In Q. B. Carroll (Ed.), *Practical Radiographic Imaging* (pp. 495–570). Charles C. Thomas.

Debono, D., Greenfield, D., Black, D., & Braithwaite, J. (2010). Workarounds: straddling or widening gaps in the safe delivery of healthcare? *Mind the Gap: 7th International Conference in Organisational Behaviour in Health Care (OBHC), Birmingham UK*.

Decker, S., & Iphofen, R. (2005). Developing the profession of radiography: Making use of oral history. *Radiography*, *11*, 262–271. https://doi.org/10.1016/j.radi.2005.01.009

Decoster, R., Mol, H., & Smits, D. (2015). Post-processing, is it a burden or a blessing? Part 1 evaluation of clinical image quality. *Radiography*, *21*(1), e1–e4. https://doi.org/10.1016/j.radi.2014.06.003

Denzin, N. K., & Lincoln, Y. S. (2005). Part III: Strategies of Inquiry. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (4th ed., pp. 375–386). SAGE Publicatons, Inc.

Devon, H. A., Block, M. E., Moyle-Wright, P., Ernst, D. M., Hayden, S. J., Lazzara, D. J., Savoy, S. M., & Kostas-Polston, E. (2007). A psychometric toolbox for testing validity and reliability. *Journal of Nursing Scholarship*, *39*(2), 155–164. https://doi.org/10.1111/j.1547-5069.2007.00161.x

Dewey, J. (1938). *Experience and education*. Kappa Delta Pi.

Di Michele, L., Thomson, K., McEntee, M., Kenny, B., & Reed, W. (2020). Knowledge translation: Radiographers compared to other healthcare professionals. *Radiography*, *26*(Supplement 2), S27–S32. https://doi.org/10.1016/j.radi.2020.06.007

Dillman, D. A. (1991). The design and administration of mail surveys. *Annual Review of*

Sociology, *12*, 225–249. https://doi.org/https://doi.org/10.1146/annurev.so.17.080191.001301

Dillman, D. A., Smyth, J., & Christian, L. (2014). *Internet, phone, mail, and mixed mode surveys: The tailored design method.* (4th ed.). John Wiley and Sons Ltd.

Don, S., MacDougall, R., Strauss, K. J., Moore, Q. T., Goske, M. J., Cohen, M. D., Herrmann, T., John, S. D., Noble, L., Morrison, G., Lehman, L., & Whiting, B. R. (2013). Image gently campaign back to basics initiative: Ten steps to help manage radiation dose in pediatric digital radiography. *American Journal of Roentgenology*, *200*(5), 431–436. https://doi.org/10.2214/AJR.12.9895

Don, S., Whiting, B. R., Rutz, L. J., & Apgar, B. K. (2012). New exposure indicators for digital radiography simplified for radiologists and technologists. *American Journal of Roentgenology*, *199*(6), 1337–1341. https://doi.org/10.2214/AJR.12.8678

Drew, T., Võ, M. L. H., & Wolfe, J. M. (2013). The invisible gorilla strikes again: Sustained inattentional blindness in expert observers. *Psychological Science*, *24*(9), 1848–1853. https://doi.org/10.1177/0956797613479386

Drost, E. A. (2011). Validity and reliability in social science research. *Education Research and Perspectives*, *38*(1), 105–123.

Eaton, A. (2018). Disadvantages of postexposure cropping. *Radiologic Technology*, *89*(4), 404–406.

Egan, I., & Baird, M. (2003). Optimising the diagnostic imaging process through clinical history documentation. *The Radiographer*, *49*(1), 11–18.

Eisenberg, R. L., Yamada, K., Yam, C. S., Spirn, P. W., & Kruskal, J. B. (2010). Electronic messaging system for communicating important, but nonemergent, abnormal imaging results. *Radiology*, *257*(3), 724–731. https://doi.org/10.1148/radiol.10101015

Ejnefjäll, T., & Ågerfalk, P. J. (2019). Conceptualizing workarounds: Meanings and manifestations in information systems research. *Communications of the Association for Information Systems*, *45*. https://doi.org/10.17705/1CAIS.04520

Elkjaer, B. (2009). Pragmatism. A learning theory for the future. In K. Illeris (Ed.), *Contemporary theories of learning. Learning theorists...in their own words* (pp.

74–89). Routledge, Taylor & Francis Group.

Ellis, P. (2014). The language of research (part 3): Cross sectional studies. *Wounds UK*, *10*(4), 108–109.

Elshami, W., Elamrdi, A., Alyafie, S., & Abuzaid, M. (2016). Continuing professional development in radiography: Practice, attitude and barriers. *International Journal of Medical Research & Health Sciences*, *5*(1), 68. https://doi.org/10.5958/2319-5886.2016.00015.1

Embo, M. P. C., Driessen, E. W., Valcke, M., & van der Vleuten, C. (2010). Assessment and feedback to facilitate self-directed learning in clinical practice of Midwifery students. *Medical Teacher*, *32*(7), e263–e269. https://doi.org/10.3109/0142159X.2010.490281

Eraut, M. (2004). Informal learning in the workplace. *Studies in Continuing Education*, *26*(2), 247–273. https://doi.org/10.1080/158037042000225245

Eraut, M., Steadman, S., Furner, J., Maillardet, F., Miller, C., Ali, A., & Blackman, C. (2004). Learning in the professional workplace: Relationships between learning factors and contextual factors. *AERA 2004 Conference, San Diego.*

Erenstein, H., Browne, D., Curtin, S., Dwyer, R. S., Higgins, R., Hommel, S. F., Menzinga, J., Pires Jorge, J. A., Sauty, M., de Vries, G., & England, A. (2020). The validity and reliability of the exposure index as a metric for estimating the radiation dose to the patient. *Radiography*, *26*(Supplement 2), S94–S99. https://doi.org/10.1016/j.radi.2020.03.012

European Society of Radiology, & European Federation of Radiographer Societies. (2019). Patient safety in medical imaging: A joint paper of the European Society of Radiology (ESR) and the European Federation of Radiographer Societies (EFRS). *Radiography*, *25*(2), e26–e38. https://doi.org/10.1016/j.radi.2019.01.009

Eva, K. W., & Regehr, G. (2005). Self-assessment in the health professions: A reformulation and research agenda. *Academic Medicine*, *80*, 46–54. https://doi.org/10.1097/00001888-200510001-00015

Farajollahi, A. R., Fouladi, D. F., Ghojazadeh, M., & Movafaghi, A. (2014). Radiographers’ professional knowledge regarding parameters and safety issues in plain radiography: A questionnaire survey. *British Journal of Radiology*, *87*(1040).

https://doi.org/10.1259/bjr.20140090

Fauber, T. L. (2016). *Radiographic imaging & exposure* (5th ed.). Elsevier.

Feilzer, M. Y. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research*, *4*(1), 6–16. https://doi.org/10.1177/1558689809349691

Feo, O. (2008). Neoliberal policies and their impact on public health education : Observations on the Venezuelan experience. *Social Medicine*, *3*(4), 223–231.

Ferris, C. (2005). *The development of specialisation in diagnostic radiography: concepts, contexts and implications*. Sheffield Hallam University.

Ferris, C. (2009). Specialism in radiography: A contemporary history of diagnostic radiography. *Radiography*, *15*, e78–e84. https://doi.org/10.1016/j.radi.2009.10.006

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs: Principles and practices. *Health Services Research*, *48*(6 PART2), 2134–2156. https://doi.org/10.1111/1475-6773.12117

Field, A. (2009). *Discovering statistics using SPSS (and sex and drugs and rock "n" roll)* (3rd ed.). SAGE Publications Ltd.

Field, C. (2018). Adapting verification processes to prevent wrong radiology events. In *The Pennsylvania Patient Safety Authority* (Vol. 15, Issue 3).

Fincham, J. E. (2008). Response rates and responsiveness for surveys, standards, and the Journal. *American Journal of Pharmaceutical Education*, *72*(2), 43. https://doi.org/10.5688/aj720243

Flinton, D. M., & Owens, A. (2010). Sampling Errors, Bias, and Objectivity. In A. Ramlaul (Ed.), *Medical imaging and radiotherapy Research: Skills and strategies* (pp. 101–109). Elsevier Ltd. https://doi.org/10.1007/978-3-030-37944-5_10

Floyd, D. M., Trepp, E. R., Ipaki, M., & Ng, C. K. C. (2015). Study of radiologic technologists' perceptions of Picture Archiving and Communication System (PACS) competence and educational issues in Western Australia. *Journal of Digital Imaging*, *28*, 315–322. https://doi.org/10.1007/s10278-014-9765-1

Foley, S. J., Evanoff, M. G., & Rainford, L. A. (2013). A questionnaire survey reviewing radiologists' and clinical specialist radiographers' knowledge of CT exposure parameters. *Insights into Imaging*, *4*(5), 637–646. https://doi.org/10.1007/s13244-013-0282-4

Freidson, E. (1974). *Professional dominance. The social structure of medical care*. Routledge.

Freitas, M. B., Pimentel, R. B., Braga, L. F., Salido, F. S. A., Neves, R. F. C. A., & Medeiros, R. B. (2020). Patient dose optimization for computed radiography using physical and observer-based measurements as image quality metrics. *Radiation Physics and Chemistry*, *172*, 1–7. https://doi.org/10.1016/j.radphyschem.2020.108768

Fridell, K. (2011). *A walk into the digital world- A long and winding road*. Karolinska Institutet.

Fridell, K., Aspelin, P., Edgren, L., Lindsköld, L., & Lundberg, N. (2008). PACS influence the radiographer's work. *Radiography*, *15*, 121–133. https://doi.org/10.1016/j.radi.2008.03.002

Fridell, K., Aspelin, P., Felländer-Tsai, L., & Lundberg, N. (2011). The effect of PACS on the practice of orthopaedic surgeons. *Journal of Telemedicine and Telecare*, *17*, 137–141. https://doi.org/10.1258/jtt.2010.100107

Fridell, K., Edgren, L., Lindsköld, L., Aspelin, P., & Lundberg, N. (2007). The impact of PACS on radiologists' work practice. *Journal of Digital Imaging*, *20*(4), 411–421. https://doi.org/10.1007/s10278-006-1054-1

Frost & Sullivan. (2009). *Digital imaging technologies reduce costs*.

Frush, D. P., Denham, C. R., Goske, M. J., Brink, J. A., Morin, R. L., Mills, T. T., Butler, P. F., McCollough, C., & Miller, D. L. (2013). Radiation protection and dose monitoring in medical imaging: A journey from awareness, through accountability, ability and action...but where will we arrive? *Journal of Patient Safety*, *9*(4), 232–238. https://doi.org/10.1097/PTS.0b013e3182a8c2c4

Gardner, K., Comello, R. J., & Watts, L. (2014). How budget issues affect technologists. *Journal of Medical Imaging and Radiation Sciences*, *45*(2), 115–118. https://doi.org/10.1016/j.jmir.2013.11.001

Gibbs, V. (2011). An investigation into the challenges facing the future provision of continuing professional development for allied health professionals in a changing healthcare environment. *Radiography*, *17*(2), 152–157. https://doi.org/10.1016/j.radi.2011.01.005

Gibson, D. J., & Davidson, R. (2012). Exposure creep in computed radiography. A longitudinal study. *Academic Radiology*, *19*(4), 458–462. https://doi.org/10.1016/j.acra.2011.12.003

Giddings, L. S., & Grant, B. M. (2006). Mixed methods research for the novice researcher. *Contemporary Nurse*, *23*(1), 3–11.

Giddings, L. S., & Grant, B. M. (2007). A Trojan horse for positivism? *Advances in Nursing Science*, *30*(1), 52–60. https://doi.org/10.1097/00012272-200701000-00006

Giddings, L. S., & Grant, B. M. (2009). From rigour to trustworthiness: Validating mixed methods. In S. Andrew & E. J. Halcomb (Eds.), *Mixed methods research for nursing and health sciences* (pp. 119–134). Wiley-Blackwell.

Gillan, C., Davis, C.-A., Moran, K., French, J., & Liszewski, B. (2015). The quest for quality: Principles to guide medical radiation technology practice. *Journal of Medical Imaging and Radiation Sciences*, *46*(4), 427–434. https://doi.org/10.1016/j.jmir.2015.07.005

Gitonga, J. W. (2006). *Work environment factors influencing the transfer of learning for online learners.* (pp. 988–995). Illinois University Press.

Goldkhul, G. (2012). Pragmatism vs interpretivism in qualitative information systems research. *European Journal of Information Systems*, *21*(2), 135–146.

Goske, M. J., Charkot, E., Herrmann, T., John, S. D., Mills, T. T., Morrison, G., & Smith, S. N. (2011). Image Gently: Challenges for radiologic technologists when performing digital radiography in children. *Pediatric Radiology*, *41*, 611–619. https://doi.org/10.1007/s00247-010-1957-3

Gough, B. (2003). Deconstructing reflexivity. In L. Finlay & B. Gough (Eds.), *Reflexivity: A practical guide for researchers in health and social sciences* (pp. 21–35). John Wiley & Sons Inc.

Greene, J. C., & Hall, J. N. (2015). Dialectics and pragmatism: Being of consequence. In A. Tashakkori & C. Teddlie (Eds.), *The SAGE handbook of mixed methods in social & behavioral research* (2nd ed., pp. 119–144). SAGE Publicatons Inc. https://doi.org/10.4135/9781506335193.n5

Grix, J. (2001). *Demystifying postgraduate research. From MA to PhD*. University of Birmingham Press.

Guba, E. G., & Lincoln, Y. S. (1982). Epistemological and methodological bases of naturalistic inquiry. *Educational Communication & Technology*, *30*(4), 233–252. https://doi.org/10.1007/BF02765185

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 105–117). SAGE Publicatons Inc.

Guðjónsdóttir, J., & Hannesdóttir, G. A. (2019). The unnecessary dose behind cropped radiographs. *Radiography Open*, *5*(1). https://doi.org/10.7577/radopen.3611

Guðjónsdóttir, J., Paalsson, K. E., & Sveinsdóttir, G. P. (2021). Are the target exposure index and deviation index used efficiently? *Radiography*, *27*(3), 903–907. https://doi.org/10.1016/j.radi.2021.02.012

Gutzeit, A., Heiland, R., Sudarski, S., Froehlich, J. M., Hergan, K., Meissnitzer, M., Kos, S., Bertke, P., Kolokythas, O., & Koh, D. M. (2019). Direct communication between radiologists and patients following imaging examinations. Should radiologists rethink their patient care? *European Radiology*, *29*(1), 224–231. https://doi.org/10.1007/s00330-018-5503-2

Hafslund, B., Clare, J., Graverholt, B., & Nortvedt, M. W. (2008). Evidence-based radiography. *Radiography*, *14*(4), 343–348. https://doi.org/10.1016/j.radi.2008.01.003

Hagland, B. Y. M. (2017). The world of imaging : A changing landscape for radiologists — and for everyone. *Healthcare Informatics*, 29–33.

Hall, J. N. (2013). Pragmatism, evidence, and mixed methods evaluation. In D. M. Mertens & S. Hesse-Biber (Eds.), *Mixed methods and credibility of evidence in evaluation. New directions for evaluation* (pp. 15–26). Wiley Periodicals Inc. https://doi.org/10.1002/ev.20054

Hall, R. (2013). Mixed methods: In search of a paradigm. In T. Le & Q. Le (Eds.), *Conducting research in a changing and challenging world. (Laboratory and Clinical Research)*. Nova Science Publishers Inc.

Hammick, M. (1995). Radiography research and the qualitative approach: A paradigm and a discourse. *Radiography*, *1*, 135–143. https://doi.org/10.1016/S1078-8174(95)80023-9

Hampel, J. R., & Pascoal, A. (2018). Comparison and optimization of imaging techniques in suspected physical abuse paediatric radiography. *British Journal of Radiology*, *91*. https://doi.org/10.1259/bjr.20170650

Hannes, K., & Lockwood, C. (2011). Pragmatism as the philosophical foundation for the Joanna Briggs meta-aggregative approach to qualitative evidence synthesis. *Journal of Advanced Nursing*, *67*(7), 1632–1642. https://doi.org/10.1111/j.1365-2648.2011.05636.x

Harding, L., Park, P., Thorniley, M., Ellis, M., Reed, C., Taylor, S., Singleton, L., Tolley, J., & Richardson, T. (2020). “Always Events® ”… just another quality improvement tool … or is it? *Radiography*, *26*(Supplement 2), S20–S26. https://doi.org/10.1016/j.radi.2020.06.002

Hardy, M., & Harvey, H. (2020). Artificial intelligence in diagnostic imaging: impact on the radiography profession. *The British Journal of Radiology*, *93*(1108), 20190840. https://doi.org/10.1259/bjr.20190840

Hart, T., Ferraro, M., Myers, R., & Ellis, C. A. (2014). Opening the black box: Lessons learned from an interdisciplinary inquiry into the learning-based contents of brain injury rehabilitation. *Archives of Physical Medicine and Rehabilitation*, *95*(1 SUPPL.), S66–S73. https://doi.org/10.1016/j.apmr.2013.03.033

Harvey, G., Llewellyn, S., Maniatopoulos, G., Boyd, A., & Procter, R. (2018). Facilitating the implementation of clinical technology in healthcare: What role does a national agency play? *BMC Health Services Research*, *18*(1), 1–10. https://doi.org/10.1186/s12913-018-3176-9

Hashimoto, N. (2006). Professional autonomy. *Japan Medical Association Journal*, *49*(3), 125–127. https://doi.org/10.1515/nor-2015-0018

Haus, A. G., & Cullinan, J. E. (1989). Screen film processing systems for medical radiography: a historical review. *Radiographics*, *9*(6), 1203–1224. https://doi.org/10.1148/radiographics.9.6.2685941

Hayes, D. (2000). Cascade training and teachers' professional development. *English Language Teaching Journal*, *54*(2), 135–145. https://academic.oup.com/eltj/article-abstract/54/2/135/413637

Hayre, C. M. (2016). "Cranking up", "whacking up" and "bumping up": X-ray exposures in contemporary radiographic practice. *Radiography*, *22*(2), 194–198. https://doi.org/10.1016/j.radi.2016.01.002

Hayre, C. M., Blackman, S., Carlton, K., & Eyden, A. (2018). Attitudes and perceptions of radiographers applying lead (Pb) protection in general radiography: An ethnographic study. *Radiography*, *24*, e13–e18. https://doi.org/10.1016/j.radi.2017.07.010

Hayre, C. M., Blackman, S., & Eyden, A. (2016). Do general radiographic examinations resemble a person-centred environment? *Radiography*, *22*(4), e245–e251. https://doi.org/10.1016/j.radi.2016.07.001

Hayre, C. M., Eyden, A., Blackman, S., & Carlton, K. (2017). Image acquisition in general radiography: The utilisation of DDR. *Radiography*, *23*(2), 147–152. https://doi.org/10.1016/j.radi.2016.12.010

Health and Disability Commissioner (Code of Health and Disability Services Consumers' Rights) Regulations 1996. https://www.hdc.org.nz/your-rights/about-the-code/code-of-health-and-disability-services-consumers-rights/

Health Navigator NZ. (2018). *Quality- 6 aims of quality healthcare*. https://www.healthnavigator.org.nz/clinicians/q/quality-6-aims-of-quality-healthcare/

Health Practitioners Competence Assurance Act 2003. https://www.legislation.govt.nz/act/public/2003/0048/latest/DLM203312.html

Health Quality and Safety Commission. (2016). *Governing for quality: A quality and safety guide for district health boards*. http://www.hqsc.govt.nz/our-programmes/other-topics/publications-and-resources/publication/2488

Hendry, J. (2019). Promoting compassionate care in radiography – What might be suitable pedagogy? A discussion paper. *Radiography*, *25*(3), 269–273. https://doi.org/10.1016/j.radi.2019.01.005

Henwood, S., & Flinton, D. M. (2012). 5 years on: Have attitudes towards continuing professional development in radiography changed? *Radiography*, *18*(3), 179–183. https://doi.org/10.1016/j.radi.2012.04.001

Henwood, S., & Munro, L. (2013). Principles of communication. In Aarthi Ramlaul & M. Vosper (Eds.), *Patient centred care in medical imaging and radiotherapy* (pp. 3–6). Elsevier.

Herrmann, T., Fauber, T. L., Gill, J., Hoffman, C., Orth, D., Peterson, P., Prouty, R. R., Woodward, A., & Odle, T. G. (2012). Best practices in digital radiography. In *American Society of Radiologic Technologists*. https://doi.org/84/1/83 [pii]

Hickman, L. (2009). John Dewey: His life and work. In Larry Hickman, S. Neubert, & K. Reich (Eds.), *John Dewey between pragmatism and constructivism* (pp. 3–18). Fordham University Press.

Holland, K., Middleton, L., & Uys, L. (2012). Professional confidence: A concept analysis. *Scandinavian Journal of Occupational Therapy*, *19*, 214–224. https://doi.org/10.3109/11038128.2011.583939

Holloway, K., Arcus, K., & Orsborn, G. (2018). Training needs analysis – The essential first step for continuing professional development design. *Nurse Education in Practice*, *28*, 7–12. https://doi.org/10.1016/j.nepr.2017.09.001

Honey, I. D., & Hogg, P. (2012). Balancing radiation dose and image quality in diagnostic imaging. *Radiography*, *18*(1). https://doi.org/10.1016/j.radi.2011.10.005

Huang, S. C., Pareek, A., Seyyedi, S., Banerjee, I., & Lungren, M. P. (2020). Fusion of medical imaging and electronic health records using deep learning: a systematic review and implementation guidelines. *Digital Medicine*, *3*(1). https://doi.org/10.1038/s41746-020-00341-z

Huda, W., & Abrahams, R. B. (2015). Radiographic techniques, contrast, and noise in x-ray imaging. *American Journal of Roentgenology*, *204*(2), W126–W131. https://doi.org/10.2214/AJR.14.13116

Huda, W., Smith, D. A., & Staab, E. V. (1997). Current status of Computed Radiography in emergency departments. *Journal of Digital Imaging*, *10*(4). https://doi.org/10.1136/bmj.2.6101.1545-a

Huenges, B., Woestmann, B., Ruff-Dietrich, S., & Rusche, H. (2017). Self-assessment of competence during post-graduate training in general medicine: A preliminary study to develop a portfolio for further education. *GMS Journal for Medical Education*, *34*(5), 1–17. https://doi.org/10.3205/zma001145

Hunt, M. R. (2009). Strengths and challenges in the use of interpretive description: Reflections arising from a study of the moral experience of health professionals in humanitarian work. *Qualitative Health Research*, *19*(9), 1284–1292. https://doi.org/10.1177/1049732309344612

Hutton, D., Beardmore, C., Patel, I., Massey, J., Wong, H., & Probst, H. (2014). Audit of the job satisfaction levels of the UK radiography and physics workforce in UK radiotherapy centres 2012. *British Journal of Radiology*, *87*(1039). https://doi.org/10.1259/bjr.20130742

Hyde, E., & Hardy, M. (2020). Patient centred care in diagnostic radiography (Part 1): Perceptions of service users and service deliverers. *Radiography*, *27*(1), 8–13. https://doi.org/10.1016/j.radi.2020.04.015

Hyde, E., & Hardy, M. (2021a). Patient centred care in diagnostic radiography (Part 2): A qualitative study of the perceptions of service users and service deliverers. *Radiography*, *27*(2), 322–331. https://doi.org/10.1016/j.radi.2020.09.008

Hyde, E., & Hardy, M. (2021b). Patient centred care in diagnostic radiography (Part 3): Perceptions of student radiographers and radiography academics. *Radiography*, *27*(3), 803–810. https://doi.org/10.1016/j.radi.2020.04.015

Illeris, K. (2009). A comprehensive undertsanding of human learning. In K. Illeris (Ed.), *Contemporary theories of learning. Learning theorists...in their own words* (pp. 7–20). Routledge.

Ingebrigtsen, T., Georgiou, A., Clay-Williams, R., Magrabi, F., Hordern, A., Prgomet, M., Li, J., Westbrook, J., & Braithwaite, J. (2014). The impact of clinical leadership on health information technology adoption: Systematic review. *International Journal of Medical Informatics*, *83*(6), 393–405.

https://doi.org/10.1016/j.ijmedinf.2014.02.005

Institute of Medicine. (2001). Crossing the quality chasm: A new health system for the 21st Century. In *Committee on the Quality of Health Care in America*. National Academies Press. https://doi.org/10.1136/bmj.323.7322.1192

International Accreditation New Zealand. (n.d.). *International Accreditation New Zealand*. Retrieved April 18, 2021, from https://www.ianz.govt.nz/

International Atomic Energy Agency. (2011). *Avoidance of unnecessary dose to patients while transitioning from analogue to digital radiology*. https://www-pub.iaea.org/MTCD/Publications/PDF/te_1667_web.pdf

International Atomic Energy Agency. (2009). Justification of medical exposure in Diagnostic Imaging. *Proceedings Of An International Workshop*, 1–190.

International Atomic Energy Agency. (2015). Radiation protection in medicine: Setting the scene for the next decade. *Proceedings of an International Conference, December*, 2–17. https://www.iaea.org/publications/10611/radiation-protection-in-medicine-setting-the-scene-for-the-next-decade

International Commission on Radiological Protection. (2007). The 2007 recommendations of the International Commission on Radiological Protection. In *ICRP Publication 103* (Issue Ann. ICRP 37 (2-4)). https://www.icrp.org/publication.asp?id=ICRP Publication 103

International Electrotechnical Commission. (2008). *IEC 62494-1 ed. 1. Medical electrical equipment—exposure index of digital x-ray imaging systems—part 1: definitions and requirements for general radiography.* International Electrotechnical Commission.

Itri, J. N. (2015). Patient-centered radiology. *Radiographics*, *35*(6), 1835–1848. https://doi.org/10.1148/rg.2015150110

Itri, J. N., Tappouni, R. R., McEachern, R. O., Pesch, A. J., & Patel, S. H. (2018). Fundamentals of diagnostic error in imaging. *Radiographics*, *38*(6), 1845–1865. https://doi.org/10.1148/rg.2018180021

Jacobs, R. L. (2002). Institutionalizing organizational change through cascade training. *Journal of European Industrial Training*, *26*(2), 177–182.

https://doi.org/10.1108/03090590210422058

Jain, S. J. (2014). Pursuing a radiology career: Private practice or academic? *Indian Journal of Radiology and Imaging*, *24*(3), 207–209. https://doi.org/10.4103/0971-3026.137021

Jamil, A., Mohd, M. I., & Zain, N. M. (2018). The consistency of exposure indicator values in digital radiography systems. *Radiation Protection Dosimetry*, *182*(4), 413–418. https://doi.org/10.1093/rpd/ncy082

Johnson, R. B., de Waal, C., Stefurak, T., & Hildebrand, D. L. (2017). Understanding the philosophical positions of classical and neopragmatists for mixed methods research. *Kolner Zeitschrift Fur Soziologie Und Sozialpsychologie*, *69*, 63–86. https://doi.org/10.1007/s11577-017-0452-3

Johnson, R. B., & Onwuegbuzie, A. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, *33*(7), 14–26. https://doi.org/10.3102/0013189X033007014

Johnston, J., Comello, R. J., Vealé, B. L., & Killion, J. (2010). Radiation exposure dose trends and radiation dose reduction strategies in medical imaging. *Journal of Medical Imaging and Radiation Sciences*, *41*(3), 137–144. https://doi.org/10.1016/j.jmir.2010.06.003

Jones, A. K., Ansell, C., Jerrom, C., & Honey, I. D. (2015). Optimization of image quality and patient dose in radiographs of paediatric extremities using direct digital radiography. *British Journal of Radiology*, *88*(1050). https://doi.org/10.1259/bjr.20140660

Jones, A. K., Heintz, P., Geiser, W., Goldman, L., Jerjian, K., Martin, M., Peck, D., Pfeiffer, D., Ranger, N., & Yorkston, J. (2015). Ongoing quality control in digital radiography: Report of AAPM Imaging Physics Committee Task Group 151. *Medical Physics*, *42*, 6658–6670. https://doi.org/10.1118/1.4932623

Jones, D. N., Thomas, M. J. W., Mandel, C., Grimm, J., Hannaford, N., Schultz, T. J., & Runciman, W. (2010). Where failures occur in the imaging care cycle: Lessons from the radiology events register. *Journal of the American College of Radiology*, *7*(8), 593–602. https://doi.org/10.1016/j.jacr.2010.03.013

Joseph, M., Inayat, S., Hussain, M., & Afzal, M. (2019). Factors influencing nurses' attitudes towards information technology in nursing practice. *European Academic Research*, *7*(3), 1751–1769.

Joyce, M., & O'Leary, D. (2014). The increased source to image-receptor distance technique: What is preventing implementation in clinical practice? *Journal of Medical Imaging and Radiation Sciences*, *45*, 260–268. https://doi.org/10.1016/j.jmir.2014.04.003

Kagadis, G. C., Walz-Flannigan, A., Krupinski, E. A., Nagy, P. G., Katsanos, K., Diamantopoulos, A., & Langer, S. G. (2013). Medical imaging displays and their use in image interpretation. *Radiographics*, *33*(1), 275–290. https://doi.org/10.1148/rg.331125096

Kanamu, L. G., van Dyk, B., Chipeya, L., & Kilaha, S. N. (2017). Barriers to continuous professional development participation for radiographers in Kenya. *African Journal of Health Professions Education*, *9*(1), 17. https://doi.org/10.7196/ajhpe.2017.v9i1.605

Karahanna, E., Evaristo, J. R., & Srite, M. (2005). Levels of culture and individual behavior: An integrative perspective. *Journal of Global Information Management*, *13*(2), 1–20. https://doi.org/10.4018/jgim.2005040101

Karuppan, C. M. (2000). Training super users in large health care facilities. *Journal of Information Technology Management*, *XI*(2–4), 21–27.

Kasprzyk, L., Chmaj-Wierzchowska, K., & Jurczyk, M. U. (2020). Physical parameters affecting the distribution of X-ray dose during hysterosalpingography. *Clinical and Experimental Obstetrics & Gynecology*, *47*(5), 729–735. https://doi.org/10.31083/j.ceog.2020.05.5262

Katowa-Mukwato, P., & Banda, S. (2016). Self-perceived versus objectively measured competence in performing clinical practical procedures by final year medical students. *International Journal of Medical Education*, *7*, 122–129. https://doi.org/10.5116/ijme.5709.2a7e

Kaushik, V., & Walsh, C. A. (2019). Pragmatism as a research paradigm and its implications for Social Work research. *Social Sciences*, *8*(9). https://doi.org/10.3390/socsci8090255

Kennedy, A. (2005). Models of continuing professional development: A framework for analysis. *Journal of In-Service Education*, *31*(2), 235–250. https://doi.org/10.1080/13674580500200277

Khalil, H. (2016). Knowledge translation and implementation science: What is the difference? *International Journal of Evidence-Based Healthcare*, *14*(2), 39–40. https://doi.org/10.1097/XEB.0000000000000086

Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, *6*(5), 26–41. https://doi.org/10.5430/ijhe.v6n5p26

Kolb, A. Y., & Kolb, D. A. (2009). The Learning Way Meta-cognitive aspects of experiential learning. *Simulation & Gaming*, *40*(3), 297–327. https://doi.org/10.1177/1046878108325713

Korica, M., & Molloy, E. (2010). Making sense of professional identities: Stories of medical professionals and new technologies. *Human Relations*, *63*(12), 1879–1901. https://doi.org/10.1177/0018726710367441

Korner, M., Weber, C. H., Wirth, S., Pfeifer, K.-J., Resier, M. F., Treitl, M., Reiser, M. F., & Treitl, M. (2007). Advances in digital radiography: Physical principles and system overview. *RadioGraphics*, *27*(3), 675–686. https://doi.org/10.1093/ndt/gfw200.40

Krosnick, J. A., & Presser, S. (2010). Question and questionnaire design. In P. V. Marsden & J. D. Wright (Eds.), *Handbook of survey research* (2nd ed., pp. 263–313). Emerald Group Publishing Ltd.

Kroth, P. J., Morioka-Douglas, N., Veres, S., Babbott, S., Poplau, S., Qeadan, F., Parshall, C., Corrigan, K., & Linzer, M. (2019). Association of electronic health record design and use factors with clinician stress and burnout. *JAMA Network Open*, *2*(8), e199609. https://doi.org/10.1001/jamanetworkopen.2019.9609

Kumar, R. (2014). *Research methodology. A step-by-step guide for beginners* (4th ed.). SAGE Publications Ltd.

Kumar, R. D. C. (2013). Leadership in healthcare. *Anaesthesia and Intensive Care Medicine*, *14*(1), 39–41. https://doi.org/10.1016/j.mpaic.2012.11.006

Laal, M. (2013). Innovation process in medical imaging. *Procedia - Social and Behavioral Sciences*, *81*, 60–64. https://doi.org/10.1016/j.sbspro.2013.06.388

Lança, L., & Silva, A. (2013). Digital radiography detectors: A technical overview. In *Digital Imaging Systems for Plain Radiography* (pp. 9–19). Springer. https://doi.org/10.6009/jjrt.2012_JSRT_68.8.961

Larkin, G. V. (1978). Medical dominance and control: Radiographers in the division of labour. *The Sociological Review*, *26*(4), 843–858. https://doi.org/10.1111/j.1467-954X.1978.tb00747.x

Larmer, P. J. (2009). *Ankle sprains: An investigation into patient perceptions and performance of physical tasks following acute ankle sprains using a mixed methods approach*. Auckland University of Technology.

Larson, D. B., Kruskal, J. B., Krecke, K. N., & Donnelly, L. F. (2015). Key concepts of patient safety in radiology. *Radiographics*, *35*(6), 1677–1693. https://doi.org/10.1148/rg.2015140277

Larsson, W. (2009). *Digital imaging use influence of digitalization on radiographers' work practice and knowledge demands*. Karolinska Institutet.

Larsson, W., Aspelin, P., Bergquist, M., Hillergård, K., Jacobsson, B., Lindsköld, L., Wallberg, J., & Lundberg, N. (2006). The effects of PACS on radiographer's work practice. *Radiography*, *13*, 235–240. https://doi.org/10.1016/j.radi.2006.02.005

Larsson, W., Aspelin, P., & Lundberg, N. (2013). Learning strategies in the planning and evaluation phase of image production. *Radiography*, *19*(4), 347–352. https://doi.org/10.1016/j.radi.2013.07.003

Larsson, W., Lundberg, N., & Hillergård, K. (2009). Use your good judgement - Radiographers' knowledge in image production work. *Radiography*, *15*(3). https://doi.org/10.1016/j.radi.2008.09.003

Lathoura, S., Dimitrakaki, C., Notara, V., Sakellari, E., & Lagiou, A. (2020). Person-Centered approach in radiology primary health care: A cross-sectional study. *International Journal of Caring Sciences*, *13*(2), 1240–1249.

Lee, C. S., Nagy, P. G., Weaver, S. J., & Newman-Toker, D. E. (2013). Cognitive and system factors contributing to diagnostic errors in radiology. *American Journal of Roentgenology*, *201*, 611–617. https://doi.org/10.2214/AJR.12.10375

Lehmann, P., Richli-Meystre, N., & Mamboury, N. (2014). Factors for lifelong job retention among Swiss radiographers. *Radiography*, *21*(2), 181–187. https://doi.org/10.1016/j.radi.2014.11.002

Lehnert, T., Naguib, N. N., Ackermann, H., Schomerus, C., Jacobi, V., Balzer, J. O., & Vogl, T. J. (2011). Novel, portable, cassette-sized, and wireless flat-panel digital radiography system: initial workflow results versus computed radiography. *American Journal of Roentgenology*, *196*(6), 1368–1371. https://doi.org/10.2214/AJR.10.5867

Levin, M., & Greenwood, D. (2011). Revitalizing universities by reinventing the social sciences: Bildung and Action Research. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (4th ed., pp. 27–42). SAGE Publicatons Inc.

Lewis, S. J., Heard, R., Robinson, J., White, K., & Poulos, A. (2008). The ethical commitment of Australian radiographers: Does medical dominance create an influence? *Radiography*, *14*(2), 90–97. https://doi.org/10.1016/j.radi.2007.01.004

Lewis, S., Pieterse, T., & Lawrence, H. (2019a). Evaluating the use of exposure indicators in digital x-ray imaging system: Gauteng South Africa. *Radiography*, *25*(3), e58–e62. https://doi.org/10.1016/j.radi.2019.01.003

Lewis, S., Pieterse, T., & Lawrence, H. (2019b). Retrospective evaluation of exposure indicators: a pilot study of exposure technique in digital radiography. *Journal of Medical Radiation Sciences*, *66*(1), 38–43. https://doi.org/10.1002/jmrs.317

LoBiondo-Wood, G., & Haber, J. (2006). *Nursing research: Methods and critical appraisal for evidence-based practice*. Mosby.

Lohikoski, K., Roos, M., & Suominen, T. (2019). Workplace culture assessed by radiographers in Finland. *Radiography*, *25*(4), e113–e118. https://doi.org/10.1016/j.radi.2019.05.003

Lomax, R. (2013). Introduction to structural equation modeling. In Y. Petscher, C. Schatschneider, & D. L. Compton (Eds.), *Applied quantitative analysis in Education and the Social Sciences* (pp. 245–264). Taylor & Francis Group.

Long, K. M., McDermott, F., & Meadows, G. N. (2018). Being pragmatic about healthcare complexity: Our experiences applying complexity theory and pragmatism to health services research. *BMC Medicine*, *16*(1), 1–9. https://doi.org/10.1186/s12916-018-1087-6

Loria, K. (2017). The DR transformation. *Radiology Today*, *18*(4), 20.

Loudon, J. (2012). Applying project management processes to successfully complete projects in radiation medicine. *Journal of Medical Imaging and Radiation Sciences*, *43*, 253–258. https://doi.org/http://dx.doi.org/10.1016/j.jmir.2012.09.003

Lundvall, L. L. (2019). *Radiography in practice- Work and learning in medical imaging*. Linkoping University.

Lundvall, L. L., Abrandt-Dahlgren, M., & Wirell, S. (2015). How do technical improvements change radiographers' practice - A practice theory perspective. *Radiography*, *21*(3), 231–235. https://doi.org/10.1016/j.radi.2014.12.002

Lundvall, L. L., Dahlgren, M. A., & Wirell, S. (2014). Professionals' experiences of imaging in the radiography process - A phenomenological approach. *Radiography*, *20*, 48–52. https://doi.org/10.1016/j.radi.2013.10.002

Machen, S., Jani, Y., Turner, S., Marshall, M., & Fulop, N. J. (2019). The role of organizational and professional cultures in medication safety: A scoping review of the literature. *International Journal for Quality in Health Care*, *31*(10), G146–G157. https://doi.org/10.1093/intqhc/mzz111

Makanjee, C. R., Bergh, A. M., & Hoffmann, W. A. (2015). Healthcare provider and patient perspectives on diagnostic imaging investigations. *African Journal of Primary Health Care and Family Medicine*, *7*(1), 1–10. https://doi.org/10.4102/phcfm.v7i1.801

Makanjee, C. R., Bergh, A. M., & Hoffmann, W. A. (2018). Distributed decision making in action: diagnostic imaging investigations within the bigger picture. *Journal of Medical Radiation Sciences*, *65*(1), 5–12. https://doi.org/10.1002/jmrs.250

Makanjee, C. R., Xu, D., Sarswat, D., & Bergh, A. M. (2020). "It is just part of life": Patient perspectives and experiences of diagnostic imaging referrals. *Australian Journal of Primary Health*, *26*(6), 507–513. https://doi.org/10.1071/PY20146

Malin, N. (2017). Developing an analytical framework for understanding the emergence of de-professionalisation in health, social care and education sectors. *Social Work and Social Sciences Review*, *19*(1), 66–162. https://doi.org/10.1921/swssr.v19i1.1082

Malterud, K., Siersma, V. D., & Guassora, A. D. (2016). Sample size in qualitative interview studies: Guided by information power. *Qualitative Health Research*, *26*(13), 1753–1760. https://doi.org/10.1177/1049732315617444

Mann, C. J. (2003). Observational research methods. Research design II: Cohort, cross sectional, and case-control studies. *Emergency Medicine Journal*, *20*(1), 54–60. https://doi.org/10.1136/emj.20.1.54

Margulis, A. R. (2010). The constantly changing field of radiology: Maintaining professionalism in an era of electronic communication. *Radiology*, *257*(1), 22–23. https://doi.org/10.1148/radiol.10100691

Margulis, A. R., & Sunshine, J. H. (2000). Radiology at the turn of the Millennium. *Radiology*, *214*(2), 15–23.

Marsh, R. M. (2020). Patient shielding in 2020. *Journal of the American College of Radiology*, *17*(9), 1183–1185. https://doi.org/10.1016/j.jacr.2020.03.024

Marshall, G. (2005). The purpose, design and administration of a questionnaire for data collection. *Radiography*, *11*, 131–136. https://doi.org/10.1016/j.radi.2004.09.002

McFadden, S., Roding, T., de Vries, G., Benwell, M., Bijwaard, H., & Scheurleer, J. (2018). Digital imaging and radiographic practise in diagnostic radiography: An overview of current knowledge and practice in Europe. *Radiography*, *24*(2), 137–141. https://doi.org/10.1016/j.radi.2017.11.004

McHugh, K. (2020). Image enhancement. In C. M. Hayre & W. A. S. Cox (Eds.), *General radiography. Principles and practices* (1st ed., pp. 31–57). CRC Press.

Meli, M., Ouma, J., & Kangau, O. (2016). *Nurses experience on modern technologies and patient safety within the gerontology care in Finland*. JAMK University of Applied Sciences.

Merriam-Webster. (n.d.-a). *Black box*. Merriam-Webster.Com Dictionary. Retrieved July 31, 2021, from https://www.merriam-webster.com/dictionary/black box

Merriam-Webster. (n.d.-b). *Muddle through*. Merriam-Webster.Com Dictionary. Retrieved July 12, 2021, from https://www.merriam-webster.com/dictionary/muddle through

Metsälä, E., & Fridell, K. (2018). Insights into the methodology of radiography science. *Radiography*, e105–e108. https://doi.org/10.1016/j.radi.2018.05.010

Mettler, F. A., Ringertz, H., & Vano, E. (2003). Managing patient dose in digital radiology. *Annals of the ICRP*, *93*. https://doi.org/10.1177/146808740500600401

Miettinen, R. (2000). The concept of experiential learning and john dewey's theory of reflective thought and action. *International Journal of Lifelong Education*, *19*(1), 54–72. https://doi.org/10.1080/026013700293458

Miller, J. M. (2020). Reflective practice and health sciences librarians: Engagement, benefits, and barriers. *Journal of the Medical Library Association*, *108*(1), 17–28. https://doi.org/10.5195/jmla.2020.777

Ministry of Health. (2003). Improving quality (IQ): A systems approach for the New Zealand health and disability sector. In *Ministry of Health* (Vol. 116, Issue 1182).

Ministry of Health. (2018). *Code of Practice for Diagnostic and Interventional Radiology: ORS C1*. Ministry of Health.

Moey, S.-F., & Shazli, Z. A. (2018). A phantom study for the optimization of image quality and radiation dose for common radiographic examinations in digital radiography. *Iranian Journal of Medical Physics*, *15*, 271–276. https://doi.org/10.22038/ijmp.2018.29825.1325

Moodley, I., & Moodley, S. (2015). A comparative cost analysis of picture archiving and communications systems (PACS) versus conventional radiology in the private sector. *South African Journal of Radiology*, *19*(1), 1–7. https://doi.org/10.4102/sajr.v19i1.634

Moolman, N., Mulla, F., & Mdletshe, S. (2020). Radiographer knowledge and practice of paediatric radiation dose protocols in digital radiography in Gauteng. *Radiography*, *26*, 117–121. https://doi.org/10.1016/j.radi.2019.09.006

Moore, Q. T. (2016). An interdisciplinary approach to improving radiation protection in digital radiography. *Radiologic Technology*, *88*(1), 9–17.

Moore, Q. T., Don, S., Goske, M. J., Strauss, K. J., Cohen, M. D., Herrmann, T., MacDougall, R., Noble, L., Morrison, G., John, S. D., & Lehman, L. (2012). Image gently: Using exposure indicators to improve pediatric digital radiography.

Radiologic Technology, *84*(1), 93–99.

Morgan, D. L. (2007). Paradigms lost and Pragmatism: Regained methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research*, *1*(1), 48–76. https://doi.org/10.1177/2345678906292462

Morgan, D. L. (2014). Pragmatism as a paradigm for social research. *Qualitative Inquiry*, *20*(8), 1045–1053. https://doi.org/10.1177/1077800413513733

Morrison, G., John, S. D., Goske, M. J., Charkot, E., Herrmann, T., Smith, S. N., Culbertson, J., & Carbonneau, K. (2011). Pediatric digital radiography education for radiologic technologists: current state. *Pediatr Radiol*, *41*(5), 602–610. https://doi.org/10.1007/s00247-010-1904-3

Morse, J. M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification strategies for establishing reliability and validity in qualitative research. *International Journal of Qualitative Methods*, *1*(2), 13–22. https://doi.org/10.1177/160940690200100202

Mothiram, U. (2014). *Factors affecting digital radiography exposure indices: are radiographers achieving the recommended levels?* University of Sydney.

Mothiram, U., Brennan, P. C., Lewis, S. J., Moran, B., & Robinson, J. (2014). Digital radiography exposure indices: A review. *Journal of Medical Radiation Sciences*, *61*(2), 112–118. https://doi.org/10.1002/jmrs.49

Mothiram, U., Brennan, P. C., Robinson, J., Lewis, S. J., & Moran, B. (2013). Retrospective evaluation of exposure index (EI) values from plain radiographs reveals important considerations for quality improvement. *Journal of Medical Radiation Sciences*, *60*(4), 115–122. https://doi.org/10.1002/jmrs.25

Mount, J. (2016). Reject analysis: A comparison of radiographer and radiologist perceptions of image quality. *Radiography*, *22*(2), e112–e117. https://doi.org/10.1016/j.radi.2015.12.001

Mukhalalati, B. A., & Taylor, A. (2019). Adult learning theories in context: A quick guide for healthcare professional educators. *Journal of Medical Education and Curricular Development*, *6*, 238212051984033. https://doi.org/10.1177/2382120519840332

Munn, Z., McArthur, A., Mander, G. T. W., Steffensen, C. J., & Jordan, Z. (2020). The only constant in radiography is change: A discussion and primer on change in medical imaging to achieve evidence-based practice. *Radiography*, *26*(xxxx), S3–S7. https://doi.org/10.1016/j.radi.2020.07.001

Murphy, A., Ekpo, E., Steffens, T., & Neep, M. J. (2019). Radiographic image interpretation by Australian radiographers: a systematic review. *Journal of Medical Radiation Sciences*, *66*(4), 269–283. https://doi.org/10.1002/jmrs.356

Murphy, F. J. (2006). The paradox of imaging technology: A review of the literature. *Radiography*, *12*(2), 169–174. https://doi.org/10.1016/j.radi.2005.03.011

Nagy, P. G., Pierce, B., Otto, M., & Safdar, N. M. (2008). Quality control management and communication between radiologists and technologists. *Journal of the American College of Radiology*, *5*(6), 759–765. https://doi.org/10.1016/j.jacr.2008.01.013

Nahapiet, J., & Ghoshal, S. (1998). Social capital, intellectual capital, and the organizational advantage. *Academy of Management Review*, *23*(2), 242–266.

Neubert, S. (2009). Pragmatism: Diversity of subjects in Dewey's philosophy and the present Dewey scholarship. In Larry Hickman, S. Neubert, & K. Reich (Eds.), *John Dewey between pragmatism and constructivism* (pp. 19–38). Fordham University Press.

New Zealand Health Information Service. (2007). Selected Health Professional Workforce in New Zealand 2006. In *Ministry of Health*.

Newton-Hughes, A. (2015). *A focussed ethnographic study of diagnostic radiographer problem solving in the trauma setting*. University of Salford.

Niemi, A., & Paasivaara, L. (2007). Meaning contents of radiographers' professional identity as illustrated in a professional journal - A discourse analytical approach. *Radiography*, *13*, 258–264. https://doi.org/10.1016/j.radi.2006.03.009

Nilsen, P., Neher, M., Ellström, P. E., & Gardner, B. (2017). Implementation of evidence-based practice from a learning perspective. *Worldviews on Evidence-Based Nursing*, *14*(3), 192–199. https://doi.org/10.1111/wvn.12212

Nixon, S. (2001). Professionalism in radiography. *Radiography*, *7*, 31–35. https://doi.org/10.1053/radi.2000.0292

Nol, J., Isouard, G., & Mirecki, J. (2006). Digital repeat analysis; setup and operation. *Journal of Digital Imaging*, *19*(2), 159–166. https://doi.org/10.1007/s10278-005-8733-1

Nortjé, N., & Hoffmann, W. A. (2018). Perspectives on the development of professionalism as experienced by radiography students. *Radiography*, *24*, 110–114. https://doi.org/10.1016/j.radi.2017.09.006

Nulty, D. D. (2008). The adequacy of response rates to online and paper surveys: What can be done? *Assessment and Evaluation in Higher Education*, *33*(3), 301–314. https://doi.org/10.1080/02602930701293231

O'Cathain, A. (2010). Assessing the quality of mixed methods research: Toward a comprehensive framework. In A. Tashakkori & C. Teddlie (Eds.), *The SAGE handbook of mixed methods in social & behavioral research* (2nd ed., pp. 531–556). SAGE Publications Inc. https://doi.org/10.4135/9781506335193.n21

O'Cathain, A., Murphy, E., & Nicholl, J. (2008). The quality of mixed methods studies in health services research. *Journal of Health Services Research and Policy*, *13*(2), 92–98. https://doi.org/10.1258/jhsrp.2007.007074

Odle, T. G. (2019). Patient-centered care in breast imaging. *Radiologic Technology*, *90*(3), 259M-277M.

Ono, Y., & Ferreira, J. (2010). A case study of continuing teacher professional development through lesson study in South Africa. *South African Journal of Education*, *30*, 59–74.

Onwuegbuzie, A., & Combs, J. P. (2015). Emergent data analysis techniques in mixed methods research: A synthesis. In A. Tashakkori & C. Teddlie (Eds.), *The SAGE handbook of mixed methods in social & behavioral research* (pp. 397–430). https://doi.org/10.4135/9781506335193.n17

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement* (2nd ed.). Continuum.

Owens, P. L. (2006). One more reason not to cut your training budget: The relationship between training and organizational outcomes. *Public Personnel Management*, *35*(2), 163–172. https://doi.org/10.1177/009102600603500205

Oxford Dictionary. (n.d.). *Button pusher*. Lexicon.Com.Dictionary. Retrieved July 22, 2021, from https://www.lexico.com/definition/button_pusher

Pallant, J. (2016). *SPSS survival manual. A step by step guide to data analysis using IBM SPSS* (6th ed.). Allen & Unwin.

Palmer, G. R., & Short, S. D. (2000). *Health care and public policy: An Australian analysis.* (3rd ed.). Macmillan Education Australia.

Papathanasiou, S., Walton, L. A., & Thompson, J. D. (2020). A systematic review of viewing conditions and monitor specifications in mammography. *Radiography*, *xxxx*, 1–7. https://doi.org/10.1016/j.radi.2020.03.001

Patton, M. (2002). *Qualitative methods and evaluation* (3rd ed.). SAGE Publications Inc.

Pederson, D. (1992). The problems and limitations of survey research. In N. S. Scrimshaw & G. R. Gleason (Eds.), *RAP, Rapid Assessment Procedures, qualitative methodologies for planning and evaluation of health related programmes*. International Nutrition Foundation for Developing Countries.

Peels, R. (2019). Replicability and replication in the humanities. *Research Integrity and Peer Review*, *4*(1), 1–12. https://doi.org/10.1186/s41073-018-0060-4

Peer, S., Peer, R., & Jaschke, W. (2006). Large PACS projects. In W. Hruby (Ed.), *Digital (R)evolution in radiology. Bridging the future of health care* (2nd ed., pp. 71–77). SpringerWien.

Peters, S. E., & Brennan, P. C. (2002). Digital radiography: Are the manufacturers' settings too high? Optimisation of the Kodak digital radiography system with aid of the computed radiography dose index. *European Radiology*, *12*(9), 2381–2387. https://doi.org/10.1007/s00330-001-1230-0

Pilz, M. (2009). Initial vocational training from a company perspective: A comparison of British and German in-house training cultures. *Vocations and Learning*, *2*(1), 57–74. https://doi.org/10.1007/s12186-008-9018-x

Pinto, A. (2010). Spectrum of diagnostic errors in radiology. *World Journal of Radiology*, *2*(10), 377–383. https://doi.org/10.4329/wjr.v2.i10.377

Pollard, N., Lincoln, M., Nisbet, G., & Penman, M. (2019). Patient perceptions of communication with diagnostic radiographers. *Radiography*, *25*(4), 333–338.

https://doi.org/10.1016/j.radi.2019.04.002

Potthoff, S., Rasul, O., Sniehotta, F. F., Marques, M., Beyer, F., Thomson, R., Avery, L., & Presseau, J. (2019). The relationship between habit and healthcare professional behaviour in clinical practice: a systematic review and meta-analysis. *Health Psychology Review*, *13*(1), 73–90. https://doi.org/10.1080/17437199.2018.1547119

Prasad, M. (2021). Pragmatism as problem solving. *Socius: Sociological Research for a Dynamic World*, *7*, 1–13. https://doi.org/10.1177/2378023121993991

Precht, H., Waaler, D., Outzen, C., Brock Thorsen, J. B., Steen, T., Hellfritzsch, M. B., Aagesen, H., Holst, A. K., Le, P., Lindequist, S., Rasmussen, L., & Tingberg, A. (2019). Does software optimization influence the radiologists' perception in low dose paediatric pelvic examinations? *Radiography*, *25*, 143–147. https://doi.org/10.1016/j.radi.2018.12.013

Price, R. C. (2001). Radiographer reporting: Origins, demise and revival of plain film reporting. *Radiography*, *7*(2), 105–117. https://doi.org/10.1053/radi.2001.0281

Price, R. C. (2009a). Diploma to degree 1976 to 1993. *Radiography*, *15*, e67–e71. https://doi.org/10.1016/j.radi.2009.10.007

Price, R. C. (2009b). Technology and its consequences. *Radiography*, *15*(3), 185–186. https://doi.org/10.1016/j.radi.2009.06.001

Prud'homme, J. (2010). 'Professional Techs': Machines, technical skills and professional aspirations in hearing prosthetics and respiratory care in Quebec, 1950-1990. *Canadian Journal of the History of Science, Technology and Medicine*, *33*(1), 71–94.

Radiation Safety Act 2016, (2016). https://www.legislation.govt.nz/act/public/2016/0006/latest/whole.html#DLM6339524

Ragab, M., & Arisha, A. (2018). Research methodology in business: A starter's guide. *Management and Organisational Studies*, *5*(1), 0–23.

Rajiah, P., & Bhargava, P. (2017). Change management—A radiology administrator's primer. *Current Problems in Diagnostic Radiology*, *46*(5), 382–384.

https://doi.org/10.1067/j.cpradiol.2017.06.010

Rao, R., Venkatesan, R., & Geethanath, S. (2015). Role of MRI in medical diagnostics. *Resonance: Journal of Science Education*, 1003–1011.

Rattray, J., & Jones, M. C. (2007). Essential elements of questionnaire design and development. *Journal of Clinical Nursing*, *16*(2), 234–243. https://doi.org/10.1111/j.1365-2702.2006.01573.x

Redfern, R. O., Langlotz, C. P., Abbuhl, S. B., Polansky, M., Horii, S. C., & Kundel, H. L. (2002). The effect of PACS on the time required for technologists to produce radiographic images in the emergency department radiology suite. *Journal of Digital Imaging*, *15*(3), 153–160. https://doi.org/10.1007/s10278-002-0024-5

Reeves, P. J. (2008). Research in medical imaging and the role of the consultant radiographer: A discussion. *Radiography*, *14*(SUPPL. 1). https://doi.org/10.1016/j.radi.2008.11.004

Reeves, P. J., & Decker, S. (2012). Diagnostic radiography: A study in distancing. *Radiography*, *18*(2), 78–83. https://doi.org/10.1016/j.radi.2012.01.001

Reich, K. (2009). Constructivism: Diversity of approaches and connections with pragmatism. In L. Hickman, S. Neubert, & K. Reich (Eds.), *John Dewey between pragmatism and constructivism* (pp. 39–64). Fordham University Press. https://doi.org/10.5422/fso/9780823230181.003.0003

Reiner, B. I., Siegel, E. L., Carrino, J. A., & Goldburgh, M. M. (2002). SCAR radiologic technologist survey: Analysis of the impact of digital technologies on productivity. *Journal of Digital Imaging*, *15*(3), 132–140. https://doi.org/10.1007/s10278-002-0021-8

Reiner, B. I., Siegel, E. L., Hooper, F. J., & Glasser, D. (1998). Effect of film-based versus filmless operation on the productivity of CT technologists. *Radiology*, *207*(2). https://doi.org/10.1148/radiology.207.2.9577498

Reiner, B. I., Siegel, E. L., & Krupinski, E. A. (2003). Digital radiographic image presentation and display. *Advances in Digital Radiography: RSNA Categorical Course in Diagnostic Radiology Physics*, *21201*, 79—89.

Reingold, L. (2015). Evaluation of stress and a stress-reduction program among radiologic technologists. *Radiologic Technology*, *87*(2), 150–162.

Ritchie, W. G. (1958). Radiographer or button pusher? *Hospital Progress*, 94–97. https://doi.org/10.1055/s-2004-815600

Rivetti, S., Lanconelli, N., Bertolini, M., Nitrosi, A., Burani, A., & Acchiappati, D. (2010). Comparison of different computed radiography systems: Physical characterization and contrast detail analysis. *Medical Physics*, *37*(2), 440–448. https://doi.org/10.1118/1.3284539

Robb, R. A. (2006). Biomedical imaging : Past, present and predictions. *Medical Imaging Technology*, *24*(1), 25–37.

Roberts, P., & Priest, H. (2006). Reliability and validity in research. *Nursing Standard*, *20*(44).

Rogers, H., Pratt, S., Brown, P., & Gambling, T. (2010). Confidence in the use of information management and technology (IM&T) in radiography: Is age a barrier? *Radiography*, *16*(3), 230–237. https://doi.org/10.1016/j.radi.2010.01.006

Rosenkrantz, A. B., Wang, W., Bodapati, S., Hughes, D. R., & Duszak, R. (2017). Private practice radiologist subspecialty classification using Medicare claims. *Journal of the American College of Radiology*, *14*(11), 1419–1425. https://doi.org/10.1016/j.jacr.2017.04.025

Rubio, E. I., & Hogan, L. (2015). Time-Out: It's radiology's turn-incidence of wrong-patient or wrong-study errors. *American Journal of Roentgenology*, *205*(5), 941–946. https://doi.org/10.2214/AJR.15.14720

Ruitenberg, C. W. (2016). The overlapping spheres of medical professionalism and medical ethics: a conceptual inquiry. *Ethics and Education*, *11*(1), 79–90. https://doi.org/10.1080/17449642.2016.1145496

Ruona, W. E. A., & Gilley, J. W. (2009). Practitioners in applied professions: A model applied to human resource development. *Advances in Developing Human Resources*, *11*(4), 438–453. https://doi.org/10.1177/1523422309344719

Sandelowski, M. (2000). Focus on research methods: Whatever happened to qualitative description? *Research in Nursing and Health*, *23*, 334–340. https://doi.org/10.1002/1098-240x(200008)23:4<334::aid-nur9>3.0.co;2-g

Satharasinghe, D. M., Wanninayake, W., Pallewatte, A. S., & Jeyasugiththan, J. (2020). Quantitative analysis of the additional radiation burden due to electronic collimation in digital radiography. *13th International Research Conference - Kotewala Defense University*, 19–22.

Sax, L. J., Gilmartin, S. K., & Bryant, A. N. (2003). Assessing response rates and nonresponse bias in web and paper surveys. *Research in Higher Education*, *44*(4), 409–432. https://doi.org/10.1023/A:1024232915870

Scally, A., & Brealey, S. (2010). Literature evaluation and critique. In A. Ramlaul (Ed.), *Medical imaging and radiotherapy research. Skills and strategies* (pp. 27–43). Churchill Livingstone.

Schaefer-Prokop, C., Neitzel, U., Venema, H. W., Uffmann, M., & Prokop, M. (2008). Digital chest radiography: An update on modern technology, dose containment and control of image quality. *European Radiology*, *18*, 1818–1830. https://doi.org/10.1007/s00330-008-0948-3

Schaefer, D. R., & Dillman, D. A. (1998). Development of a standard e-mail methodology: Results of an experiment. *Public Opinion Quarterly*, *62*(3), 378. https://doi.org/10.1086/297851

Schaetzing, R. (2005). A comparison of screen/film and digital imaging: Image processing, image quality, and dose. In *American Association of Physicists in Medicine*.

Schein, E. H. (2002). Models and tools for stability and change in human systems. *Reflections: The SoL Journal*, *4*(2), 34–46. https://doi.org/10.1162/152417302762251327

Schiavo, R. (2014). *Health communication: From theory to practice* (2nd ed.). Jossey-Bass.

Schmidt, A. F., & Finan, C. (2018). Linear regression and the normality assumption. *Journal of Clinical Epidemiology*, *98*, 146–151. https://doi.org/10.1016/j.jclinepi.2017.12.006

Schoville, R. R. (2009). Work-arounds and artifacts during transition to a computer physician order entry: What they are and what they mean. *Journal of Nursing Care Quality*, *24*(4), 316–324. https://doi.org/10.1097/NCQ.0b013e3181ac8378

Schultz, T. J., Hannaford, N., & Mandel, C. (2016). Patient safety problems from healthcare information technology in medical imaging. *BJR Case Reports*, *2*. https://doi.org/10.1259/bjrcr.20150107

Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching*, *5*(9), 9–16. https://doi.org/10.5539/elt.v5n9p9

Scott, A. W., Zhou, Y., Allahverdian, J., Nute, J. L., & Lee, C. (2016). Evaluation of digital radiography practice using exposure index tracking. *Journal of Applied Clinical Medical Physics*, *17*(6), 343–355.

Sedgwick, P. (2013). Convenience sampling. *BMJ*, *347*, 6304–6304. https://doi.org/10.1136/bmj.f6304

Seeram, E. (2014). The new exposure indicator for digital radiography. *Journal of Medical Imaging and Radiation Sciences*, *45*, 144–158. https://doi.org/10.1016/j.jmir.2014.02.004

Seeram, E. (2019). *Digital radiography. Physical principles and quality control* (2nd ed.). Springer Nature Singapore Pte.Ltd. https://doi.org/10.1007/978-981-13-3244-9

Seeram, E., Davidson, R., Bushong, S., & Swan, H. (2013). Radiation dose optimization research: Exposure technique approaches in CR imaging - A literature review. *Radiography*, *19*, 331–338. https://doi.org/10.1016/j.radi.2013.07.005

Seeram, E., Davidson, R., Bushong, S., & Swan, H. (2015). Education and training required for the digital radiography environment: A non-interventional quantitative survey study of radiologic technologists. *International Journal of Radiology & Medical Imaging*, *1*(1). https://doi.org/10.15344/2456-446x/2015/103

Seeram, E., Davidson, R., Bushong, S., & Swan, H. (2016). Optimizing the exposure indicator as a dose management strategy in computed radiography. *Radiologic Technology*, *87*(4), 380–391.

Seibert, J. A., & Morin, R. L. (2011). The standardized exposure index for digital radiography: An opportunity for optimization of radiation dose to the pediatric population. *Pediatric Radiology*, *41*(5), 573–581. https://doi.org/10.1007/s00247-

010-1954-6

Sein, M. K., Bostrom, R. P., & Olfman, L. (2001). Rethinking end-user training strategy: Applying a hierarchical knowledge-level model. In N. G. Shaw (Ed.), *Strategies for managing computer software upgrades* (pp. 153–164). Idea Group Publishing.

Shet, N., Chen, J., & Siegel, E. L. (2011). Continuing challenges in defining image quality. *Pediatric Radiology*, *41*(5), 582–587. https://doi.org/10.1007/s00247-011-2028-0

Silva, T. R., & Yoshimura, E. M. (2014). Patient dose, gray level and exposure index with a computed radiography system. *Radiation Physics and Chemistry*, *95*, 271–273. https://doi.org/10.1016/j.radphyschem.2012.12.043

Sim, J., & Radloff, A. (2009). Profession and professionalisation in medical radiation science as an emergent profession. *Radiography*, *15*, 203–208. https://doi.org/10.1016/j.radi.2008.05.001

Singh, N., Knight, K., Wright, C., Baird, M., Akroyd, D., Adams, R. D., & Schneider, M. (2017). Occupational burnout among radiographers, sonographers and radiologists in Australia and New Zealand: Findings from a national survey. *Journal of Medical Imaging and Radiation Oncology*, *61*(3), 304–310. https://doi.org/10.1111/1754-9485.12547

Slechta, A. M., & Reagan, J. T. (2008). An examination of factors related to radiation protection practices. *Radiologic Technology*, *79*(4), 297–305. http://www.ncbi.nlm.nih.gov/pubmed/18340020

Smith, A. (2006). *Remote x-ray operator radiography: A case study in interprofessional rural clinical practice* [University of Newcastle]. https://doi.org/10.1080/13561820701240298

Smith, B. (2018). Generalizability in qualitative research: misunderstandings, opportunities and recommendations for the sport and exercise sciences. *Qualitative Research in Sport, Exercise and Health*, *10*(1), 137–149. https://doi.org/10.1080/2159676X.2017.1393221

Snaith, B. (2016). Evidence based radiography: Is it happening or are we experiencing practice creep and practice drift? *Radiography*, *22*(4), 267–268. https://doi.org/10.1016/j.radi.2016.06.004

Snaith, B., Field, L., Lewis, E. F., & Flintham, K. (2019). Variation in pelvic radiography practice: Why can we not standardise image acquisition techniques? *Radiography*, *25*(4), 374–377. https://doi.org/10.1016/j.radi.2019.05.005

Society And College of Radiographers. (n.d.). *Society of Radiographers: Identity statement*.

Spector, P. E. (2019). Do not cross me: Optimizing the use of cross-sectional designs. *Journal of Business and Psychology*, *34*(2), 125–137. https://doi.org/10.1007/s10869-018-09613-8

Squibb, K. (2013). *Australian rural radiographers: radiographic interpretation, communication and disclosure of their radiographic opinion*. University of Tasmania.

St. George, S. (2010). Applied interpretation: A review of Interpretive Description by Sally Thorne. *Qualitative Report*, *15*(6), 1624–1628.

Stagnitti, K., Schoo, A., Reid, C., & Dunbar, J. (2005). Clinical Access and attitude of rural allied health professionals to CPD and training. *International Journal of Therapy and Rehabilitation*, *12*(8), 355–361. https://doi.org/10.12968/ijtr.2005.12.8.19538

Standing, M., & Standing, M. (2010). Reflexive-pragmatism : logic, practicality, rigour and relevance. In Mooi Standing (Ed.), *Clinical judgement and decision-making: Nursing and interprofessional healthcare* (pp. 205–238). Open University Press.

Stats NZ Tatauranga Aotearoa. (2018). *2018 Census*. 2018 Census. https://www.stats.govt.nz/2018-census/

Stevens, J. P. (2009). *Applied multivariate statistics for the social sciences* (5th (ed.)). Taylor & Francis Group.

Streffer, C. (2007). The ICRP 2007 recommendations. *Radiation Protection Dosimetry*, *127*(1), 2–7.

Strudwick, R. (2011). *An ethnographic study of the culture in a diagnostic imaging department* [University of Salford]. https://doi.org/10.4135/978144627305014537965

Strudwick, R. (2014). The radiographic image: A cultural artefact? *Radiography*, *20*, 143–147. https://doi.org/10.1016/j.radi.2013.10.009

Strudwick, R. (2016). Labelling patients. *Radiography*, *22*, 50–55. https://doi.org/10.1016/j.radi.2015.05.004

Strudwick, R., Mackay, S., & Hicks, S. (2011). Is diagnostic radiography a caring profession? *Synergy: Imaging & Therapy Practice*, *June*, 4–6.

Sung, D.-W., & Choi, B. I. (2014). Status of medical diagnostic radiation safety in Korea. In L. Lau & K.-H. Ng (Eds.), *Radiological safety and quality: Paradigms in leadership and innovation* (pp. 379–390). Springer Netherlands. https://doi.org/10.1007/978-94-007-7256-4_22

Suzuki, T. (2008). The effectiveness of the cascade model for in-service teacher training in Nepal. *2nd International Multi-Conference on Society, Cybernetics and Informatics*, 272–277.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Allyn & Bacon/Pearson Education. https://doi.org/10.1037/022267

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Takaki, T., Takeda, K., Murakami, S., Ogawa, H., Ogawa, M., & Sakamoto, M. (2016). Evaluation of the effects of subject thickness on the exposure index in digital radiography. *Radiological Physics and Technology*, *9*(1), 116–120. https://doi.org/10.1007/s12194-015-0341-2

Takase, M., Yamamoto, M., Sato, Y., Niitani, M., & Uemura, C. (2015). The relationship between workplace learning and midwives' and nurses' self-reported competence: A cross-sectional survey. *International Journal of Nursing Studies*, *52*(12), 1804–1815. https://doi.org/10.1016/j.ijnurstu.2015.06.016

Tamjidyamcholo, A., Baba, M. S. B., Tamjid, H., & Gholipour, R. (2013). Information security: Professional perceptions of knowledge-sharing intention under self-efficacy, trust, reciprocity, and shared-language. *Computers and Education*, *68*, 223–232. https://doi.org/10.1016/j.compedu.2013.05.010

Tan, K., Cashell, A., & Bolderston, A. (2012). Encouraging reflection: Do professional development workshops increase the skill level and use of reflection in practice? *Journal of Radiotherapy in Practice*, *11*(3), 135–144. https://doi.org/10.1017/S1460396911000203

Tarkiainen, T., Haapea, M., Liukkonen, E., Tervonen, O., Turpeinen, M., & Niinimäki, J. (2020). Adverse events due to unnecessary radiation exposure in medical imaging reported in Finland. *Radiography*, *26*(4), e195–e200. https://doi.org/10.1016/j.radi.2020.02.002

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53–55. https://doi.org/10.5116/ijme.4dfb.8dfd

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. SAGE Publications Inc.

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. In C. Willig & W. Stainton-Rogers (Eds.), *The SAGE handbook of qualitative research in psychology* (2nd ed., pp. 17–37). SAGE Publicatons Inc.

Terwee, C. B., Bot, S. D. M., de Boer, M. R., van der Windt, D. A. W. M., Knol, D. L., Dekker, J., Bouter, L. M., & de Vet, H. C. W. (2007). Quality criteria were proposed for measurement properties of health status questionnaires. *Journal of Clinical Epidemiology*, *60*, 34–42. https://doi.org/10.1016/j.jclinepi.2006.03.012

The College of Radiographers. (2013). *Preliminary clinical evaluation and clinical reporting by Radiographers: Policy*. https://www.sor.org/learning/document-library/preliminary-clinical-evaluation-and-clinical-reporting-radiographers-policy-and-practice-guidance

The Medical Radiation Practice Board of Australia. (2012). *When it is necessary to be registered as a Medical Radiation Practitioner?* Australian Health Practitioner Regulation Agency. https://www.medicalradiationpracticeboard.gov.au/Codes-Guidelines/Policy.aspx

The Medical Radiation Practice Board of Australia. (2014). *Code of Conduct*.

The New Zealand Institute of Medical Radiation Technology. (2019). *NZIMRT annual report 2018/2019*.

The New Zealand Medical Radiation Technologists Board. (n.d.-a). *Continuing professional development (CPD)*. Continuing Professional Development (CPD)

The New Zealand Medical Radiation Technologists Board. (n.d.-b). *CPD and compliance audits*. Retrieved April 3, 2021, from https://www.mrtboard.org.nz/for-practitioners/recertification/cpd-and-compliance-audits/

The New Zealand Medical Radiation Technologists Board. (2013). Annual Report. 1 April 2012 - 31 March 2013. In *Annual Report*.

The New Zealand Medical Radiation Technologists Board. (2018). *Policy and guidelines: Competence standards for Medical Imaging and Radiation Therapy Practice in New Zealand*. https://www.mrtboard.org.nz/assets_mrtb/Uploads/2018-Jul-V2-MRT-Competence-Standards.pdf

The New Zealand Medical Radiation Technologists Board. (2019). *MRTB annual report. 1 April 2018-31 March 2019.*

The New Zealand Medical Radiation Technologists Board. (2020). *CPD for annual recertification of Medical Imaging and Radiation Therapy practitioners*.

The Royal Australian and New Zealand College of Radiologists. (2018). Image interpretation by Radiographers - Not the right solution. Position statement. In *Image Interpretation by Radiographers – Not the Right Solution, Version 1*. https://www.ranzcr.com/fellows/clinical-radiology/professional-documents/image-interpretation-by-radiographers-not-the-right-solution-position-statement

The Royal College of Radiologists. (2011). *Standards and recommendations for the reporting and interpretation of imaging investigations by non-radiologist medically qualified practitioners and teleradiologists*. https://www.rcr.ac.uk/sites/default/files/docs/radiology/pdf/BFCR%2811%292_Reporting.pdf

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2010). Sources and effects of ionizing radiation. Report of the United Nations Scientific Committee on the effects of atomic radiation to the General Assembly. In *UNSCEAR 2008 Report* (Vol. 1). https://doi.org/10.1093/oxfordjournals.rpd.a079988

Thingnes, E. R., & Lewis, S. J. (2011). Radiographers' experiences on learning arenas, learning needs and lifelong learning in the radiography profession. *Radiographer*, *58*(1), 9–14. https://doi.org/10.1002/j.2051-3909.2011.tb00139.x

Thomas, J., & McDonagh, D. (2013). Shared language: Towards more effective communication. *Australasian Medical Journal*, *6*(1), 46–54. https://doi.org/10.4066/AMJ.2013.1596.

Thompson Burdine, J., Thorne, S., & Sandhu, G. (2021). Interpretive description: A flexible qualitative methodology for medical education research. *Medical Education*, *55*(3), 336–343. https://doi.org/10.1111/medu.14380

Thorne, S. (2016). *Interpretive Description. Qualitative research for applied practice* (2nd ed.). Routledge, Taylor & Francis Group.

Thorne, S., Kirkham, S. R., & Macdonald-Emes, J. (1997). Interpretive description: A noncategorical qualitative alternative for developing nursing knowledge. *Research in Nursing & Health*, *20*(2), 169–177.

Thorne, S., Kirkham, S. R., & O'Flynn-Magee, K. (2004). The analytic challenge in Interpretive Description. *International Journal of Qualitative Methods*, *3*(1), 1–11. https://doi.org/10.1177/160940690400300101

Toennies, K. D. (2017). Digital image acquisition. In *Guide to medical image analysis. Methods and algorithms* (2nd ed., pp. 23–94). Springer. https://doi.org/10.1007/978-1-4471-7320-5

Tonkopi, E., Daniels, C., Gale, M. J., Schofield, S. C., Sorhaindo, V. A., & Vanlarkin, J. L. (2012). Local diagnostic reference levels for typical radiographic procedures. *Canadian Association of Radiologists Journal*, *63*, 237–241. https://doi.org/10.1016/j.carj.2011.02.004

Towns, E., & Ashby, S. (2014). The influence of practice educators on occupational therapy students' understanding of the practical applications of theoretical knowledge: A phenomenological study into student experiences of practice education. *Australian Occupational Therapy Journal*, *61*(5), 344–352. https://doi.org/10.1111/1440-1630.12134

Tracy, S. J. (2010). Qualitative quality: Eight "big-tent" criteria for excellent qualitative research. *Qualitative Inquiry*, *16*(10), 837–851.

https://doi.org/10.1177/1077800410383121

Tsalafoutas, I. A. (2018). Electronic collimation of radiographic images: Does it comprise an overexposure risk? *British Journal of Radiology*, *91*(1086). https://doi.org/10.1259/bjr.20170958

Tsang, S., Royse, C. M., & Terkawi, A. S. (2017). Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine. *Saudi Journal of Anaesthesia*, *11*(Supplement 1), S80–S89.

Tunlind, A., Granström, J., & Engström, Å. (2015). Nursing care in a high-technological environment: Experiences of critical care nurses. *Intensive and Critical Care Nursing*, *31*(2), 116–123. https://doi.org/10.1016/j.iccn.2014.07.005

Turner, F., Brownhill, S., & Wilson, E. (2017). The transfer of content knowledge in a cascade model of professional development. *Teacher Development*, *21*(2), 175–191. https://doi.org/10.1080/13664530.2016.1205508

Tynjälä, P. (2008). Perspectives into learning at the workplace. *Educational Research Review*, *3*(2), 130–154. https://doi.org/10.1016/j.edurev.2007.12.001

Tzeng, W. S., Kuo, K. M., Lin, H. W., & Chen, T. Y. (2013). A Socio-technical assessment of the success of picture archiving and communication systems: The radiology technologist's perspective. *BMC Medical Informatics and Decision Making*, *13*(1). https://doi.org/10.1186/1472-6947-13-109

Uffmann, M., & Schaefer-Prokop, C. (2009). Digital radiography: The balance between image quality and required radiation dose. *European Journal of Radiology*, *72*(2), 202–208. https://doi.org/10.1016/j.ejrad.2009.05.060

Uniyal, S. C., Chaturvedi, V., & Sharma, S. D. (2017). Measurement of dose area product received by adult patients undergoing digital radiography examinations in Uttarakhand, India and establishment of local Diagnostic Reference Levels. *International Conference on Radiation Protection in Medicine: Achieving Change in Practice*.

Valentin, J. (2004). Managing patient dose in digital radiology. In *Annals of the ICRP* (Vol. 34, Issue 1). https://doi.org/10.1016/S0146-6453(04)00013-2

Vanckavičiene, A., Macijauskiene, J., Blaževičiene, A., Basevičius, A., & Andersson, B. T.

(2017). Assessment of radiographers' competences from the perspectives of radiographers and radiologists: A cross-sectional survey in Lithuania. *BMC Medical Education*, *17*, 17–25. https://doi.org/10.1186/s12909-017-0863-x

Vano, E. (2007). ICRP publications on medical exposures: Digital radiology. *IFMBE Proceedings*, *14*(6), 4216–4219.

Vassallo, P. (2005). Are educators training or trainers educating? *ETC: A Review of General Semantics*, *62*(2), 134–136.

Verrier, W., & Harvey-Lloyd, J. (2010). An investigation into work related stressors on diagnostic radiographers in a local district hospital. *Radiography*, *16*, 115–124. https://doi.org/10.1016/j.radi.2009.09.005

Vikestad, K. G., Hafskjold, L., Kjelle, E., Sebuødegård, S., & Hofvind, S. (2017). Radiographers' opinions on radiography research in Norway – A national survey. *Radiography*, *23*, 135–140. https://doi.org/10.1016/j.radi.2016.12.006

Vom, J., & Williams, I. (2017). Justification of radiographic examinations: What are the key issues? *Journal of Medical Radiation Sciences*, *64*(3), 212–219. https://doi.org/10.1002/jmrs.211

Waite, S., Scott, J., Drexler, I., Martino, J., Legasto, A., Gale, B., & Kolla, S. (2018). Communication errors in radiology – Pitfalls and how to avoid them. *Clinical Imaging*, *51*, 266–272. https://doi.org/10.1016/j.clinimag.2018.05.025

Waite, S., Scott, J., Gale, B., Fuchs, T., Kolla, S., & Reede, D. (2017). Interpretive error in radiology. *American Journal of Roentgenology*, *208*(4), 739–749. https://doi.org/10.2214/AJR.16.16963

Walker, S., Allen, D., Burnside, C., & Small, L. (2011). Determining the between exposure factors, dose and exposure index value in digital radiographic imaging. *Synergy*, *October*, 14–17.

Wani, A. H., Parry, A. H., Khanday, S. A., & Gojwari, T. A. (2019). Improvement in radiographic quality workflow due to use of digital imaging and picture archiving and communication system. *International Journal of Advances in Medicine*, *6*(3), 701. https://doi.org/10.18203/2349-3933.ijam20191518

Warren-Forward, H., Arthur, L., Hobson, L., Skinner, R., Watts, A., Clapham, K., Lou, D.,

& Cook, A. (2007). An assessment of exposure indices in computed radiography for the posterior–anterior chest and the lateral lumbar spine. *The British Journal of Radiology*, *80*(949), 26–31. https://doi.org/https://doi.org/10.1259/bjr/59538862

Watling, C. J., Ajjawi, R., & Bearman, M. (2020). Approaching culture in medical education: Three perspectives. *Medical Education*, *54*(4), 289–295. https://doi.org/10.1111/medu.14037

Watson, L., & Odle, T. G. (2013). The technologist's role in patient safety and quality in medical imaging. *Radiologic Technology*, *84*(5), 536–541.

Weaver, K., & Olson, J. K. (2006). Understanding paradigms used for nursing research. *Journal of Advanced Nursing*, *53*(4), 459–469. https://doi.org/10.1111/j.1365-2648.2006.03740.x

Wedell, M. (2005). Cascading training down into the classroom: The need for parallel planning. *International Journal of Educational Development*, *25*(6), 637–651. https://doi.org/10.1016/j.ijedudev.2005.03.004

Ween, B., Kristoffersen, D. T., Hamilton, G. A., & Olsen, D. R. (2005). Image quality preferences among radiographers and radiologists. A conjoint analysis. *Radiography*, *11*(3), 191–197. https://doi.org/10.1016/j.radi.2005.03.002

Westbrook, C. (2017). Is there a relationship between how MRI is learned and knowledge? *Radiography*, *23*, S43–S47. https://doi.org/10.1016/j.radi.2017.05.007

Westphal, J., Lancaster, R., & Park, D. (2014). Work-arounds observed by fourth-year nursing students. *Western Journal of Nursing Research*, *36*(8), 1002–1018. https://doi.org/10.1177/0193945913511707

White, N. (2003). Reflective practice in radiotherapy radiography. *Synergy*, *Jun*, 7–9. http://search.proquest.com.ezp01.library.qut.edu.au/docview/212419113

Whiting, C. (2009). Promotíng professionalism. *Synergy Imaging & Therapy Practice*, *September*.

Williams, M. B., Krupinski, E. A., Strauss, K. J., Breeden, W. K., Rzeszotarski, M. S., Applegate, K., Wyatt, M., Bjork, S., & Seibert, J. A. (2007). Digital radiography image quality: Image acquisition. *Journal of the American College of Radiology*, *4*(6), 371–388. https://doi.org/10.1016/j.jacr.2007.02.002

Williams, P., Wilford, B., & Cutler, S. (2010). Qualitative analysis. In Aarti Ramlaul (Ed.), *Medical imaging and radiotherapy research. Skills and strategies* (pp. 209–232). Churchill Livingstone.

Workman, A., & Cowan, A. R. (1992). Exposure monitoring in photostimulable phosphor computed radiography. *Radiation Protection Dosimetry*, *43*, 135–138.

Woznitza, N. (2014). Radiographer reporting. *Journal of Medical Radiation Sciences*, *61*(2), 66–68. https://doi.org/10.1002/jmrs.51

Yielder, J. (2006). Leadership and power in medical imaging. *Radiography*, *12*(4), 305–313. https://doi.org/10.1016/j.radi.2005.07.006

Yielder, J., & Davis, M. (2009). Where radiographers fear to tread: Resistance and apathy in radiography practice. *Radiography*, *15*, 345–350. https://doi.org/10.1016/j.radi.2009.07.002

Zetterberg, L. G., & Espeland, A. (2011). Lumbar spine radiography - Poor collimation practices after implementation of digital technology. *British Journal of Radiology*, *84*(1002), 566–569. https://doi.org/10.1259/bjr/74571469

Zhang, M., Liu, K., Niu, X., & Liu, X. (2013). A method to derive appropriate exposure parameters from target exposure index and patient thickness in pediatric digital radiography. *Pediatric Radiology*, *43*(5), 568–574. https://doi.org/10.1007/s00247-012-2555-3

Zhang, W., & Creswell, J. W. (2013). The use of mixing procedure of mixed methods in health services research. *Medical Care*, *51*(8), 51–57. https://doi.org/10.1097/MLR.0b013e31824642fd

Žunic, L. (2019). The legal framework for academic professional development for radiographers in Higher Education. *Medicine, Law & Society*, *12*(1), 65–84. https://doi.org/10.18690/ml&s.12.1.65-84.2019

Glossary

Analogue	film-screen imaging technology
Cassette	rigid device to encase x-ray film or CR screens
Computed Radiography (CR)	digital imaging system using photostimulable storage phosphor detectors
Digital	digitally acquired and displayed image
District Health Board	responsible for the provision or funding of health services in their region of Aotearoa New Zealand
Flat-panel detector	digital imaging detector containing thin-film-transistors in a flat panel substrate.
Flat-panel Digital Radiography (FPDR)	digital imaging system using a flat-panel detector
Image	processed image for review
Medical Imaging	the process of obtaining images of internal structures of the body for diagnosis or screening In this thesis “Medical Imaging” is used interchangeably with “Radiography”.
Medical Imaging Technologist	a trained healthcare professional licensed to produce medical images for diagnosis or screening (also known as radiographer/radiologic technologist). In this thesis, “Medical Imaging Technologist” is used, except in consideration of the historical influences on the profession
Planar imaging	production of 2-dimensional x-ray images
Plate	flexible phosphor screen used in CR Imaging
Projection	relates to patient orientation to detector and direction of central x-ray beam
Radiologist	a medical doctor who has specialised in radiology

Appendices

Appendix A: Phase One flyer and information sheet

PARTICIPANTS NEEDED FOR RESEARCH INTO:

THE USE OF DIGITAL RADIOGRAPHY SYSTEMS IN PLANAR

(TWO DIMENSIONAL) IMAGING (PHASE 1)

I am looking for volunteers to take part in a study on:

- The experiences of Medical Imaging Technologists regarding the introduction and ongoing use of new digital technology.

To participate in this study you need to meet all of the following criteria:

- Have a current Annual Practising Certificate;
- Be working at least 50% of the time in planar (two dimensional) radiography;
- Have experienced the change from film to computerised radiography and/or digital radiography. Or have experienced a change from computerised radiography to digital radiography and vice versa.
- Be working in the greater Auckland region

As a participant in this study, you would be asked to:

- Attend a face to face semi-structured interview.
- Pilot an online questionnaire.

Your participation would involve approximately 3.75 hours of your time, comprising:

30 minutes maximum travel time to interview venue

1 -1.5 hour interview

1 hour to confirm transcription accuracy

45 minutes to complete pilot survey.

For more information about this study, or to volunteer to be interviewed, please contact: Joanna Thorogood, Primary Researcher.

Email: ssk5556@autuni.ac.nz

Phone: 09 8154321 ext. 5214

Approved by the Auckland University of Technology Ethics Committee on 3rd May 2016

AUTEC Reference number: 16/102

Participant Information Sheet

Phase One (Semi-structured interviews)

Date Information Sheet Produced:

10th February 2016.

Project Title

What are the experiences of Medical Imaging Technologists regarding the introduction and ongoing use of new digital technology?

Invitation

My name is Joanna Thorogood. I am a Medical Imaging lecturer, studying a Doctor of Health Science qualification at Auckland University of Technology. I am particularly interested in knowledge transfer and the way in which new technology is introduced into clinical practice. I would like to invite you to participate in my research study exploring "What are the experiences of Medical Imaging Technologists regarding the introduction and ongoing use of new digital technology?"

You have been sent this Information Sheet via the NZIMRT.

Your participation in this study is entirely voluntary; whilst I would appreciate your support there is no obligation to take part in this study. Should you agree to take part, you may withdraw from the study, including the withdrawal of any/all information provided before data analysis has begun. Once data analysis has started it may not be possible to separate data from individuals. You may withdraw without being penalised or disadvantaged in any way.

What is the purpose of this research?

The purpose of my doctoral study is to explore MITs' experiences of using digital technology; the impact this technology has had on their confidence and perceived competence; and whether the level of knowledge they have is sufficient to enable them to work confidently. As such the keys aims of the research are to:

1. Explore MITs' personal experiences of the introduction and ongoing use of digital technology, and its perceived impact on practice

2. Describe MITs' knowledge and understanding of imaging and its application, as well as their confidence in using digital technology.

The final report will be published as a Doctoral thesis which will be available in the AUT library. In addition to my thesis, it is intended that findings from my study will be published in both national and international professional journals. They may also be presented at conferences and seminars.

How was I identified and why am I being invited to participate in this research?

You have responded to my advertisement via the NZIMRT and have met the following inclusion criteria:

- Have a current Annual Practising Certificate;
- Be working at least 50% of the time in planar (two dimensional) radiography;
- Have experienced the change from film to computerised radiography and/or digital radiography. Or have experienced a change from computerised radiography to digital radiography and vice versa.

However, I do need to emphasise that if you meet either of the following criteria, you are unfortunately excluded from participating in this phase of the study:

- You are an MIT working under an MRTB supervision agreement.
- You are a Medical Imaging Clinical Tutor employed within Auckland District Health Board, Counties Manakau District Health Board, Northland District Health Board, or Waitemata District Health Board.

What will happen in this research?

As a participant you will be asked to attend a face to face semi-structured interview. The key purpose of this phase will be to gain an in-depth understanding of how MIT's have experienced the introduction of digital technology, and what has been the perceived impact on practice.

The interview will last for approximately an hour to 90 minutes and will take place in a place which is private and convenient to you. You will be asked about your experiences of using digital imaging equipment in planar imaging. I will take notes during the interview, and the interview will be recorded and transcribed verbatim at a later date by a professional transcriber. The audio files and transcripts will remain confidential to myself, my research supervisors and the transcriptionist. A pseudonym or false name will be used on all transcripts and subsequent reports to protect your identity. You will be given the opportunity to read the transcript of your interview, prior to data analysis to ensure accuracy and clarity.

Phase Two of the research study incorporates designing a questionnaire. Participants from Phase One will be invited to pilot the questionnaire to assess suitability prior to its release. It is anticipated that it will take approximately 45 minutes to complete the questionnaire and submit feedback electronically.

What are the discomforts and risks?

I do not anticipate any risks to you if you take part in this study. However, occasionally interviews such as these may raise feelings that are either distressing or give rise to embarrassment.

Although I am not auditing clinical practice, if you reveal concerns about your own clinical practice you will be provided with a list of suggested support mechanisms where you may seek additional advice and assistance.

How will these discomforts and risks be alleviated?

You may stop the interview at any time.

You are able to withdraw consent up until data analysis has begun.

What are the benefits?

As a practitioner, the benefits to you are limited. However, some people who have participated in this type of research previously, have found it helpful to talk thorough and reflect on their experiences.

It is hoped that this research may allow me to develop an in-depth understanding of the current knowledge that MITs have of digital imaging and its application; and an understanding of what MITs experienced when this technology was introduced and its perceived impact on practice. It is intended that this research will lead to the awarding of a Doctor of Health Science qualification.

The findings of this research will add to the body of knowledge in this area. It may inform professional development opportunities for MIT's to ensure safe and effective use of digital imaging in practice, as well as inform strategies for the implementation of new technologies in the future.

How will my privacy be protected?

For anonymity, you will be given a pseudonym. This pseudonym will be used to identify the interview transcript, and in the thesis and any subsequent publications or presentations. No-one, apart from me, the Primary Researcher, will know that you are a participant in the study. Any information which may identify you and/or your workplace will be removed from the transcript. All data will be kept confidential and stored in a secure location.

Access to the interview transcripts will be restricted to me, the Primary Researcher, and my supervisors. The transcriptionist will only have access to the audio files and will be required to sign a confidentiality agreement before access is permitted. The electronic audio files and transcription documents will be password protected for confidentiality purposes and securely stored for a period of 6 years following the completion of this research.

Locked filing cabinets will be used to store the Consent Forms in the primary supervisor's AUT office and paper data in the second supervisor's AUT office. After six years the data and consent forms will be shredded and disposed of in a confidential waste paper bin.

Electronic data will be password protected and stored on a secure cloud based system such as OneDrive. After six years all electronic data will be completely erased from the drive.

What are the costs of participating in this research?

It is anticipated that participating in this phase will take approximately 3.75 hours of your time.

What opportunity do I have to consider this invitation?

2 weeks.

How do I agree to participate in this research?

You will be asked to sign a Consent Form indicating consent to be interviewed and audiotaped. I will give you the Consent Form immediately prior to the interview, which will give you the opportunity to ask any questions/seek further clarification.

Will I receive feedback on the results of this research?

A summary report of the research findings will be made available to you.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Deborah Payne, dpayne@aut.ac.nz, 09 921 9999 ext.7112

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 09 921 9999 ext. 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Joanna Thorogood, ssk5556@autuni.ac.nz, 09 815 4321 ext. 5214

Project Supervisor Contact Details:

Dr Deborah Payne, dpayne@aut.ac.nz, 09 921 9999 ext. 7112

Approved by the Auckland University of Technology Ethics Committee on 3rd May 2016.

AUTEC Reference number: 16/102

Appendix B: Phase Two flyer

THE EXPERIENCES OF MEDICAL IMAGING TECHNOLOGISTS (MITs) REGARDING THE INTRODUCTION AND ONGOING USE OF NEW DIGITAL TECHNOLOGY.

- Are you an MIT with a full and current Annual Practising Certificate?
- Are you working at least 50% of the time in planar (two dimensional) radiography?

If so, you are invited to participate in a research project.

Why this study?

There is no information about New Zealand MIT's use of digital technology. This survey aims to find out more.

What is involved?

Answering an anonymous online survey to gather information about your experiences. Your participation would involve a maximum of 30 minutes.

All the information collected will be stored securely and will only be used for this study.

Please use this link to access the survey: https://redcap.aut.ac.nz/surveys/?s=9L9L7NJFW7

If you have any issues accessing the survey and for further information about the study contact:

Deborah Payne

Phone: (09) 921 9999, extn 7112

Email: dpayne@aut.ac.nz

OR

Joanna Thorogood

Phone: (09) 815 4321, extn 7537

Email: ssk5556@autuni.ac.nz

Approved by the Auckland University of Technology Ethics Committee on: 28/11/2018

AUTEC Reference number: 16/102

Thank you for your time.

Appendix C: Phase One consent form

Consent Form

Project title: ***What are the experiences of Medical Imaging Technologists regarding the introduction and ongoing use of new digital technology?***

Project Supervisor: ***Dr Deborah Payne***

Researcher: ***Joanna Thorogood***

○ I have read and understood the information provided about this research project in the Information Sheet dated 10 February 2016.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.

○ I understand that the Primary researcher may provide a list of suggested support mechanisms should concerns about my clinical practice be revealed during the interview process

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ If I withdraw, I understand that all relevant information including tapes and transcripts, or parts thereof, will be destroyed.

○ I agree to take part in this research.

○ I confirm that I meet all of the inclusion criteria (please tick all that apply):

1. Have a current Annual Practising Certificate;
   Yes ○ No ○

2. Am working at least 50% of the time in planar (two dimensional) radiography;
   Yes ○ No ○

3. Have experienced the change from film to computerised radiography and/or digital radiography. Or have experienced a change from computerised radiography to digital radiography and vice versa.
   Yes ○ No ○

○ I understand that if ether of the following apply, I am <u>excluded</u> from participating (please tick all that apply):

1. I am an MIT working under an MRTB supervision agreement.
   Yes ○ No ○

2. I am a Medical Imaging clinical tutor employed within Auckland District Health Board, Counties Manakau District Health Board, Northland District Health Board, or Waitemata District Health Board.
   Yes ○ No ○

○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 3rd May 2016

***AUTEC Reference number* 16/102**

Note the participant should keep a copy of this form.

Appendix D: Phase One indicative interview questions

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Semi Structured Interviews: Indicative Questions

1. Could you tell me about the first time you worked with digital imaging equipment?
2. Can you tell me about your experience of ongoing use of this technology in your practice?
3. How do you think your practice has changed as a result of using this technology?
4. From your perspective, what are the benefits/challenges of utilising this equipment?
5. From your experience, what knowledge/professional development opportunities are needed to ensure safe and effective use of digital technology in your practice environment?
6. How do you currently manage your continuing professional development in this area of practice?

Additional prompts will be used to further explore responses to these questions, such as:

1. Can you tell me more about that?
2. How did that feel?
3. How did that affect you?

Appendix E: Phase One transcriptionist confidentiality agreement

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Confidentiality Agreement

Project title: ***What are the experiences of Medical Imaging Technologists regarding the introduction and ongoing use of new technology?***

Project Supervisor: ***Dr. Deborah Payne***

Researcher: ***Joanna Thorogood***

- ✓ I understand that all the material I will be asked to transcribe is confidential.
- ✓ I understand that the contents of the tapes or recordings can only be discussed with the researchers.
- ✓ I will not keep any copies of the transcripts nor allow third parties access to them.

Transcriber's signature: [redacted] ....

Transcriber's name: ....

Transcriber's Contact Details (if appropriate):

...[redacted]..

....

....

....

Date: 10th May 2017

Project Supervisor's Contact Details (if appropriate):

....

....

....

....

Approved by the Auckland University of Technology Ethics Committee on 3rd May 2016

AUTEC Reference number 16/102

Note: The transcriber should retain a copy of this form.

Appendix F: Interview memo excerpt: Potential candidate themes

Looking Across the Interviews -Memo

1. Knowledge

Summary statement

Is this encapsulated by: "we didn't know what we didn't know" …? Link to learning theory moving from unconscious incompetence to unconscious competence. What is required in order to move through the learning stages. (Consider what equates to competency)

What are the knowledge gaps and how can they be filled? Do the participants want to fill them? For some they were happy not to be aware of how the equipment functions, as they did not consider it to be required to fulfil their role requirements. And yet many of the challenges identified by MITs was the concern that people could be button pushers. There seems to be a disconnect between what is articulated.

The more they know, the less they understand. What does this mean in terms of education pedagogy?

Feedback does not seem to be used to support professional development; it does not seem to be received or if so only as a negative.

Some identify worries that the profession was being dumbed down particularly linked to the "button pusher" quotes. Is this the case or is this a misconception and that the knowledge needed now, is just different but nevertheless valid? Who determines that the knowledge is less- is it those who have identified they do not understand how the equipment works and they are transferring onto others?

Support within interviews

*we haven't done a real patient, we've tested it, it should work..." (*10)
we didn't know what we didn't know (8)
Do not need to understand how it works (1)
Relies on others (1) (2)
Algorithms are mathematical and more hands on (1)
Loss of educational opportunities due to lack of inter-professional communication/links to isolation (1)
Removal from entire imaging process (1)
Feels useless due to lack of knowledge (2)
Disengaged (2)
Qualified MRTS should know it all- expectation (2)
Proactive approach by *playing with/using equipment* (3) (4) (6) (8) (9)
Self-reliant (3) (10)
Feels she has insufficient knowledge to challenge apps spec (4)
Didn't understand what was important to know (8)

2. Trust:

Summary statement

Encompasses not only trust or distrust of the equipment, it also relates to feelings of trust with work colleagues and the applications specialists. For some, there seems to be an inherent distrust in the applications specialists, perhaps because the information provided during training and the "research" behind it flies in the face of what people have been taught and practiced. Is there then a link between "seeing it with your own eyes" before believing that the system works. If MI is Evidence Based practice perhaps the evidence is lacking from the apps specialist/manufacturer and also within the research? The lack of trust with apps spec seems to be exacerbated by a perceived inability to clearly articulate or explain how the equipment functions. This may have led to an inability to take the participants seriously or in some cases believe them. The participants describe being "fobbed off" or simply refusing to ask further questions due to the unsatisfactory responses they have experienced in the past.

Trust can be generated by team working overtime and workplace culture, do the MITs see the apps specialists as outsiders? Participants indicated that they use their colleagues, including students on clinical placement, to assist them when they are unsure. Therefore, is there a cultural element here (Consider "radiographer tribe" reference). What generates trust within a team and how does leadership link into this?

Distrust also occurs when MITs have had previous experiences which were negative. In some instances, they trust themselves and their decision making over that of the machine. In some cases, due to the machine being set up incorrectly (link to professionalism here and reporting it). For others it seems to be a lack of understanding as to how to use the equipment; or it not being seen as a requirement in order to complete their tasks. The link to legislation and ALARA principle would fit here-CSP5.

There is an interesting paradox here: we are working in a highly technical environment using complex machinery and yet there is a distrust of the equipment which is supposed to be aiding and supporting us in our job. We have always used equipment at the forefront of technology, has this always been a concern when new technology has been introduced? Fear of losing autonomy/skills to a machine? This distrust of equipment is not age specific within the interview participants. Is it due to not understanding what the equipment can do; is related to trust within the work environment and how this is created? (Consider "quality police" quote)

<u>Support within interviews</u>

Not able to trust/rely on equipment (1) (2) (7) (10)
Reliance on operator to change/manipulate image as settings are for average pt. (4)
Staff rely on equipment to set itself up properly and not adjust it (4)
Fear of the equipment (5)
Always override settings as know better (5)
Blaming technology for errors- staff (4)

3. Feelings:

<u>Summary statement</u>

The feelings described frequently linked to trust. Whilst there were some positive indicators the majority of words and phrases appear to have negative connotations.

Those using more positive phrases seemed to be those that indicated that they were happy to play with the equipment and "see what happens"; whereas others were nervous about touching things and potentially making things worse. Is there any evidence that those interviewed who felt confident with the equipment, were also confident in other areas?

Privilege was mentioned- feeling honoured to be the first to have the new equipment installed. The "flagship" practice.

Some participants recognised that their level of knowledge was less than ideal, despite this they identified feelings of frustration when the equipment "failed" or things did not go to plan. There did not seem to be any connection between knowledge and the effective functioning of the equipment from the participants. One concern raised by a number of the interviewees was not wanting to look foolish in front of other staff; particularly those within other professions in the hospital/practice environment. A fear of failing or being seen to fail was discussed. Frustration was indicated when a lack of understanding as to the role of the MIT and the functionality of the equipment (i.e. lack of) was seen from these staff. An increased level of isolation was also highlighted specifically due to reduced need for interaction with radiologist (tele radiology) and inter-professional communication (face to face). This could link to the lack of knowledge/understanding demonstrated by other professions.

Staff who had worked with film welcomed the change to digital systems due increased speed in the imaging chain and no longer needing to use a darkroom and the chemical processing. Nevertheless, a number of participants highlighted the time delays when waiting for engineers to undertake repairs to the equipment. In the past MITs were able to adjust and make temporary repairs to the processing equipment in order for it to function; this is no longer feasible. There were worries/concerns about who to go to get help. Does this indicate a lack of clear communication/work processes or again concerns about lack of understanding as to how the machine works and not wanting to appear stupid to managers?

Although some indicated that they accepted that change was inevitable there was a level of *despair/ lack of control in order to change anything.* Indicating powerlessness – change is inevitable. Consideration as to how change management processes could have influenced these feelings.

<u>Support within interviews</u>

Fear (5)
Frustration (2) (4) (10)
Annoyed (4)
Isolation (1) (2)
Panic (5)
Distrust (1) (2) (5)
Vulnerability if system breaks down (5) (6) (7)
Excitement (1) (6)
Confidence built by being left alone to work with equipment (6)
Happy (6)
Quality police/ horrible/terrible (6)
"Sweaty palms" (6)
'If they can do it, so can I" (6)
Uncomfortable (4) (8)
Lack of confidence (2) (4)
Difficulties (2)
Useless (2)
Disappointed (2)
Stressed (2)
Enjoyment (3)
Scary (8) (10)
Acceptance (1) (8) (10)
Nervous (9)
Lack of confidence (9)
Anxious (10)

Unsatisfying (10)
Deflating (10)
Confused (10).
Not being listened to (2)

4. Anthropomorphism:

Summary statement

Some participants do not seem to demonstrate autonomy/reluctance to take responsibility evidenced through the blaming of the equipment when things go wrong. Does this indicate that machines have taken over some of our key tasks rather than making things more effective? This change in technology has led to feelings of isolation for some.
It would seem that staff are using workarounds in order to achieve the required outcome of the imaging process. Link this to nursing research.

Support within interviews

Lie to the computer (5)
It refuses to do it… (5)
...*it knows* if you've dropped it, it knows if you've done this, it knows if you've done that apparently so. I don't know how." (7)
Do not permit staff to access… (8)
Worried the system would trip me up (10)
More forgiving. (10)
It just throw's wobblies (1)

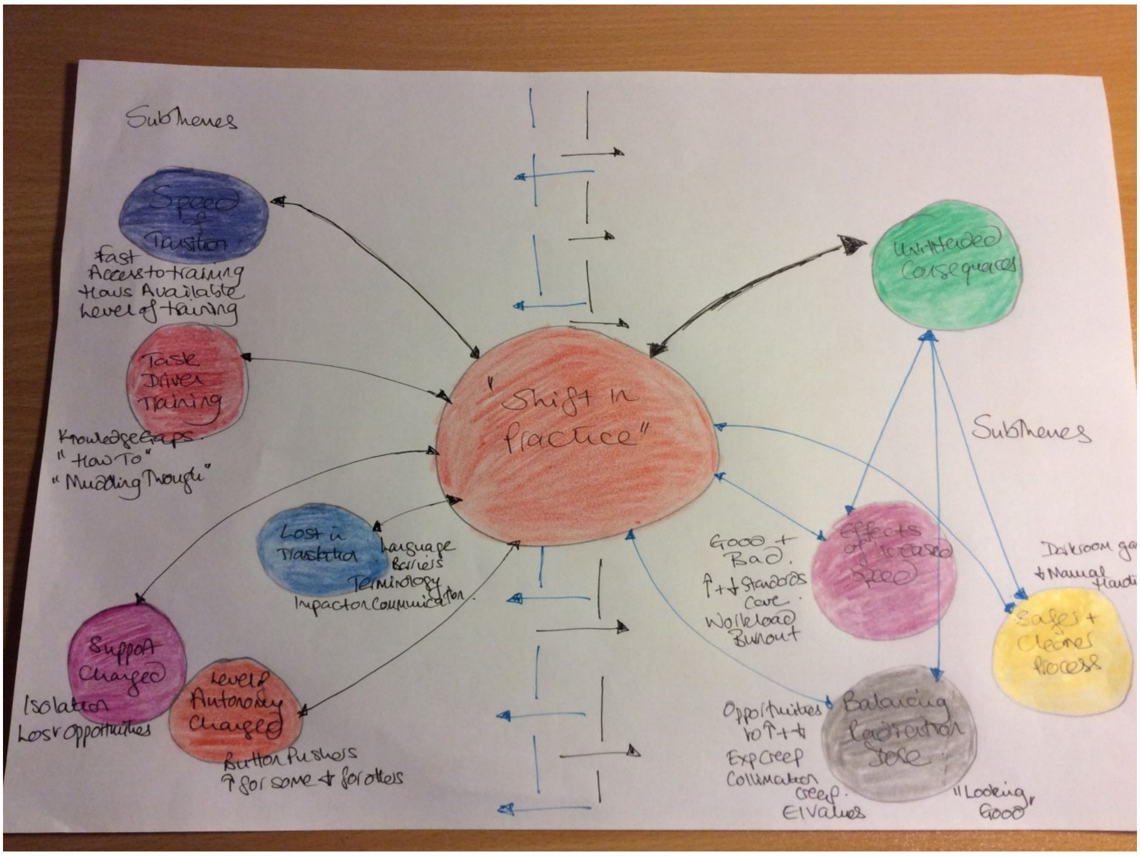
Appendix G: Initial interview coding excerpt

Interview; page	Comment	Initial Thoughts
1	Just getting round the systems and working out where things were and if you didn't get things right, how to fix them, those challenges. Other than that, no not, not many.	A challenge was the need to create workarounds in order to complete the tasks. There could be a link to nursing workarounds article
2	Not on a weekly basis but if something's changing like we just had an upgrade to, the PACS system, it's like where's my red button gone?! No you click on the blue one now. Okay!! And you find your old images through a different route	When the system is upgraded or modified it requires another workaround in order to complete the task.
5	But I found a way that it works for me and whether that's, the correct way and I wouldn't say I'm really understanding it but I know how, how to make it work for me so that I get decent radiograph .	Creating a work around to get the job done but without understanding the processes involved. How does she know that her image is appropriate; what reference points is she using.
5	you have to adapt it and make it work for you. So I don't know that it was much different really	Creating a work around with the information you are given to make it useful.
5	And I definitely because I ask questions, and I'm not scared to take something on, I think I got up to skill level that as good as any of the others that rotate through.	She asks questions to gain further knowledge. Creating a way to make things work. Potentially another work around process.
9	it's like any other computer programme. There's always a different way around it.	Finding a way which works and allows you to move forward.
10	Virtually as I was leaving I did a patient. But once you, once you've done a couple of different systems they are, they have similarities, they have differences and similarities, this one's a little bit more like that one and what have you. So I'm not daunted by the change anymore because, it's just something else to do. Keeps it interesting.	Using knowledge as to how the systems work to move forward.
13	my biggest things are definitely collimating properly, be, because you, you've got so much space. Um. Knowing your exposure's enough. So that when your EI's right and when your EI's wrong. Ah and not over exposing. As in increasing your exposure to be on the safe side. You've got to be, those are probably the three biggest things. And oh and repeating unnecessarily so you look good rather than for the patient's benefit.	The main challenges for her in terms of digital imaging. Whilst exposure and collimatior creep have been discussed in the literature, the comments around repeating to make yourself look good and the EI value in relation to exposures are new to me.
16	we write it in the notes for the radiologist, or go do another view if it's just that you think, another view will demonstrate it. So yeah, those are um, those are definitely leeways we have in the private practice. We don't, we all work together with the radiologist as well and they do, they do pay attention to the notes we put in	A way to get around the monitor issues
18	Those images you know transferring them, that's one of the other issues at the moment with, we're getting there but, passing those images backwards and forwards between different places, bit by bit by bit we're getting better at it, we're getting further afield and further afield but there's still, there's still a bit of a shimmy around swapping images over and getting them accepted from one place to another, get them verified and you know that kind of thing...somebody has to come back and say can you send those images, you have to go in and retrieve them, bring them up and send them, and then email the PACS staff administrator at the other end to say I'm sending these images, so it's all a bit laborious at the moment.	The challenge in sharing images with different places; and the need for the MITs to do this on behalf of the requesting clinican if in private pratcice and referring the patient to a DHB. The Drs are unable to do this themselves.
17	Because you still complete the job to the level that you would of completed the job um. They can't get to talk to a radiologist whereas in the past a radiologist would, if a patient, say a patient came for a mammogram and it was a cancer, they would often talk to the radiologist as well like that doesn't happen anymore because they're not onsite. So maybe that, maybe that does impact on them a little bit. But also maybe it's less scary if the doctor doesn't get involved! I don't know. It is, that is a slight challenge, with not so much personal stuff going on because it's all, on computer....there's nobody there. They're at a computer somewhere!	But it has affected the radiologist -patient interaction i.e this no longer happens. Previously it would happened when necessary; aprticualrly in Mammography or other areas where the radiologist may come and speak to the patient. Now the radiologist relies on the MIT to do the required projections or act as the "middle man" /interpretor and report back

1;17	sometimes, sometimes the images are read before, somewhere around the country, images are sometime read before the patient even leaves. So um, the feedback to their GP will already be there by the time they get back to their GP so that, that's a bonus from the, from the patient's perspective. The speed of the report.	The benefit to the patient in terms of the turnaround time in relation to report writing
1; 1	Oh great, excited. The film processor left!	The removal of the darkroom and the "dirty" aspect of film processing. Chemicals. Is there a link to H&S here? Marjorie Gordon.
1;6	Definitely the speed. Definitely the cleanliness and lack of, not having to clean a film processor is great. I mean basically we don't do any of that, manual labour stuff anymore . If anything goes wrong with computers, or the other equipment, usually just call somebody in. If anything goes wrong with computers, or the other equipment, usually just call somebody in. Whereas with the film processor you were forever taking them to bits, screwdrivers were out and cogs were going in and yeah, you always tried that before you called anybody else in so yeah I've certainly enjoyed moving away from tha	A cleaner less manual process which is much faster.
1;6	like not breathing in all those fumes that has to be a benefit	Link to H&S aspects here- Marjorie Gordon.
1;7	the picture comes straight up, you haven't walked away, down the corridor, and spent 15 minutes process it and then look at it. You flick straight up	A faster process which allows you the ability to review your image almiost instantaneously. The ability to repeat is easier.
1;7	I think it's just so much easier to repeat something now whereas before, you would have struggled with your patient, they've already moved away from the plate, you're going to have to set them up again and you might not get it any better. Because you're starting from scratch again. You've gone away and there's been time. But now they're right there and you can look at it and go, okay I know that, just need to be internally rotated that little bit more and it will be, and you have to go, is that for the patient's benefit or is that my benefit	The process previously took more time to repeat and there was no guarantee that a repeat would be an improvement. Therefore had to consider not only benefit to patient but likelihood that it may not be "worthwhile" in terms of time and end esult. Now it is much easier as patient is still in position.
1;15	Not in, not in a um, end result radiographic way, in a how to get there yes. That's changed a lot. Um. And it's become very quick now so it's very a speedy process and I think you forget about that. It just happens. It's a gradual process and it's speeded up so much	The fact that the imaigng process is much faster now.
1;15	the pictures are so nice now you can feel really good about yourself quite easily these days whereas before you'd get a picture and it, oh you've done you've really worked hard but they're not great...With CR and DR you can see everything you need to see. Yeah that's fabulous, so you should feel better about yourself I think...	The image quality is better and can make you feel better about yourself. The judgment of the quality of your work and how that makes you feel.
1;17	sometimes, sometimes the images are read before, somewhere around the country, images are sometime read before the patient even leaves. So um, the feedback to their GP will already be there by the time they get back to their GP so that, that's a bonus from the, from the patient's perspective. The speed of the report.	The benefit to the patient in terms of the turnaround time in relation to report writing
1;15	I think the biggest thing from a practising point of view, is more changes in protocols and you just change the protocol. The end result's still the same	No real change to her practice just how the end result is achieved. Despite her commentary arouund how her knowledge is less than it used to be in relation to the equipment and no longer using cassettes.
1;15	we don't work so hard to get a decent picture at the end. Because everything used to be so hard. Couple of kV this way or that way and your picture was ruined, that isn't the case now and you can trim it up and make it look better. If it's wonky you can straighten things up and they look better	The entire process is easier now in terms of creating a good image particualrly in relation to exposure factor selection and also post processing.
1;15	I think just that, the end result I think is changed. I think you can see so much more	Although she previously identifies the end result is the same, here she talks about it in terms of the quality of the images and the improved appearance of these particualrly in relaiton to soft tissue.
1;16	as time has gone one I think we've become slightly more isolated. CR and DR isolated us because we used to talk to the radiologists and we used to talk to the A&M doctors. Now we're just groping on the computer and go, gone. Messaged them but you don't actually talk to them anymore! ...I think that's a disadvantage. We used to learn a lot from the radiologists when you used to take the films to them, pop them up in front of them. And they would say oh look at that blah, blah, blah and you'd say what do you think that is and they, you would talk to them. And that's gone now. That just doesn't happen anymore	Clinical practice has become more isolated (possibly more so in private practice where branches may be single handed) with teleradiology and radiologists no longer on site. She identifies missed educationla opportunities in terms of image interpretation and review.

8	So you can't trust, you can't trust the machines all the time they are just a machine.	Whilst recognising the limitations of the technology she does not trust it. Does this trust relate to relaibility, accuracy or the way it assesses/reads the image?
8	***And talking about the exposure index, how useful do you find that?*** **It's a pain!** ***Okay why is that?*** **There are times when you know you've give the right exposure and this is probably, makes it really difficult for the young people who perhaps haven't got such a good handle on exposures, you know you've give it good exposure...and the EI comes up like rubbish, but you know you've got it, you know you've given an exposure that is in the ball park, that's tricky.**	The difficulty with EI readings; especially when the reading does not reflect the fact that from experience the MIT is aware that the exposure factors set were correct.
8	there's a lot of things where you do two views, and you do say a DP hand and you get a good EI, you just turn that hand a fraction, and suddenly you get this totally bizarre EI and it's just like, and you've got to keep remembering it's reading this bit as well and it's reading that bit as well, it's not just reading the bony part that you're looking at	Identifies that the EI will vary according to positioning and that it is importnant to be aware as to how it is calculated.
8	So it's a guide but you know it's not a, um not a bible.	Acknowledging the limitations of the EI readings and that they are are there to assist the MIT.
8	I wouldn't repeat something just because the EI was abnormal whatever. I would first use all the tools to, to see what was going on. And if it looks like I've got a decent image...erect laterals in particularly you've got a sway back it would read all the air that was in the, the way, so the EI would come up absolute rubbish	Not repeating an image just due to the EI. Again aware of the limitations of the system.
8	I wouldn't repeat something just because the EI was abnormal whatever. I would first use all the tools to, to see what was going on. And if it looks like I've got a decent image,	Managing abnormal EI readings. Different equipment manufacturers provide different post processing functions which can assist with this.
8	Or sometimes it just throws wobblies as well, sometimes it just comes up useless.	The system "does it's own thing". Indicating a lack of control from her prespective.
	I'm not sure about the reduced dose. Not, not so much because of exposure creep that they talk about, more because, people don't worry about the exposure so much if they're going to get an image. So they, a lot of the younger people just do not have a grasp of how much radiation they're giving I mean definitely have to have, make them look at those EIs because they just don't appreciate that so much	Knowledge that has been lost or is no longer used due to the change in technology
7	Well I think they're just not as, we were so careful with exposures because we had to be. Because if you, if your four kV different, you didn't have a picture half the time. Whereas now it doesn't matter you're going to have pictures, those, those are a bit of a worry.	Again the identification that exposure knowledge and of how that impacted your image (in relation to film) has been lost
8	There are times when you know you've give the right exposure and this is probably, makes it really difficult for the young people who perhaps haven't got such a good handle on exposures, you know you've give it good exposure...and the EI comes up like rubbish, but you know you've got it, you know you've given an exposure that is in the ball park, that's	Issues for staff who have less knowledge about exposure factors in terms of knowling whether an expsoure should be correct rather than just relying on EI.
7	I can get that a bit better. And then you have to go is this for the patient's benefit or is this just so I look better? ...They're right there, all you need to do is pop back you know if you just go back and click so low you're going to get a beautiful lateral knee. But is it actually benefitting the patient? You're radiating them again, just so you look good.	Repeating images in order to look like a more proficient MIT. Who do you look better to? I am assuming the clinician and the radiologists. But would you look better when considering personal repeat rates?
7	Same because they're right there, your pictures pop straight up in front of you, I think it's more tempting to repeat something, just because you can make it textbook rather than because it's going to benefit the patient.	To improve your reputation.
7	It's like, as long as you're in the ball park now you're going to get a picture. It's not like, it's not like the old days where it was absolutely crucial.	Reduced requirement to take care and be specific when setting exposure factors. Implies a more casual approach to setting the exposures.
	[illegible]	[illegible]

Appendix H: Final interview themes



Appendix I: Survey feedback rubric

Pilot Survey Feedback Form

Purpose

The purpose of this survey is to describe knowledge and understanding regarding the application of new technology into Medical Imaging practice, and additionally explore the relationship between key variables with level of Medical Imaging Technologists (MIT's) knowledge and understanding. These include training and education in the use of different technologies; experienced key transitions in technology in the clinical environment; number of years post qualification and percentage of time using the equipment.

Preamble

This survey has been derived using a multi-level process; (1) ensuring key questions are incorporated from international existing literature; (2) these questions were then modified following phase 1 (participant interviews to ensure relevance and familiarity for the New Zealand demographic being assessed). I am requesting your feedback in stage (3) to check resonance of the questionnaire with the aims of phase 2 of my research.

Hypothesis

It is hypothesised that those MIT's who learnt about Digital Radiography (DR) or Computerised Radiography (CR) in their Undergraduate (UG) programme, have received training in these technologies and have spent more time using this equipment on a weekly basis, will demonstrate better knowledge and understanding of digital technology.

The following questions will assist in proving or disproving the hypothesis:

1. What is MITs knowledge and understanding of the practical applications of digital technology? Specifically, do MITs understand:
    - i. How digital systems respond to different levels of radiation exposure?
    - ii. How different functionalities of the equipment influence best practice?
    - iii. Whether their practice is meeting the ALARA principle?
2. What methods do MITs employ to evaluate the quality of their performance?

Questionnaire Design

The questionnaire is designed to gain knowledge about MITs' knowledge and use of digital technology. The questionnaire should cover the following areas to address the key hypotheses:

To address the hypothesis	Survey question(s)
What is MITs knowledge and understanding of the practical applications of digital technology?	Competency based questions *(Section A)* Applications based questions *(Sections B &G)*
Do MITs understand how digital systems respond to different levels of radiation exposure?	Multiple choice questions relating to equipment design *(Section F)* Questions relating to radiation exposure and education (*Sections D & E)*
Do MITs understand how different functionalities of the equipment influence best practice?	Multiple choice questions relating to equipment design and use *(Section F)* Applications based questions *(Sections B & G)*
Do MITs understand whether their practice is meeting the ALARA principle?	Questions relating to radiation exposure, image acquisition, quality assurance and education *(Sections C, D & E)*
What methods do MITs employ to evaluate the quality of their performance?	Questions relating to quality assurance, quality control work station and education *(Sections C, D & E)* Applications based questions *(Section G)*

Request

Could I please ask you to review the questionnaire with this information in mind? I have attached a feedback rubric below which you may find helpful in structuring your feedback.

Once again, I would like to thank you for assisting me in my study, it is much appreciated
Do let me know if you have any questions
Very best wishes
Jo

Feedback Rubric

Please identify the appropriate question for which you had one or more of the following concerns regarding clarity of the survey:

Survey question	Question is not specific	Question is not understandable	Question is ambiguous	Terminology used is not clear	Terms used are not understandable	Images are not clear	Instructions are not clear

Please identify the appropriate question for which you had one or more of the following concerns regarding the construction of the survey:

Survey question	Question was not concise	Question was duplicated	Order of question was inappropriate	Question was irrelevant

If you felt there were any additional points, you would like to raise (or to elaborate on from above), please do so here:

If you felt that the survey read well, and contained all relevant questions, in an appropriate order and was presented in an easy-to-read and understand format, please confirm this here: Yes/No

Appendix J: Phase Two survey

DHSc Survey

Participant Information Sheet

Phase Two (Questionnaire)

Date Information Sheet Produced: 14th October 2018

Project Title: What are the experiences of Medical Imaging Technologists (MITs) regarding the introduction and ongoing use of new digital technology?

Invitation:

Hello, my name is Joanna Thorogood. I am a Medical Imaging lecturer, studying a Doctor of Health Science qualification at Auckland University of Technology. I am particularly interested in knowledge transfer and the way in which new technology is introduced into clinical practice. I would like to invite you to participate in my research study exploring "What are the experiences of Medical Imaging Technologists regarding the introduction and ongoing use of new digital technology?"

Your participation in this study is entirely voluntary; whilst I would appreciate your support there is no obligation to take part in this study. If you do not wish to particpate there is no need to continue with this survey.

What is the purpose of this research?

The purpose of my doctoral study is to explore MITs' experiences of using digital technology; the impact this technology has had on their confidence and perceived competence; and whether the level of knowledge they have is sufficient to enable them to work confidently. As such the keys aims of the research are to:

1.Explore MITs' personal experiences of the introduction and ongoing use of digital technology, and its perceived impact on practice

2.Describe MITs' knowledge and understanding of imaging and its application, as well as their confidence in using digital technology.

The final report will be published as a Doctoral thesis which will be available in the AUT library. In addition to my thesis, it is intended that findings from my study will be published in both national and international professional journals. They may also be presented at conferences and seminars.

How was I identified and why am I being invited to participate in this research?

You have been selected as a potential participant as a Medical Imaging Technologist practising in New Zealand. To participate in this study you need to meet both of the following inclusion criteria:

Have a current Annual Practising Certificate;

Be working at least 50% of the time in planar (two dimensional) radiography.

If you meet the following criterion, you are unfortunately excluded from participating in this phase of the study:

You are an MIT working under an MRTB supervision agreement.

What will happen in this research?

As a participant you are asked to complete the questionnaire. The key purpose of this phase is to gain an awareness of MITs' knowledge and understanding of digital imaging and its application, as well as their confidence in using this technology.

It is anticipated that it will take approximately 30 minutes to complete the questionnaire and submit feedback electronically. You may stop and return to the survey at any point.

What are the discomforts and risks?

I do not anticipate any risks to you if you take part in this study.

How will these discomforts and risks be alleviated?

You may stop completing the questionnaire at any time.

What are the benefits?

As a practitioner, the benefits to you are limited. It is hoped that this research may allow me to develop an in-depth understanding of the current knowledge that MITs have of digital imaging and its application; and an understanding of what MITs experienced when this technology was introduced and its perceived impact on practice. It is intended that this research will lead to a Doctor of Health Science qualification.

The findings of this research will add to the body of knowledge in this area. It may inform professional development opportunities for MIT's to ensure safe and effective use of digital imaging in practice, as well as inform strategies for the implementation of new technologies in the future.

How will my privacy be protected?

The electronic questionnaire responses will be securely stored for a period of 6 years following the completion of this research. The survey is designed to ensure that it is completed anonymously.Therefore you will not be identified in the data collection, data anlaysis, thesis or subsequent publications.

What are the costs of participating in this research?

It is anticipated that participating in this phase will take approximately 30 minutes of your time.

How do I agree to participate in this research?

Completion of the survey will signify that you consent to participate in this research.

Will I receive feedback on the results of this research?

A summary report of the research findings will be made available via a URL.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Deborah Payne, dpayne@aut.ac.nz, 09 921 9999 ext.7112

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, ethics@aut.ac.nz , 09 921 9999 ext. 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Joanna Thorogood, ssk5556@autuni.ac.nz, 09 815 4321 ext. 7537

Project Supervisor Contact Details:

Dr Deborah Payne, dpayne@aut.ac.nz, 09 921 9999 ext. 7112

Approved by the Auckland University of Technology Ethics Committee on: 28/11/2018

AUTEC Reference number: 16/102

Please answer all of the following questions, thank you

A: Competency

In this section I would like to explore your feelings of competency in a number of areas. For the following scenarios please rate how competent you feel:

	High	Good	Average	Low	None
Adjusting exposures to suit patient body habitus	○	○	○	○	○
Ensuring patient dose is As Low As Reasonably Achievable	○	○	○	○	○
Manipulating exposure factors in computed radiography (CR)	○	○	○	○	○
Manipulating exposure factors in digital radiography (DR)	○	○	○	○	○
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	○	○	○	○	○
Recognising equipment faults from the image artefacts produced	○	○	○	○	○
Evaluating the diagnostic quality of the image in relation to the clinical indications	○	○	○	○	○
Optimising image quality by reducing the signal to noise ratio	○	○	○	○	○
Optimising image quality by increasing the contrast to noise ratio	○	○	○	○	○
Performing post-processing procedures	○	○	○	○	○
Using new equipment, immediately post training	○	○	○	○	○
Ongoing use of new equipment, one month post training	○	○	○	○	○
Ongoing use of new equipment, six months post training	○	○	○	○	○

B: Image Acquisition:
In this section I would like to find out how much time you spend undertaking different activities. Please indicate the approximate proportion of time spent (per week) for each of these activities :

	0-25%	26-50%	51-75%	76-100%
Work undertaken on computed radiography (CR) equipment	○	○	○	○
Work undertaken on digital radiography (DR) equipment	○	○	○	○
Utilisation of automatic exposure device	○	○	○	○

C: Quality Control

In this section I would like to find out how much time you spend undertaking different QC activities. Please indicate the approximate proportion of time spent (per week) for each of these activities :

	0-25%	25-50%	51-75%	76-100%
Adjusting the electronic post-collimators (mask/shutter) to align with the collimation field	○	○	○	○
Manipulating the brightness and contrast of your image, at the work station monitor	○	○	○	○
Manipulating the "look-up" table for your image, at the work station monitor	○	○	○	○
Removing the electronic post-collimators (mask/shutter) to view your collimation borders	○	○	○	○
Attempting to improve image quality by re-processing under another body part/projection	○	○	○	○
Adjusting the electronic post-collimators (mask/shutter) to "crop" your image and reduce the field of view	○	○	○	○

In what percentage of cases, do you adjust your image at a high quality (high resolution) monitor?

○ Never
○ < 25%
○ 26-50%
○ 51-75%
○ 76-100%

If never, please explain why

____

Does adjusting the image at the work station affect the exposure index/ sensitivity (S)/ IGm value?

○ Yes
○ No
○ Sometimes
○ Not sure

D: Quality Assurance

In this section I would like to explore different factors which may impact on QA.

Do you have a way to monitor your repeat/reject rate?	◯ Yes ◯ No
If no, is this due to: (Please select any/all that apply)	☐ System not set up to allow this ☐ Restricted access to this data e.g. PACS staff only ☐ Not within my role description ☐ Do not know how to access this information ☐ Other
Please specify other:	__________________________________
What are the most common causes for your rejected images?	____
What percentage of your exposures require repeat images due to poor image quality?	◯ 0-25% ◯ 25-50% ◯ 51-75% ◯ 76-100%
Do you check/pass your own images?	◯ Yes, always ◯ Yes, sometimes ◯ No, this is undertaken by another Medical Imaging Technologist
If sometimes, please comment:	__________________________________
Has your department adopted a target exposure index (TEI) and deviation index (DI) against which images are assessed?	◯ Yes ◯ No ◯ Unsure
If no, please comment	__________________________________
Do Medical Imaging Technologists approve/pass examinations they have not undertaken or supervised?	◯ Yes ◯ No
If yes, please comment (eg. only those in a team leader role)	__________________________________
Are recommended exposure values established for your place of work?	◯ Yes for all equipment ◯ No ◯ Yes for some equipment ◯ Unsure
If you selected no, or for some equipment, please comment:	__________________________________
Is there a mechanism in place to determine the percentage of examinations that fall into the acceptable range, or that produce too much or too little exposure?	◯ Yes ◯ Yes, but it is not effective ◯ No ◯ Unsure

If not effective, please comment:	__________________________________
How do Radiologist's expectations of image quality, affect your ability to produce high quality, low dose Computed Radiography/Digital Radiography images?	__________________________________
Who is permitted to adjust the post processing parameters/settings on the equipment? (Please select any/all that apply)	☐ Service Engineer ☐ Manufacturer ☐ Medical Radiation Physicist ☐ Applications Specialist ☐ Super User ☐ Other
If other, please specify:	__________________________________
What do you feel contributes to, or causes, excess radiation exposures when performing Computed Radiography procedures? (Please select any/all that apply)	☐ Poorly calibrated equipment ☐ Insufficient applications training ☐ Use of increased mAs to avoid quantum mottle (exposure creep) ☐ Lack of exposure charts ☐ Poor clinical practice ☐ Too much variation between equipment manufacturers ☐ Radiologist preferences ☐ Inconsistent departmental standards ☐ Variability of exposures indices ☐ Workload ☐ Other
If other, please specify:	__________________________________
What do you feel contributes to, or causes, excess radiation exposures when performing Digital Radiography procedures? (Please select any/all that apply)	☐ Poorly calibrated equipment ☐ Insufficient applications training ☐ Use of increased mAs to avoid quantum mottle (exposure creep) ☐ Lack of exposure charts ☐ Poor clinical practice ☐ Too much variation between equipment manufacturers ☐ Radiologist preferences ☐ Inconsistent departmental standards ☐ Variability of exposures indices ☐ Workload ☐ Other
If other, please specify:	__________________________________

E: CR and DR Education

This section is exploring the different types of training you may have received in using new equipment

Which of these have you accessed for Computed Radiography education? (Please select any/all that apply)	☐ Undergraduate (UG) education ☐ Postgraduate (PG) education ☐ Applications training (in-house) ☐ Applications training (off-site) ☐ Training from another MIT (cascade training) ☐ Equipment manufacturer ☐ Other
For other please specify type e.g. journal articles	__________________________________
Please indicate approximately how many hours spent on CR training in each area EXCLUDING Undergraduate and Postgraduate education. Please include the role of the trainer e.g applications specialist, super user, engineer.	____
Which of these have you accessed for Digital Radiography education? (Please select any/all that apply)	☐ Undergraduate (UG) education ☐ Postgraduate (PG) education ☐ Applications training (in-house) ☐ Applications training (off-site) ☐ Training from another MIT (cascade training) ☐ Equipment manufacturer ☐ Other
For other please specify e.g. journal articles	__________________________________
Please indicate approximately how many hours spent on DR training in each area EXCLUDING Undergraduate and Postgraduate education. Please include the role of the trainer e.g applications specialist, super user, engineer.	____
What educational materials would you like manufacturers to provide to MITs who operate the equipment?	__________________________________
What educational materials would you like to be provided with regarding radiation dose?	__________________________________
What emphasis is placed on radiation dose reduction for Computed Radiography/Digital Radiography at your workplace?	◯ Emphasised all the time ◯ Emphasised most of the time ◯ Emphasised some of the time ◯ Never emphasised

F: Multiple Choice Questions

Please could you complete this section by selecting one answer for each of the following questions?

Image brightness on a digital image is adjusted by the:	◯ Window width ◯ Scanning lines ◯ Window level ◯ Matrix size
Automated rescaling of an image:	◯ Corrects size of image ◯ Compares and adjusts image to reference histogram ◯ Magnifies the image ◯ Collimates the image.
Which of the following actions will result in increased image contrast on a digital image?	◯ Increasing window level ◯ Increasing window width ◯ Decreasing window width ◯ Decreasing window level
Compared to powder scintillators, structured scintillators: A. Reduce lateral light scattering B. Improve contrast resolution C. Are needle like in structure D. Improve x-ray absorption	◯ A and B ◯ C and D ◯ A, C and D ◯ A,B, C and D
The exposure index is calculated from the:	◯ Amount of ionisation detected in the Automatic Exposure Device ◯ kVp selected by the Medical Imaging Technologist ◯ The radiation exposure incident on the detector. ◯ Dose received by the patient
Exposure Index (Indicator) Errors may be caused by: (Please select any/all that apply)	☐ Foreign bodies in the radiation field ☐ Extreme over exposure ☐ Extreme under exposure ☐ Delays in processing a CR plate ☐ Scatter ☐ Histogram errors
Excessive exposure to the digital receptor would result in:	◯ Acceptable brightness ◯ Excessive brightness ◯ Insufficient brightness ◯ Increased quantum noise.
The standardised exposure index is used with recommended target exposure index and deviation index values. In this situation a deviation exposure index of +3 indicates:	◯ 100% more than the desired exposure, ◯ 50% more than the desired exposure ◯ 30% more than the desired exposure ◯ 50% less than the desired exposure

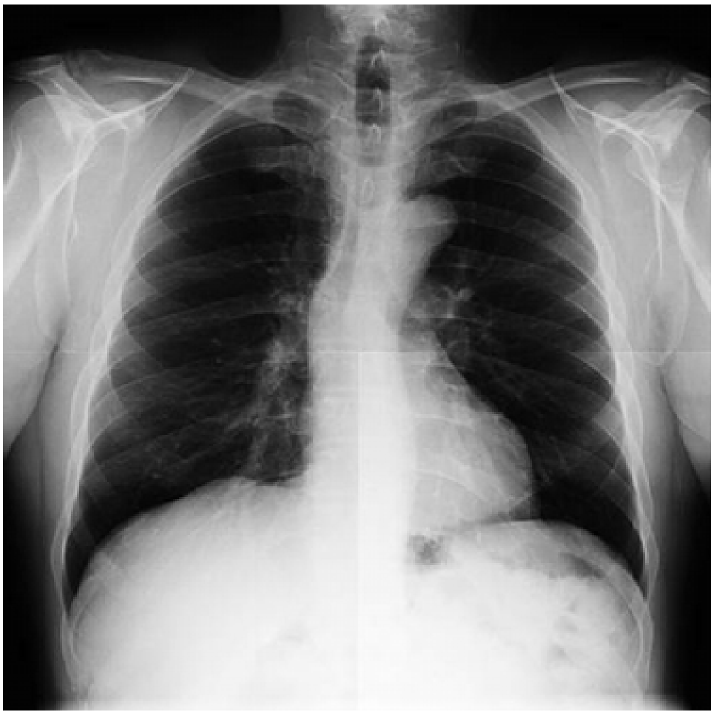
G: Application Questions

These are "practical" questions exploring DR image artefacts

What has caused the artefact on the following DR image?

- ◯ Artefact on detector
- ◯ Tiled array issue
- ◯ Data transmission problem.
- ◯ Flawed gain calibration

Image for previous question



What has caused the artefact on the following DR image?

- ◯ Malfunctioning amplifier
- ◯ Damage to Thin Film Transistor
- ◯ Damage to phosphor layer
- ◯ Pixel 'drop out'

Image for previous question

Following an inadvertent and excessive exposure to a CR plate, the following may be required:

- ◯ A primary erasure cycle
- ◯ A secondary erasure cycle
- ◯ Several primary erasure cycles
- ◯ None of the above.

H: Demographic Information
This section is designed to gather your demographic information

Please indicate your age:	○ Under 25 ○ 26 - 40 ○ 41 - 54 ○ 55 and over
What gender do you identify as?	○ Male ○ Female ○ Gender diverse ○ Prefer not to answer
If you indicated gender diverse, please state	__________________________________
Please indicate your ethnicity. (Please select any/all that apply)	☐ African ☐ American ☐ Chinese ☐ Cook Island Māori ☐ European ☐ Fijian ☐ Indian ☐ Kiribati ☐ Māori ☐ Middle Eastern ☐ New Zealand European ☐ Niuean ☐ Other Asian ☐ Samoan ☐ South American ☐ Tokelauan ☐ Tongan ☐ Tuvaluan ☐ Other
If other please specify:	__________________________________
Please specify the number of years you have been working as a qualified Medical Imaging Technologist:	__________________________________
Please indicate your employment status:	○ Part- time ○ Full - time
Please indicate your highest radiography related qualification:	○ Diploma or DCR ○ BSc or BHSc ○ BSc (hons) or BHSc (hons) ○ Postgraduate Certificate ○ Postgraduate Diploma ○ Master of Science ○ Doctorate ○ Other
If other please specify:	__________________________________

Which of the following best describes your current work area/s? (Please select any/all that apply)	☐ General Radiography ☐ CT ☐ MRI ☐ Ultrasound ☐ Nuclear medicine ☐ PACS ☐ Cardiac Catheter Lab ☐ Mammography ☐ Angiography ☐ Bone Densitometry ☐ Management ☐ Education
Which of the following best describes your place of employment? (Please select any/all that apply)	☐ District Health Board ☐ Private Practice ☐ Other
Please specify time allocation for each employer:	______________________
If other, please specify and indicate time allocation for each employer	______________________
Which of the following titles best describes your current position?	○ Staff MIT ○ Grade/Senior MIT/Clinical Specialist ○ Charge MIT/ Team Leader ○ Radiology Services Manager ○ Other
If other, please specify	______________________
Please indicate which of the following you have experienced. (Please select any/all that apply)	☐ Undergraduate training in DR ☐ Undergraduate training in CR ☐ Undergraduate training in Film-Screen ☐ Transition from Film-Screen to CR ☐ Transition from Film-Screen to DR ☐ Transition from CR to DR ☐ Transition from DR to CR ☐ Formal Postgraduate training in CR ☐ Formal Postgraduate training in DR ☐ Received applications training in CR ☐ Received applications training in DR ☐ Trained others in CR ☐ Trained others in DR ☐ Other
If other, please specify	______________________

Appendix K: Dependent and independent variables used in Linear Regression model

Dependent and Independent variables used in Linear Regression Model

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
1. MIT knowledge of how digital imaging systems respond to different levels of radiation and whether their practice is meeting the ALARA principle.	MCQ score – knowledge subdomain	Total perceived competency score Highest educational qualification Position (seniority) Emphasis on dose reduction at work Image cropping Adjust image on high resolution monitor Can monitor repeat rate Target EI adopted Most common causes for rejected images Factors causing excess radiation (CR) Factors causing excess radiation (DR) Transitions experienced Trained others Time spent using CR per week Time spent using DR per week Time spent using AEDs per week Align collimators Manipulate LUT Hours CR training Hours DR training Cascade training Manufacturer training Applications training Mechanism to determine percentage exams in acceptable range Recommended exposure values available Requested educational materials on dose Requested educational materials from manufacturer CR education UG DR education UG Employer Employment status- f/time or p/time Number of work areas Years since qualified Brightness and contrast manipulation Reprocessing images Remove shutters to view collimation borders CR education PG DR education PG Age range Gender EI

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
2. MIT knowledge of how different functionalities of the equipment influence best practice	Total MCQ score	Total perceived competency score
		Hours DR training
		Hours CR training
		Applications training
		Cascade training
		Manufacturer training
		Age range
		DR education UG
		CR education UG
		Time spent using DR per week
		Time spent using CR per week
		Highest educational qualification
		Requested educational materials from manufacturer
		Percentage of exams that require repeats
		Most common cause rejected images
		Trained others
		Number of work areas
		Position (seniority)
		Years since qualified
		Image cropping
		Employer
		DR education PG
		CR education PG
		Gender
		Employment status- f/time or p/time
		Transitions experienced
		Time spent using AEDs per week
		Adjust image on high resolution monitor
		Brightness and contrast manipulation
		Manipulate LUT
		Can monitor repeat rate
		Reprocessing images
		Align collimators
		EI

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
3. How MIT self-rate their competencies	Total competency score	Total MCQ score
		Applications training
		Cascade training
		Manufacturer training
		Highest educational qualification
		Trained others
		Transitions experienced
		Recommended exposure values available
		Hours CR training
		Hours DR training
		DR education UG
		CR education UG
		Emphasis on dose reduction at work
		Time spent using AEDs per week
		Employer
		Time spent using DR per week
		Time spent using CR per week
		Requested educational materials from manufacturer
		Target EI adopted
		Mechanism to determine percentage exams in acceptable range
		Factors causing excess radiation (CR)
		Factors causing excess radiation (DR)
		Can monitor repeat rate
		Image cropping
		Adjust image on high resolution monitor
		Reprocessing images
		Brightness and contrast manipulation
		Manipulate LUT
		Check collimation borders
		Align collimators
		Most common cause rejected images
		Percentage of exams that require repeats
		Able to check own images
		Number of work areas
		CR education PG
		DR education PG
		Age range
		Gender
		Employment status- f/time or p/time
		Years since qualified

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
4. MIT self-rated competencies in relation to patient radiation dose and the ALARA principle	Competency scores - radiation dose subdomain	Total MCQ score Able to check own images Percentage of exams that require repeats Recommended exposure values available Mechanism to determine percentage exams in acceptable range Hours DR training Hours CR training Requested educational materials from manufacturer Emphasis on dose reduction at work Applications training Cascade training Manufacturer training Target EI adopted Most common cause rejected images Can monitor repeat rate DR education UG CR education UG Trained others Time spent using DR per week Time spent using CR per week Factors causing excess radiation (DR) Factors causing excess radiation (CR) Image cropping Time spent using AEDs per week Transitions experienced Brightness and contrast manipulation Manipulate LUT Reprocessing images Adjust image on high resolution monitor Align collimators Check collimation borders Highest educational qualification Number of work areas Employer Employment status- f/time or p/time Gender Position (seniority) Years since qualified DR education PG CR education PG Age range EI knowledge

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
5. MIT self-rated competencies in relation to the use of existing imaging equipment	Competency scores - existing equipment subdomain	Total MCQ score Hours DR training Hours CR training Applications training Cascade training Manufacturer training DR education UG CR education UG Time spent using DR per week Time spent using CR per week Percentage of exams that require repeats Requested educational materials from manufacturer Most common cause rejected images Highest educational qualification Trained others Image cropping Align collimators Brightness and contrast manipulation Manipulate LUT Reprocessing images Time spent using AEDs per week Transitions experienced Number of work areas Position (seniority) Employer Employment status- f/time or p/time DR education PG CR education PG Age range Gender EI Knowledge

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
6. MIT self-rated competencies in relation to the use of new imaging equipment	Competency scores - new equipment subdomain	Total MCQ score Hours DR training Hours CR training Applications training Cascade training Manufacturer training DR education UG CR education UG Time spent using DR per week Time spent using CR per week Most common cause rejected images Percentage of exams that require repeats Image cropping Highest educational qualification Trained others Adjust image on high resolution monitor Align collimators Brightness and contrast manipulation Manipulate LUT Reprocessing images Time spent using AEDs per week Transitions experienced Number of work areas Position (seniority) Employer Employment status- f/time or p/time DR education PG CR education PG Age range Years qualified Gender EI knowledge

To assess predictors of:	Dependent variables	Independent Variables & Clinical Ranking
7. MIT self-rated competencies of best practice in relation to image quality and evaluation.	Competency scores - image evaluation & quality subdomain	Total MCQ score Hours DR training Hours CR training Applications training Cascade training Manufacturer training DR education UG CR education UG Time spent using DR per week Time spent using CR per week Target EI adopted Recommended exposure values available Mechanism to determine percentage exams in acceptable range Image cropping Highest educational qualification Trained others Reprocessing images Align collimators Brightness and contrast manipulation Manipulate LUT Check collimation borders Adjust image on high resolution monitor Most common causes for rejected images Transitions experienced Number of work areas EI affected by work station Radiologists' expectations EI knowledge DR education PG CR education PG Can monitor repeat rate Percentage of exams that require repeats Able to check own images Age range Factors causing excess radiation (CR) Factors causing excess radiation (DR) Requested educational materials from manufacturer Employer Employment status- f/time or p/time Time spent using AEDs per week Position (seniority) Years since qualified Gender

Appendix L: Ethics approval Phases One and Two

Phase 1 AUTEC

AUTEC Secretariat

Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

3 May 2016

Deborah Payne
Faculty of Health and Environmental Sciences

Dear Deborah

Re Ethics Application: **16/102 What are the experiences of Medical Imaging Technologists (MITs) regarding the introduction and ongoing use of new digital technology?**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 2 May 2019.

This approval is only for the first stage of the research involving interviews. Full information about the later stages needs to be provided to and approved by AUTEC before recruitment and data collection for those stages commences.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 2 May 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 2 May 2019 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

[redacted]

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Joanna Thorogood ssk5556@autuni.ac.nz, Nicola Kayes; Priya Parmar

Phase 2 AUTEC

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

28 November 2018

Deborah Payne
Faculty of Health and Environmental Sciences

Dear Deborah

Re: Ethics Application: **16/102 What are the experiences of Medical Imaging Technologists (MITs) regarding the introduction and ongoing use of new digital technology?**

Thank you for your request for approval of an amendment to your ethics application.

The questionnaire phase (2) of the research is approved.

Non-Standard Conditions of Approval

1. Please use the NZ Statistical Standard for gender identity

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

I remind you of the **Standard Conditions of Approval**.

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/research/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/research/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/research/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. If the research is undertaken outside New Zealand, you need to meet all locality legal and ethical obligations and requirements.

For any enquiries please contact ethics@aut.ac.nz

Yours sincerely,

[redacted]

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: ssk5536@autuni.ac.nz; Nicola Kayes; Priya Parmar

Appendix M: Phase One counselling support

AUT

Memorandum

To	Joanna Thorogood
From	Paul Wedge
cc	
Subject	AUT Counselling services for research participants
Date	1 March 2016

Dear Joanna

As the Head of Counselling of AUT Health Counselling and Wellbeing, I would like to confirm that our counselling service is able to offer confidential counselling support for the participants in your AUT research project entitled:

"What are the experiences of Medical Imaging Technologists (MITs) regarding the introduction and ongoing use of new digital technology?"

The free counselling, for participants who require it, will be provided by our professional counsellors for a maximum of three sessions, and must be in relation to issues arising from their participation in your research project.

Please inform your participants:

- They will need to drop into our centres at WB219 or AS104 or phone 921 9992 City Campus or 921 9998 North Shore campus to make an appointment
- They will need to let the receptionist know that they are a research participant
- They will need to provide your contact details to confirm this
- They can find out more information about our counsellors and counselling on our website http://www.aut.ac.nz/students/student_services/health_counselling_and_wellbeing

Current AUT students also have access to our counsellors and online counselling as part of our normal service delivery.

[redacted]

Paul Wedge
Head of Counselling

From the office of: Paul Wedge, Head of Counselling,
AUT Health, Counselling and Wellbeing
e: paul.wedge@aut.ac.nz | p: 09 921 9999 xtn 6045

Appendix N: Phase Two supplementary results tables

Table 1: Supplementary, Number of years qualified: Comparison between gender

Years Qualified n (%)							
	All	**0-5 years**	**>5-15 years**	**>15-25 years**	**>25 years**	**x^2 value**	***p*-value**
Male	8 (16.7)	4 (50.0)	2 (25.0)	1 (12.5)	1 (12.5)		
Female	40 (83.3)	10 (25.0)	14 (35.0)	5 (12.5)	11 (27.5)		
Total	48 (100)	14 (29.2)	16 (33.3)	6 (12.5)	12 (25.0)	2.30	0.526

Table 2: Supplementary, Number of years qualified: Comparison between groups with different employment

Years Qualified n (%)							
	All	**0-5 years**	**>5-15 years**	**>15-25 years**	**>25 years**	**x^2 value**	***p*-value**
Employer							
DHB only	30 (61.2)	12 (40.0)	8 (26.7)	4 (13.3)	6 (20.0)		
Private only	17 (34.7)	1 (5.9)	8 (47.1)	2 (11.8)	6 (35.3)		
DHB & Private	2 (4.1)	1 (50.0)	0 (0)	1 (50.0)	0 (0)		
						10.246	0.115
Employment status							
Full-time	31 (63.3)	12 (38.7)	6 (19.4)	4 (12.9)	9 (29.0)		
Part-time	18 (36.7)	2 (11.1)	10 (55.6)	3 (16.7)	3 (16.7)		
Total	49 (100)	14 (28.6)	16 (32.7)	7 (14.3)	12 (24.5)		
						8.430	**0.038**

Table 3: Supplementary, Mean MCQ scores achieved: Comparison between groups with different: training hours; work type; highest qualification; total competency ranking; age and weekly use of equipment

	MCQ- Knowledge (/8)		**MCQ- Total Score (/11)**	
	Number (Median)	***p*-value**	**Number (Median)**	***p*-value**
Hours of CR training*				
Total	49 (3.00)	0.585	49 (4.00)	0.657
Not specified / 0	19 (3.00)		19 (4.00)	
<3.75	20 (4.00)		20 (4.00)	
4-15	6 (3.00)		6 (3.00)	
>15	4 (3.50)		4 (3.50)	
Hours of FPDR training**				
Total	49 (3.00)	0.613	49 (4.00)	0.379
Not specified / 0	15 (4.00)		15 (4.00)	
<3.75	10 (3.50)		10 (5.00)	
4-15	18 (4.00)		18 (4.00)	
>15	6 (2.50)		6 (2.50)	
Type of work				
Total	49 (3.00)	0.589	49 (4.00)	0.449
General only	23 (4.00)		23 (5.00)	
General + 1 additional area	15 (3.00)		15 (4.00)	
General + Multiple roles	11 (3.00)		11 (3.00)	
Highest qualification				
Total	49 (3.00)	0.578	49 (4.00)	0.300
Diploma	13 (3.00)		13 (3.00)	
UG Degree	28 (4.00)		28 (4.00)	
PG Qualification	8 (3.50)		8 (4.50)	
Overall competency rating				
Total	49 (3.00)	0.688	49 (4.00)	0.654
35-44	7 (4.00)		7 (4.00)	
45-54	29 (3.00)		29 (4.00)	
55-60	13 (4.00)		13 (4.00)	
Position				
Total	49 (3.00)	0.582	49 (4.00)	0.767
Staff	37 (3.00)		37 (4.00)	
Grade	6 (4.00)		6 (4.00)	
Charge	6 (2.50)		6 (3.50)	

	MCQ- Knowledge (/8)		MCQ- Total Score (/11)	
	Number (Median)	***p*-value**	**Number (Median)**	***p*-value**
CR use per week				
Total	49 (3.00)	0.264	49 (4.00)	0.735
0-25%	28 (4.00)		28 (4.00)	
26-50%	12 (3.00)		12 (4.00)	
51-75%	5 (3.00)		5 (5.00)	
75-100%	4 (2.00)		4 (3.00)	
FPDR use per week				
Total	49 (3.00)	0.703	49 (4.00)	0.714
0-25%	9 (3.00)		9 (3.00)	
26-50%	6 (4.50)		6 (5.00)	
51-75%	7 (4.00)		7 (4.00)	
75-100%	27 (3.00)		27 (4.00)	
AED use per week				
Total	49 (3.00)	0.206	49 (4.00)	0.447
0-25%	8 (3.5)		8 (3.50)	
26-50%	12 (2.00)		12 (2.50)	
51-75%	19 (4.00)		19 (4.00)	
75-100%	10 (4.00)		10 (4.00)	

* 30 responses ** 34 responses

Table 4: Supplementary, Mean MCQ scores achieved: Comparison between groups with different transitions

	MCQ- Knowledge (/8)			**MCQ- Total Score (/11)**		
	Number	**Mean (SD)**	***p*-value**	**Number**	**Mean (SD)**	***p*-value**
Transitions						
Transition FS-CR	22	3.50 (1.946)	0.500	22	3.82 (2.281)	0.239
Transition FS-FPDR	9	3.89 (2.261)	0.732	9	4.22 (2.819)	0.949
Transition CR-FPDR	35	3.60 (1.834)	0.719	35	4.09 (2.228)	0.615
Transition FPDR-CR	4	3.25 (1.500)	0.683	4	3.25 (1.500)	0.396

Table 5: Supplementary, Mean MCQ scores achieved: Comparison between groups requesting different educational materials

	MCQ- Knowledge (/8)		**MCQ- Total Score (/11)**	
	Number (Median)	***p*-value**	**Number (Median)**	***p*-value**
Educational Materials requested from manufacturers				
Total	49 (3.00)	0.833	49 (4.00)	0.764
None specified	6 (4.00)		6 (4.00)	
Manuals & guides including EI & dose	25 (4.00)		25 (4.00)	
Troubleshooting guides	7 (3.00)		7 (4.00)	
Teaching materials online or face to face	11 (2.00)		11 (3.00)	
Educational Materials requested in relation to radiation dose				
Total	49 (3.00)	0.388	49 (4.00)	0.254
None specified	10 (4.00)		10 (4.00)	
Practical guidelines	11 (3.00)		11 (4.00)	
Dose and EI ranges	4 (2.50)		4 (2.50)	
Charts; dose ranges & DRLs	20 (3.00)		20 (3.50)	
Manufacturer/online training	4 (5.00)		4 (6.50)	

Table 6: Supplementary, The level of MIT competencies: Comparison between groups with different number of years since qualification

Years qualified						
	All	**0-5 years**	**>5-15 years**	**>15-25 years**	**>25 years**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	51.00	50.00	47.00	52.50	0.710
Radiation dose subdomain	16-25 (21.00)	21.00	20.00	20.00	22.50	0.371
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.50	4.00	4.00	5.00	0.631
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.00	4.00	4.50	0.654
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	5.00	4.00	4.00	4.50	0.907
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.00	4.00	5.00	0.123
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.00	4.00	4.50	0.372
Image evaluation and quality subdomain	11-20 (16.00)	16.00	16.00	16.00	16.00	0.965
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	4.00	0.817
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	4.50	5.00	4.00	5.00	0.581
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	4.00	0.985
Performing post-processing procedures	2-5 (4.00)	4.50	4.00	4.00	4.00	0.807
Existing equipment use subdomain	30-45 (37.00)	38.00	37.00	36.00	39.50	0.614
New equipment use subdomain	9-15 (13.00)	13.50	12.50	11.00	12.50	0.359
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	3.00	4.00	0.275
Ongoing use of new equipment, one month post training	3-5 (4.00)	5.00	4.00	4.00	4.00	0.444
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	5.00	4.00	4.50	0.165

*1 missing; 48 responses

Table 7: Supplementary, The level of MIT competencies: Comparison between groups with different number of CR training hours

CR Training Hours						
	All	**Not specified/0**	**<3.75**	**4-15**	**>15**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	51.00	51.00	47.50	49.00	0.737
Radiation dose subdomain	16-25 (21.00)	21.00	22.00	20.00	20.00	0.669
Adjusting exposures to suit patient body habitus	3-5 (4.00)	5.00	4.00	4.50	4.00	0.851
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.00	5.00	4.00	0.756
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	4.00	5.00	4.50	4.00	0.507
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.00	4.00	4.00	0.659
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.00	4.50	4.00	0.627
Image evaluation and quality subdomain	11-20 (16.00)	17.00	16.00	16.00	15.50	0.416
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	4.00	0.569
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	5.00	5.00	4.00	4.00	0.127
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	3.50	0.642
Performing post-processing procedures	2-5 (4.00)	5.00	4.00	4.00	4.00	0.282
Existing equipment use subdomain	30-45 (37.00)	37.00	38.00	36.00	35.50	0.563
New equipment use subdomain	9-15 (13.00)	13.00	13.00	12.00	12.50	0.226
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	4.00	3.50	0.254
Ongoing use of new equipment, one month post training	3-5 (4.00)	4.00	4.00	4.00	4.00	0.472
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	5.00	4.00	5.00	0.085

*1 missing; 48 responses

Table 8: Supplementary, The level of MIT competencies: Comparison between groups with different types of CR training mode

CR training mode									
	All	**UG (I)**	**Inhouse (II)**	**I & II**	**Trained others (III)**	**II & III**	**I, II & III**	**Other**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	50.50	47.50	51.00	55.00	55.50	50.00	55.00	0.571
Radiation dose subdomain	16-25 (21.00)	20.50	20.00	21.00	21.00	24.50	20.00	23.00	0.630
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.00	4.00	4.00	5.00	4.50	5.00	5.00	0.778
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.00	4.00	5.00	5.00	5.00	4.00	0.168
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	4.00	4.00	5.00	1.00	5.00	4.00	5.00	0.230
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.00	4.00	5.00	5.00	4.00	5.00	0.195
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.00	4.00	5.00	5.00	3.00	4.00	0.304
Image evaluation and quality subdomain	11-20 (16.00)	16.00	16.00	16.00	20.00	18.00	18.00	18.00	0.282
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	5.00	4.50	4.00	4.00	0.659
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	4.00	4.00	5.00	5.00	5.00	5.00	5.00	0.283
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	5.00	4.50	4.00	4.00	0.270
Performing post-processing procedures	2-5 (4.00)	4.50	4.00	4.00	5.00	4.50	5.00	5.00	0.559
Existing equipment use subdomain	30-45 (37.00)	37.00	36.50	38.00	41.00	42.50	38.00	41.00	0.417
New equipment use subdomain	9-15 (13.00)	13.50	12.50	12.50	14.00	12.50	12.00	14.00	0.731
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.747
Ongoing use of new equipment, one month post training	3-5 (4.00)	4.50	4.00	4.00	5.00	4.00	4.00	5.00	0.622
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	4.50	5.00	5.00	4.50	4.00	5.00	0.342

*1 missing; 48 responses

Table 9: Supplementary, The level of MIT competencies: Comparison between groups with different types of FPDR training mode

FPDR training mode	**All**	**UG (I)**	**Inhouse (II)**	**I & II**	**Trained others (III)**	**II & III**	**I, II & III**	**Other**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	51.00	49.00	51.00	No Data	55.50	50.00	55.00	0.752
Radiation dose subdomain	16-25 (21.00)	21.00	20.00	20.00	No data	24.50	20.00	21.00	0.601
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.00	4.50	4.00	No data	4.50	4.00	5.00	0.905
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.00	4.00	No data	5.00	4.00	5.00	0.075
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	5.00	4.00	5.00	No data	5.00	4.00	1.00	0.280
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.00	4.00	No data	5.00	4.00	5.00	0.198
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.00	4.00	No data	5.00	4.00	5.00	0.428
Image evaluation and quality subdomain	11-20	16.00	16.00	16.00	No data	18.00	18.00	20.00	0.253
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	5.00	4.00	4.00	No data	4.50	4.00	5.00	0.399
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	4.00	4.00	5.00	No data	5.00	5.00	5.00	0.485
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	3.00	4.00	4.00	No data	4.50	4.00	5.00	0.296
Performing post-processing procedures	2-5 (4.00)	5.00	4.00	4.00	No data	4.50	5.00	5.00	0.603
Existing equipment use subdomain	30-45 (37.00)	37.00	37.00	36.00	No data	42.50	38.00	41.00	0.547
New equipment use subdomain	9-15 (13.00)	14.00	12.00	13.00	No data	12.50	13.00	14.00	0.688
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	4.00	No data	4.00	4.00	4.00	0.858
Ongoing use of new equipment, one month post training	3-5 (4.00)	5.00	4.00	4.00	No data	4.00	4.00	5.00	0.622
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	4.50	5.00	No data	4.50	5.00	5.00	0.492

*1 missing; 48 responses

Table 10: Supplementary, The level of MIT competencies: Comparison between groups with different DR equipment usage per week

DR Equipment Use (per week)						
	All	**<25%**	**26-50%**	**51-75%**	**>76%**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	52.00	50.00	50.00	51.00	0.935
Radiation dose subdomain	16-25 (21.00)	21.00	22.00	20.00	21.00	0.934
Adjusting exposures to suit patient body habitus	3-5 (4.00)	5.00	4.00	4.00	4.00	0.202
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.50	4.00	4.00	0.985
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	5.00	5.00	4.00	4.00	0.469
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.50	4.00	4.00	0.348
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.50	4.00	4.00	0.876
Image evaluation and quality subdomain	11-20 (16.00)	18.00	16.50	18.00	16.00	0.754
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	4.00	4.00	0.673
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	5.00	4.50	5.00	4.00	0.253
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	4.00	4.00	0.671
Performing post-processing procedures	2-5 (4.00)	4.00	4.00	4.00	4.00	0.993
Existing equipment use subdomain	30-45 (37.00)	38.00	38.50	38.00	37.00	0.882
New equipment use subdomain	9-15 (13.00)	14.00	12.00	12.00	12.00	0.500
Using new equipment, immediately post training	2-5 (4.00)	4.00	3.50	4.00	4.00	0.655
Ongoing use of new equipment, one month post training	3-5 (4.00)	5.00	4.00	4.00	4.00	0.241
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	4.50	5.00	5.00	0.866

*1 missing; 48 responses

Table 11: Supplementary, The level of MIT competencies: Comparison between groups with different CR equipment usage per week

CR Equipment Use (per week)						
	All	**<25%**	**26-50%**	**51-75%**	**>76%**	
Competency	**Range (Median)**	**Median**	**Median**	**Median**	**Median**	***p*-value**
Total Competency	39-60 (51.00)	51.50	50.00	47.00	54.50	0.415
Radiation dose subdomain	16-25 (21.00)	21.00	20.00	20.00	23.00	0.571
Adjusting exposures to suit patient body habitus	3-5 (4.00)	4.50	4.00	4.00	5.00	0.074
Ensuring patient dose is As Low As Reasonably Achievable*	3-5 (4.00)	4.00	4.50	4.00	5.00	0.342
Manipulating exposure factors in computed radiography (CR)	1-5 (4.00)	4.00	4.00	4.00	5.00	0.222
Manipulating exposure factors in digital radiography (FPDR)	1-5 (4.00)	4.00	4.00	4.00	4.50	0.194
Ensuring doses remain within Diagnostic Reference Levels (DRLs)	3-5 (4.00)	4.00	4.00	4.00	4.50	0.472
Image evaluation and quality subdomain	11-20 (16.00)	16.00	16.50	16.00	18.00	0.493
Recognising equipment faults from the image artefacts produced	3-5 (4.00)	4.00	4.00	3.00	4.00	0.190
Evaluating the diagnostic quality of the image in relation to the clinical indications	3-5 (5.00)	4.50	5.00	4.00	5.00	0.167
Optimising image quality by increasing the contrast to noise ratio	2-5 (4.00)	4.00	4.00	3.00	4.50	0.656
Performing post-processing procedures	2-5 (4.00)	4.00	4.00	5.00	4.50	0.604
Existing equipment use subdomain	30-45 (37.00)	37.50	37.50	35.00	40.00	0.550
New equipment use subdomain	9-15 (13.00)	13.00	12.00	12.00	14.00	0.345
Using new equipment, immediately post training	2-5 (4.00)	4.00	4.00	4.00	4.00	0.599
Ongoing use of new equipment, one month post training	3-5 (4.00)	4.00	4.00	4.00	5.00	0.221
Ongoing use of new equipment, six months post training	4-5 (5.00)	5.00	4.50	4.00	5.00	0.384

*1 missing; 48 responses