# Diagnosing occult radiocarpal fractures in Aotearoa: What is the current detection rate, and which patients are accessing early CBCT imaging?

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# Abstract

**Introduction.** Wrist injuries are common, and radiographic (X-ray) imaging remains the standard first-line diagnostic tool. However, its limited sensitivity for detecting carpal fractures can result in misdiagnosis, leading to delayed treatment, and prolonged recovery. Advancements in high-resolution imaging, including cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI), allow earlier and more accurate detection of occult fractures. In Aotearoa New Zealand, specialist referral is required for CBCT and MRI, often leading to long wait times and delays in diagnosis. On-site CBCT in acute care settings offers the potential to improve diagnostic speed and accuracy.

**Objective.** Following the installation of an on-site CBCT scanner at a privately operated 24-hour clinic in a large urban area of New Zealand, a noticeable increase in radiocarpal fracture diagnoses was observed through the specialist fracture clinic service. This study evaluates radiocarpal fractures identified via CBCT in comparison with those detected through standard X-ray imaging, in patients presenting with acute wrist trauma. In addition, it explores patient demographics (including age, sex, ethnicity, and distance travelled to attend the clinic) and referral patterns for CBCT imaging.

**Methods.** A retrospective observational review was conducted for patients with acute wrist trauma attending the specialist fracture clinic between 1 December 2023 and 30 May 2024, (n= 333). The clinic operates five days per fortnight and is staffed by a multidisciplinary team of emergency medicine specialists, radiographers, nurses and hand therapists. Ethical approval was granted by AUTEC (Ref 24/344). Data were extracted from patient electronic health and imaging records. Descriptive statistics and bivariate hypothesis testing were used to analyse imaging modality, fracture detection rates, and demographic characteristics.

**Results.** A total of 325 wrist injuries were included in this study, with 186 fractures identified. Initial X-ray imaging detected approximately 75% of these fractures; however, one in four were occult. Cone beam computed tomography revealed a considerable number of fractures in patients whose wrist X-rays appeared normal, highlighting the limitations of traditional radiographic imaging in the assessment of radiocarpal fractures.

X-ray imaging predominantly revealed fractures of the distal radius and scaphoid bones. Cone beam computed tomography however, detected a far broader spectrum of carpal injuries, particularly non-scaphoid fractures, with statistical analysis confirming significantly higher detection rates achieved with CBCT compared to X-ray.

Paediatric fractures were predominantly diagnosed via X-ray, with 90% detected by this method, compared to 70% in adults. Despite similar overall fracture rates, adults were more frequently referred for CBCT (60% vs. 25%) and more likely to present with occult fractures. This disparity suggests potential underdiagnosis in paediatric cases and warrants caution when interpreting the true incidence of fractures in this population.

No statistically significant differences in outcomes or imaging referral were observed by sex, ethnicity, or distance travelled to access the service. Due to small sample sizes, non-European ethnic groups were combined for analysis, though limited representation, particularly of Māori and Pasifika patients, reduced statistical power. No significant association was found between ethnicity and CBCT referral, but wide confidence intervals indicate uncertainty. Larger, more representative cohorts are needed to assess potential disparities.

**Conclusion.** CBCT detects a wide range of carpal fractures, many of which are missed on standard X-ray imaging. Integrating CBCT into acute care settings enhances diagnostic accuracy, enabling more informed decisions about patient management.

**Keywords:** wrist fracture, radiocarpal, distal radius, carpal, fracture, occult, adult, paediatric, cone beam computed tomography, CBCT, radiography, X-ray, Aotearoa, New Zealand

# Table of Contents

# List of Figures

# List of Tables

# 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 of 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 institute of higher learning."

*Johanna Buick*

# Co-authorship Contributions & Dissemination of Research

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## Co-authorship Contributions & Dissemination of Research

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# Ethical Approval

This research was approved by the Auckland University of Technology Ethics Committee (AUTEC) on the 27th of November 2024. Reference: 24/344.

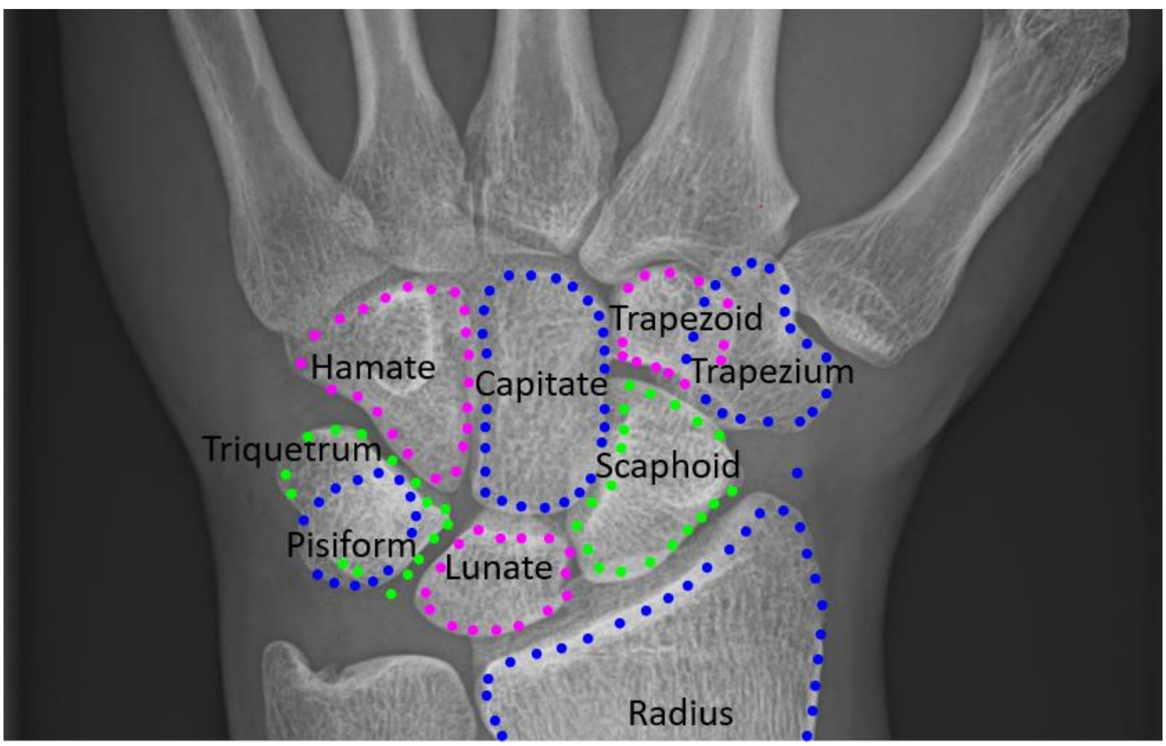
# Introduction

## 1.1 Background

Acute wrist trauma is a common presentation in medical settings and successful rehabilitation of wrist injury depends on both accurate diagnosis and effective management (Colville et al., 2022). This study focuses on radiocarpal fractures, defined as fractures involving the distal radius and/or carpal bones (see Figure 1), which are distinct from injuries to the distal ulna, metacarpals, or phalanges. In addition, the study addresses the challenge of occult fractures, which are not detectable on standard X-ray imaging and therefore complicate timely and accurate diagnosis.

Figure 1

*X-ray image of the wrist outlining the radiocarpal bones*



X-ray is the initial imaging modality of choice for the assessment of wrist injury due to its low cost and ease of access. However, the diagnostic accuracy of X-ray is low, with a sensitivity of 39% for carpal fractures, 58% for distal radius fractures, and between 66 and 81% for scaphoid fractures (Balci et al., 2015; Welling et al., 2012). Even with repeat imaging, some fractures are missed either due to lack of displacement or limitations of imaging (Fitzpatrick et al., 2022).

Advancements in high-resolution imaging, including cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI), have enabled earlier and more accurate detection of occult fractures. Initially developed for dental imaging, CBCT technology has evolved to support orthopaedic applications, offering high spatial resolution (slice thickness as thin as 0.2 mm), low radiation exposure, and shielding of radiosensitive organs (Neubauer et al., 2018; Vitez et al., 2021). Two recent systematic reviews with meta-analysis found that CBCT is an accurate diagnostic tool for occult radiocarpal fractures, with a specificity of 99% and sensitivity of 88% for diagnosing scaphoid fractures (Fitzpatrick et al., 2022; Yang et al., 2021). Clinical studies agree that CBCT provides more diagnostic information than X-ray and could replace or supplement X-ray (Colville et al., 2022; Edlund et al., 2016; Krayem et al., 2021; Neubauer et al., 2018). Magnetic resonance imaging is considered the gold standard in fracture identification due to its high sensitivity and specificity of 94% and 98% respectively (Fitzpatrick et al., 2022) but has a significantly higher cost; one and a half times the cost of CBCT imaging and nine times the cost of X-ray (Health New Zealand Te Whatu Ora, 2025b).

## 1.2 Evaluation of Current Situation

Internationally, there is some variation as to which practitioners may refer patients for high-resolution imaging. In the UK, physiotherapists with extended scope practice or first contact physiotherapy roles, can refer patients for CBCT or MRI scans. However, they must be appropriately trained and competent to do so, and their scope of practice must include ordering imaging (Chartered Society of Physiotherapy, 2021). In the USA and Canada physical therapist scope of practice and legislation regarding the ordering imaging varies between regions (American Physical Therapy Association, 2024).

In Aotearoa, New Zealand, CBCT and MR imaging of the wrist is by specialist referral only. Long wait times for a specialist consultation can delay diagnosis, particularly for occult fractures, impacting timely treatment. Misdiagnosis of occult fractures can result in unnecessary pain, dysfunction, prolonged recovery, and increased costs for both patients and the healthcare system. The availability of CBCT imaging in acute healthcare settings offers the potential to address these challenges by enabling earlier and more accurate diagnoses. This is important for several reasons: Firstly, fracture healing is expedited by cast immobilisation (ElHawary et al., 2021). Missed diagnosis of occult fractures on X-ray can lead to premature mobilisation, delaying bone healing. Correct diagnosis of scaphoid waist or proximal pole fractures is particularly important due to the high risk of non-union of these fractures (Clementson et al., 2020; Colville et al., 2022; Edlund et al., 2016; Peterson et al., 2020). If identified early, scaphoid non-union can be treated with surgical fixation and bone grafting. In the long term, missed scaphoid fractures can result in wrist fusion should scaphoid non-union progress to advanced collapse of the carpal bones (SNAC wrist).

Secondly, experimental and clinical studies have demonstrated that early, controlled mobilisation is more effective than immobilisation in treating acute musculoskeletal soft-tissue injuries (Clementson et al., 2020; Kannus, 2000). Despite this, current practice for suspected wrist fractures typically involves initial assessment with X-ray imaging. If no fracture is visible but clinical suspicion remains high, a cast is applied, and the patient undergoes repeat X-ray and examination after 10 to 14 days. At that stage, bone healing may reveal a previously occult fracture. However, this conservative approach leads to substantial overtreatment, with only 4–20% of patients ultimately diagnosed with a fracture (Clementson et al., 2020). These findings highlight the need for more accurate early diagnostic tools to reduce unnecessary immobilisation and improve patient outcomes.

Finally, an accurate diagnosis enables safe and realistic planning. It gives the patient, their employer and their treating therapist greater clarity around normal healing timeframes and allows for the estimation of time for return to work. In Sweden, Krayem et al. (2021), performed CBCT imaging on all wrist trauma presenting to a single hospital over a three-month period, comparing results to a three-month period when only conventional radiography was used. The authors found that the incidence of carpal fractures was three times higher during the CBCT study period (92/100,000 per annum) when compared with the radiography-only period (29/100,000 per annum). Therefore, the true incidence of radiocarpal fractures may be much higher than that previously suggested in literature.

## 1.3 Importance of the Research

Research in this emerging area has identified limitations of X-ray imaging and the benefits of CBCT in the diagnosis of radiocarpal fractures. Currently, there is a lack of data from New Zealand regarding which patients are accessing CBCT imaging in the acute clinical setting, or the current detection rate of occult radiocarpal fractures.

For the past decade, the specialist fracture clinic service where the data were collected for this study, has operated from an acute care 24HR surgery, located in a large urban centre of New Zealand. The clinic operates five days per fortnight and is a multidisciplinary service staffed by emergency medicine specialists, radiographers, nurses, and hand therapists. Since the installation of a CBCT scanner to the 24-Hour clinic in July 2023, there has been an increase in the number of radiocarpal fractures diagnosed through the fracture clinic service. Previously, imaging was conducted off-site, requiring patients to return for a follow-up appointment to review results and discuss treatment. The availability of same-day imaging and consultation has streamlined care, reduced delays and eliminated the need for multiple visits.

This retrospective observational study examined imaging referral over a six-month period (from 1st December 2023 to 30th May 2024 inclusive). While all patients received an initial X-ray, referral for subsequent imaging was determined by the attending emergency specialist based on established clinical guidelines considering mechanism of injury, assessment findings and the presence or absence of risk factors (Appendix A).

This study ascertained the number of radiocarpal fractures identified on initial X-ray and the number of fractures missed on initial X-ray but subsequently identified on CBCT imaging. Results will help guide clinical decision-making around imaging referral and will be of interest to a range of providers across New Zealand. If results are consistent with international findings, ways of improving the accessibility of CBCT in the acute setting can be explored.

This study also examined the demographic and clinical characteristics of individuals presenting with suspected radiocarpal fractures, focusing on those referred for CBCT imaging. It paid particular attention to groups that often face barriers to healthcare, including Māori and Pacific peoples (Jeffreys et al., 2024; Wren, 2015), and individuals living in rural areas (Buhler et al., 2024; Whitehead et al., 2022). By examining cohort composition and referral trends, the study aimed to identify disparities in access to advanced imaging that could affect diagnosis and treatment. These findings will help inform equitable referral practices that better serve those communities facing challenges in accessing care across Aotearoa New Zealand.

## 1.4 Statement of Aims

Primary aim: To determine the detection rate of radiocarpal fractures using CBCT compared with initial X-ray imaging.

Secondary aim: to determine the characteristics of people presenting to fracture clinic with potential radiocarpal fracture, and to identify who is being referred for CBCT imaging.

## 1.5 Outline of Order of Information

This chapter (**Chapter 1**) has outlined the need for and the objectives of the study.

**Chapter 2** presents an Integrative Literature Review. The review identifies, evaluates, and summarises the findings of relevant individual studies from a broad range of databases, providing a foundation on which to position this new research.

**Chapter 3** describes the study Methods and clearly outlines the research process, including how data were collected and analysed.

**Chapter 4** outlines key study findings and presents salient data. Results were used to answer the research questions and to provide the foundation for further analysis and interpretation in the discussion.

**Chapter 5** presents a synthesises of the research findings and compares them with existing literature. It discusses the clinical implications of the results, outlines the study's strengths and limitations, and identifies directions for future research.

**Chapter 6** concludes the study, presenting the main points of interest and key contributions to informed clinical practice.

# Chapter 2

# Integrative Literature Review

## 2.1 Introduction and Background

This integrative review principally seeks to answer the question: What is the comparative diagnostic accuracy of X-ray imaging versus cone beam computed tomography (CBCT) in the detection of radiocarpal fractures?

Two systematic reviews with meta-analysis have been published in this area, both in 2021. Researchers from two different continents aimed to establish the diagnostic performance of CBCT. In Taiwan, Yang et al. (2021) focused specifically on scaphoid fractures, while in the United Kingdom, Fitzpatrick et al. (2022) examined CBCT's diagnostic accuracy for all radiocarpal fractures. Both systematic reviews included the same four studies (Borel et al., 2017; Edlund et al., 2016; Gibney, Smith, et al., 2019; Neubauer et al., 2018), with Fitzpatrick adding a fifth study by Grunz et al. (2023). Their findings were consistent: CBCT demonstrated a pooled sensitivity of 0.88 and a pooled specificity of 0.99 for the diagnosis of scaphoid fractures. Fitzpatrick et al. (2022) extended the analysis further, reporting that for other carpal fractures, CBCT exhibited a pooled sensitivity of 90.6% and a specificity of 100%. For distal radius fractures, sensitivity and specificity were found to be 90% and 100%, respectively. Both reviews concluded that CBCT has excellent diagnostic performance for carpal cortical fractures.

However, several limitations were acknowledged. Variability in imaging protocols and the absence of a uniform reference standard, restricted the strength of pooled estimates. Additionally, the small sample sizes and the fact that all included studies were conducted in Europe may limit the generalisability of the findings to other populations and geographic regions.

This integrative literature review explored current evidence on the detection of radiocarpal fractures (not limited to scaphoid fractures) using CBCT, to determine whether new findings have emerged in the past four years and sought to identify gaps in the literature and highlight areas for future research.

## 2.2 Search Strategy

A comprehensive search of electronic databases was undertaken in February 2025. Databases used were EBSCO health databases (CINAHL complete, MEDLINE) and Scopus. Registers searched were ProQuest and the Cochrane Library.

Two key concepts were identified and searched separately. The first was "radiocarpal fracture detection" and the second was "X-ray or CBCT". Alternative terms that reflected these concepts were also used (Table 1). "Radiocarpal fracture detection" and the alternative terms were designated as "search1" (S1), and "X-ray or CBCT" and the alternative terms were designated as "search 2" (S2). Final results were determined by combining S1 and S2. Search terms were combined with "AND" and all alternatives were combined with OR, or a proximity operator, this process was conducted for each database.

Table 1

*Literature Review Search Terms*

| **Order of terms searched** | **Search terms and operators** |
|---|---|
| Search 1 (S1) | ("radiocarpal fracture*" OR "scaphoid fracture*" OR "lunate fracture*" OR "capitate fracture*"OR "triquetrum fracture*" OR "trapezium fracture*" OR "trapezoid fracture*" OR "pisiform fracture*" OR "hamate fracture*" OR "carpal fracture*") N6/W6 (diagnos* OR detect* OR ident*) |
| Search 2 (S2) | (radiograph* OR X-ray or CBCT OR "cone-beam CT" OR "cone-beam computed tomography") |

### 2.2.1 Inclusion Criteria

To be included studies had to focus specifically on radiocarpal injury. Eligible studies were written in English, published in a peer-reviewed journal, with access to the full text available. Only papers published in the past 10 years were included to reflect current clinical practices and advancements in treatment. Although CBCT was introduced into musculoskeletal imaging prior to this period, its use in wrist imaging was relatively limited and largely experimental. The past decade has seen broader clinical adoption of CBCT, making recent literature more representative of contemporary diagnostic capabilities. Studies were included if they were comparative studies, of human subjects, where an adequate description of the research protocol was provided. Studies were included if comparative data included both X-ray and CBCT imaging, with or without MRI data.

### 2.2.2 Exclusion Criteria

Studies investigating artificial intelligence (AI), systematic reviews and single case reports were excluded. Studies considering only one imaging type (e.g., X-ray or CBCT but not in combination) or focused on only one carpal bone (e.g. scaphoid data only) or studies where imaging was conducted for the planning of surgical intervention were excluded.

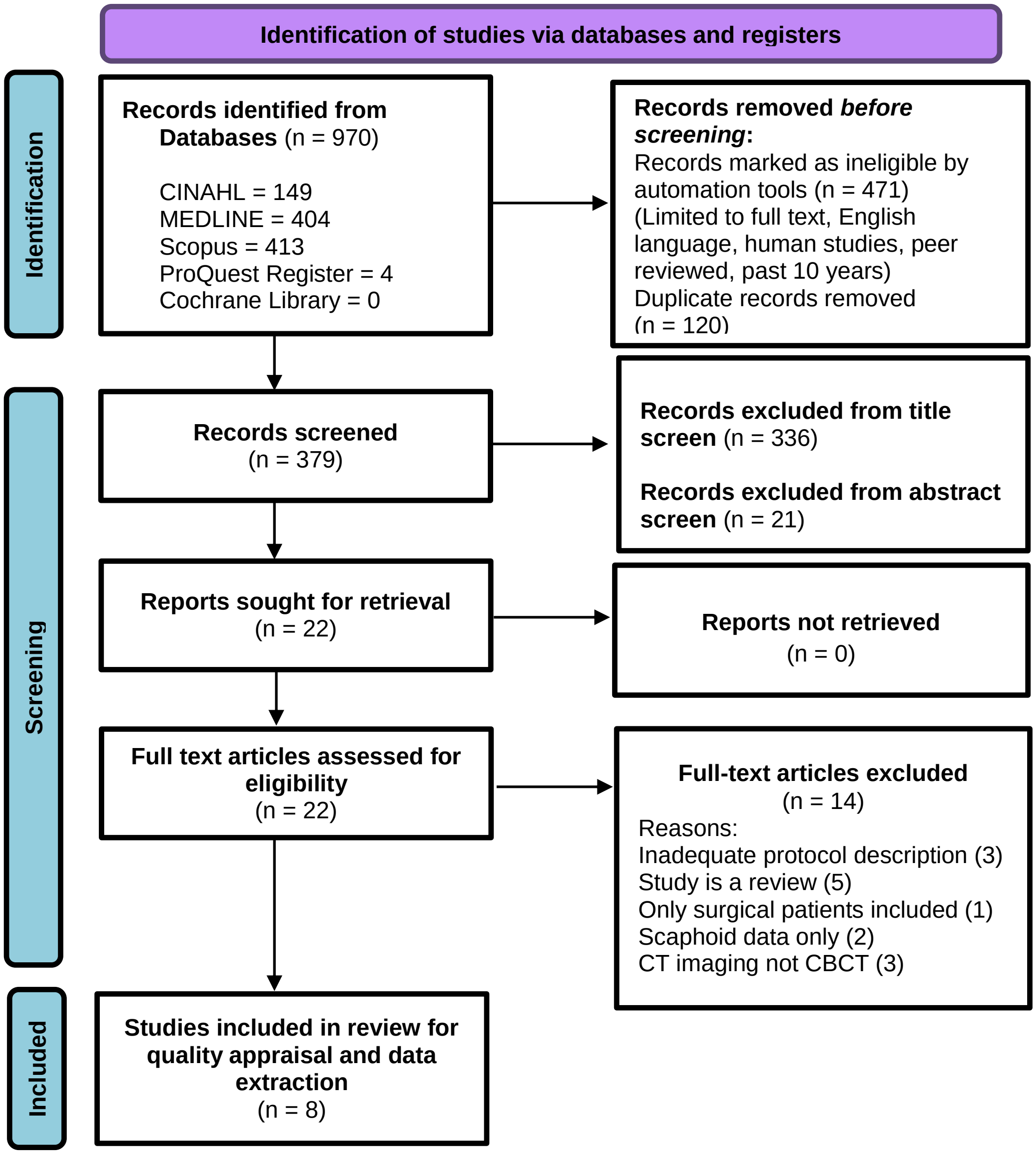
## 2.3 Results

### 2.3.1 Study Selection

Figure 2 illustrates the selection process for studies included in the quality appraisal and data extraction. The initial search across all databases identified 970 articles. This was reduced to 499 after applying database limiters for English language, peer reviewed status, publication in the last 10 years, human studies, and availability of the full text. Removing duplicates and screening titles across all databases resulted in the exclusion of 456 articles. The abstracts of the remaining studies were read for relevance, and 22 studies were retained, while 21 were excluded. Full texts of these retained studies were then reviewed to determine if the study met the inclusion criteria. Fourteen further articles were excluded at this stage, for reasons outlined in Table 2. Reference lists of the identified studies were reviewed for potential additional studies, but no new studies were identified. Eight articles remained for quality appraisal and data extraction as shown in Table 3. Five studies were identified that had not been included in earlier systematic reviews, potentially contributing new insights to the topic.

Figure 2

*Search strategies and results*




Adapted from (PRISMA, 2020)

Table 2

*Studies excluded on full text read*

| **Principal author (year)** | **Study type** | **Reason for Exclusion** |
|---|---|---|
| Alshamrani (2023) | Retrospective | Scaphoid data only |
| Basha et al. (2018) | Prospective | Multidetector computed tomography (MDCT) was used, rather than CBCT. |
| Boeddrich et al. (2023) | Retrospective | Inadequate protocol description |
| Catalano et al. (2020) | Review | Review |
| Clementson et al. (2020) | Review | Review |
| Etli et al. (2020) | Retrospective | Whole-body CT scanner, not CBCT |
| Fitzpatrick et al. (2022) | Systematic Review | Systematic review |
| Geijer et al. (2025) | Retrospective | Whole-body CT scanner, not CBCT |
| Grunz et al. (2023) | Prospective | Only patients proceeding to surgery included |
| Neubauer et al. (2018) | Retrospective | Scaphoid data only |
| Pallaver and Honigmann (2019) | Review | Review |
| Ricci et al. (2019) | Retrospective | Inadequate protocol description |
| Yang et al. (2021) | Systematic Review | Systematic review |
| Zander et al. (2024) | Retrospective | The number of fractures identified by each imaging modality was not reported. |

Table 3

*Overview of studies included in review*

| **Principal author (year)** | **Study type** | **Imaging** | **Country of origin** | **Sample size** |
|---|---|---|---|---|
| Borel et al. (2017) | Prospective | All participants imaged with XR, CBCT & MRI | France | 49 |
| Colville et al. (2022) | Prospective | Normal XR, suspicion of #, proceed to CBCT | UK | 99 |
| Edlund et al. (2016) | Prospective | All participants imaged with XR & CBCT | Sweden | 95 |
| Gibney, Murphy, et al. (2019) | Prospective | Normal XR, suspicion of #, proceed to CBCT | Ireland | 166 |
| Gibney, Smith, et al. (2019) | Prospective | Normal XR, suspicion of #, proceed to CBCT | Ireland | 117 |
| Krayem et al. (2021) | Retrospective<br>Retrospective | Group one – conventional radiograph only<br>Group two – CBCT only | Sweden | XR 643<br>CBCT 415 |
| Snaith et al. (2022) | Prospective | Normal XR = proceed to CBCT | UK | 68 |
| Vitez et al. (2021) | Retrospective | All participants imaged with XR & CBCT | Switzerland | 56 |

### 2.3.2 Quality of Included Studies

Studies were appraised using the CASP checklist for diagnostic test accuracy studies. Table 4 summarises the scoring and key outcomes for each included study. Only one study (Borel et al., 2017) met all appraisal criteria. This prospective investigation, conducted in a hospital setting in France, is the only study to date in which all participants underwent X-ray, CBCT, and MRI. This comprehensive imaging allowed for full comparison against the reference standard, lending strength to the study's validity. However, such an approach is significantly limited by its high cost, particularly in healthcare environments driven by cost-reduction strategies.

In two investigations (Edlund et al., 2016; Vitez et al., 2021), all patients underwent both X-ray and CBCT imaging, allowing for direct comparison of diagnostic yield. Several studies adopted a tiered imaging approach in the evaluation of wrist trauma, where CBCT was used selectively following normal X-ray findings but persistent clinical suspicion of fracture (Borel et al., 2017; Colville et al., 2022; Gibney, Murphy, et al., 2019; Gibney, Smith, et al., 2019), reflecting a pragmatic strategy that aligns closely with current practice in fracture clinics.

One study (Krayem et al., 2021) did not utilise MRI. Instead, the researchers conducted a retrospective comparison between two cohorts: one from the pre-CBCT era and another from a period when CBCT was used exclusively. This study design could not be ethically replicated prospectively today, as withholding high-resolution imaging from patients with suspected fractures would be considered unacceptable. In the other six studies, MRI was used as the reference standard selectively, applied only when CBCT results were normal but clinical concern for fracture persisted.

All studies reported objectives, methods and results. This reflects the inclusion criteria of this literature review, which required adequate description of the research protocol. All the studies included were undertaken in Europe and in the hospital acute demand setting. Results were thought to be transferable to our acute demand fracture clinic service in New Zealand. To determine if this assumption is justified, it is necessary to gather data from New Zealand and compare the findings with those from international studies.

Table 4 *CASP critical appraisal scoring of the research papers included in literature review*

| 1st Author (year) | CASP criterion [a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| Borel et al. (2017) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | All participants imaged with XR, CBCT & MRI<br>CBCT = 100% Sensitivity, 95% Specificity,<br>96% PPV, 100% NPV | ✓ | ✓ | ✓ | ✓ | Improved diagnostic performance = early, accurate diagnosis of occult fractures. |
| Colville et al. (2022) | ✓ | p | p | p | ✓ | ✓ | Normal XR, suspicion of fracture, proceed to CBCT.<br>MRI if negative CBCT and ongoing concern<br>CBCT = 96% Sensitivity, 100% Specificity,<br>100% PPV, 98.7% NPV | ✓ | ✓ | ✓ | ✓ | Increased detection of radiographically occult fractures.<br>25% of scans = occult fracture identified |
| Edlund et al. (2016) | ✓ | p | p | p | ✓ | ✓ | All participants imaged with XR & CBCT<br>MRI if negative CBCT<br>CBCT =69% Sensitivity<br>XR = 44% Sensitivity | p | ✓ | ✓ | ✓ | CBCT provides a more accurate diagnosis than XR<br>Bone bruising/contusion on MRI included as fracture diagnosis. |
| Gibney, Murphy, et al. (2019) | ✓ | p | p | p | ✓ | ✓ | Normal XR, suspicion of fracture, proceed to CBCT.<br>MRI if negative CBCT and ongoing concern<br>50% of patients with negative XR had an acute fracture identified on CBCT. | ✓ | ✓ | ✓ | ✓ | Trapezium fracture is the most common occult fracture, unreliably diagnosed on XR but reliably diagnosed on CBCT. |
| Gibney, Smith, et al. (2019) | ✓ | p | p | p | ✓ | ✓ | A Normal XR, suspicion of fracture, proceed to CBCT.<br>MRI if negative CBCT and ongoing concern<br>CBCT = 98% sensitivity, 100% specificity,<br>PPV 100% and NPV of 98% | ✓ | ✓ | ✓ | ✓ | CBCT provides more diagnostic information than XR and can reduce the need for MRI. |
| Krayem et al. (2021) | ✓ | x | x | x | ✓ | ✓ | Group one – conventional radiograph only<br>Group two – CBCT only<br>Incidence of carpal fracture:<br>CBCT period [92/100,000 p.a.]<br>XR period [29/100,000 p.a.] | ✓ | ✓ | ✓ | ✓ | Carpal fractures appear to be more common than previously thought & the spectrum of anatomical location of fractures varies considerably between CBCT & XR. |
| Snaith et al. (2022) | ✓ | p | p | p | ✓ | ✓ | Normal XR = proceed to CBCT<br>MRI if negative CBCT and ongoing concern<br>Definitive diagnosis available within 2 days for 94% of cases. CBCT confirmed 2 suspected fractures on XR and diagnosed 9 (16%) occult carpal fractures. No further # identified on MRI. | ✓ | ✓ | ✓ | ✓ | Patients with a negative CBCT scan can be discharged with splint and guidance, providing there is a safety net (e.g. hand therapy follow-up). |
| Vitez et al. (2021) | ✓ | x | x | x | ✓ | ✓ | All participants imaged with XR, CBCT<br>CBCT = 99% Sensitivity, 90% specificity<br>XR = 83% Sensitivity, 79% specificity | p | ✓ | ✓ | ✓ | Improved detection: 69% of carpal fractures not visible on XR. |

[a]CASP criterion: 1. Are the results of the study valid? 2. Was there a comparison with an appropriate reference standard? 3. Did all patients get the diagnostic test and reference standard? 4. Could the results of the test have been influenced by the results of the reference standard? 5. Is the disease status of the population clearly described? 6. Were the methods for performing the test described in sufficient detail? 7. What are the results? 8. How sure are we about the results? 9. Can the results be applied to your patients/the population of interest? 10. Can the test be applied to your patient or population of interest? 11. Were all outcomes important to the individual or population considered? 12. What would be the impact of using this test on your patients/population?

CASP scoring: Criterion is completely met = ✓
Criterion is partially met = p
Criterion not applicable, not met, or not mentioned = x

CBCT: cone beam computed tomography; CI: confidence interval; MRI: magnetic resonance imaging; NPV: negative predictive value; PPV: positive predictive value; XR: X-ray/radiographic imaging

### 2.3.3 The Sensitivity and Specificity of CBCT

Five studies discussed the specificity and sensitivity of CBCT imaging (see Table 4). Four of the studies reported sensitivity rates ranging 96%-100% and specificity rates between 90%-100% (Borel et al., 2017; Colville et al., 2022; Snaith et al., 2022; Vitez et al., 2021). Borel et al. (2017) authored the only study in which MRI was the reference standard for all participants. Therefore, their results of 100% sensitivity, 95% specificity, 96% positive predictive value and 100% negative predictive value could be considered the most reliable. In contrast Edlund et al. (2016) presented much lower values of 69% sensitivity and 44% specificity. This can largely be explained by the inclusion of bone contusion (as viewed on MRI) in their results, giving false low values. Bone contusion (or bone bruising) is caused by trabecular micro fractures, without a discrete fracture line or contour abnormality and is visible only by increased signal on MRI. Bone contusion is not complicated by non-union and is considered to be a benign injury with predictable recovery (Borel et al., 2017). Other studies included only cortical fractures, where the outer layer of the bone is disrupted, creating a visible fracture line on imaging.

CBCT has demonstrated high diagnostic performance in most studies, with sensitivity ranging from 96% to 100%, indicating strong accuracy in detecting cortical fractures. This allows clinicians to confidently exclude bone injury when no fracture is present. Similarly, reported specificity between 90% and 100% suggests CBCT is highly effective at confirming true negatives, minimising the likelihood of false positives. This has clinical significance in terms of patient outcomes; when CBCT is both highly sensitive and specific, patients benefit from faster and more accurate diagnoses, enabling timely intervention. Precise identification of cortical fractures ensures that those with confirmed injuries receive appropriate and targeted management.

### 2.3.4 Incidence

Krayem et al. (2021) conducted a retrospective study at a Swedish hospital comparing carpal fracture incidence across two imaging periods. During 2013–2014, X-ray was used exclusively, while in 2016–2017, CBCT was the primary modality. The incidence of carpal fractures was three times higher during the CBCT period (92 per 100,000 annually) compared to the X-ray-only period (29 per 100,000), highlighting CBCT's superior sensitivity in fracture detection. The true incidence of carpal fracture may be even higher, as MRI was not utilised in this study and remains the gold standard for carpal fracture diagnosis. Results do suggest that fractures of the carpal bones are more common than previously reported. These findings could have important clinical implications, prompting a reassessment of imaging protocols to ensure fractures are accurately diagnosed and appropriately managed.

### 2.3.5 Methodological Quality of Included Studies

Varied approaches to image interpretation across studies have notable implications for both diagnostic reliability and inter-study comparability. While most studies utilised dual-radiologist assessments, methods ranged from independent, blinded evaluations to consensus-based readings. In a study by Borel et al. (2017), radiologists were blinded to previous imaging and each other's reports, minimising potential interpretive bias. In contrast, other studies employed consensus-based interpretation between two radiologists (Edlund et al., 2016; Gibney, Murphy, et al., 2019). Vitez et al. (2021) included an orthopaedic consultant alongside two radiologists, while Krayem et al. (2021) incorporated a third radiologist with over 20 years of experience to review the images. Colville et al. (2022) had X-rays interpreted by a specialist radiographer and CBCT/MRI by consultant musculoskeletal radiologists.

Considering the approaches taken, the involvement of multiple imaging specialists appears to enhance diagnostic accuracy and reduce individual bias. While consensus-based readings promote consistency, they may also introduce shared interpretive assumptions. Notably, only Borel et al. (2017) employed a blinded method, offering the strongest design for limiting interpretation bias and external influence. In contrast, Snaith et al. (2022) did not specify their method of image interpretation, which limits both transparency and the ability to critically appraise their findings.

These findings highlight the need for future research to adopt standardised, clearly defined methods for interpreting images. This would make results more consistent, easier to compare, and more transparent.

### 2.3.6 Time to Diagnosis

Variations between time to diagnosis across studies suggests that hospitals and clinics may need clearer guidelines on the timing of CBCT imaging when radiocarpal fractures are suspected. However, differences in CBCT timing might reflect variations in hospital protocols, patient load, or access to advanced imaging rather than intentional study design. In a study by Edlund et al. (2016), all patients underwent CBCT imaging on the day of presentation. Similarly, a high proportion of patients received CBCT within one day in Colville et al. (2022) and within two days in Snaith et al. (2022). Borel et al. (2017) conducted imaging within seven days of the initial event. Other studies reported CBCT imaging within 14 days (Gibney, Murphy, et al., 2019; Gibney, Smith, et al., 2019; Vitez et al., 2021), while one study (Krayem et al., 2021) did not specify the timing of diagnosis.

These findings highlight the value of early CBCT to achieve faster, more accurate diagnosis and timely treatment, especially when radiocarpal fractures are suspected. A two-week window appears to be a reasonable upper limit for CBCT in such cases, although earlier imaging is often preferable. While early CBCT is ideal, a cost-benefit analysis could help determine optimal timing recommendations that balance diagnostic accuracy with efficient use of health resources.

### 2.3.7 Limitations of the Evidence

A review of the available literature retrieved a limited number of studies, most with relatively small sample sizes, which limits the robustness and generalisability of conclusions drawn from the data. Methodological consistency was also a concern: five of the eight studies employed multiple reference standards (Borel et al., 2017; Colville et al., 2022; Gibney, Murphy, et al., 2019; Gibney, Smith, et al., 2019; Snaith et al., 2022), introducing potential bias and reducing comparability across studies Two studies used CBCT as the reference standard (Krayem et al., 2021; Vitez et al., 2021), with only one study using MRI (Borel et al., 2017), the recognised gold standard.

All included studies were conducted in Europe, raising concerns about external validity. Regional differences in clinical practices, imaging infrastructure, and patient demographics may limit the applicability of findings to other healthcare settings globally, particularly in regions with different healthcare delivery models or resource constraints.

CBCT acquisition times across the included studies ranged from 15 to 36 seconds, introducing the risk of motion artefact due to patient movement (Neubauer et al., 2018). MRI, by contrast, requires approximately 10 minutes of stillness in a confined space (Edlund et al., 2016). CBCT's shorter image acquisition time and less invasive positioning make it particularly suited to fast-paced or high-throughput clinical environments such as emergency departments and fracture clinics. For patients (especially those in pain, with limited mobility, or experiencing anxiety) this translates to a more comfortable and tolerable imaging experience. When used as a second-line tool after X-ray, CBCT provides sufficient diagnostic accuracy with faster throughput. However, variation in acquisition protocols and imaging parameters across studies introduces technical heterogeneity, which may limit comparability.

A prospective study design was used in six of eight studies, which generally offers stronger data integrity (Table 4). The remaining two studies undertook retrospective analysis of data. Retrospective reviews are limited by their reliance on pre-existing data, which can lead to missing information and selection bias, potentially impacting the reliability of the findings compared to a prospective study.

### 2.3.8 Gaps in the Research

There is currently limited demographic data on patients receiving CBCT for radiocarpal fractures. Of the eight studies included in this review, six reported patient sex and/or age (Table 5), showing a broad age range and representation of both male and female patients. However, none reported patient ethnicity, which is a significant limitation. Demographic data is essential not only for assessing the representativeness of study samples but also for identifying potential disparities in access, diagnosis, and outcomes. Analysing patient demographics provides a valuable snapshot of the study population and can help assess whether different groups are proportionately represented. While this analysis can highlight potential imbalances, it does not, on its own, confirm the presence of bias or explain differences in outcomes. Instead, demographic information offers a lens through which researchers can reflect on study design, recruitment practices, and broader patterns that may warrant further investigation.

Table 5

*Patient demographics from included studies*

| **Study** | **Mean Age (range in years)** | **Male (%)** | **Female (%)** |
|---|---|---|---|
| Borel et al. (2017) | not reported | - | - |
| Colville et al. (2022) | 44 (8-79) | 33 | 67 |
| Edlund et al. (2016) | 40 (15-86) | 60 | 40 |
| Gibney, Murphy, et al. (2019) | 40 (16-90) | 50 | 50 |
| Gibney, Smith, et al. (2019) | 41 (16-81) | 51 | 49 |
| Krayem et al. (2021) | 46 (14-89) | - | - |
| Snaith et al. (2022) | 41 (-) | 40 | 60 |
| Vitez et al. (2021) | not reported | - | |

The absence of ethnicity data is particularly relevant in Aotearoa New Zealand, where promoting equitable healthcare outcomes for Māori and Pacific populations remains a central focus of national health policy (Minister of Health, 2023b, 2024, 2023a). Without this information, it is difficult to evaluate whether current imaging practices are equitable or if barriers exist for these communities. Understanding the demographics of CBCT users could inform targeted healthcare strategies, ensuring equitable access to advanced imaging for all groups.

### 2.3.9 Implications of the results of this literature review

This literature review examined the diagnostic accuracy of X-ray imaging compared to cone beam computed tomography (CBCT) in detecting radiocarpal fractures. Although the available evidence is limited, findings consistently indicate that CBCT offers superior diagnostic performance, identifying a greater number of carpal fractures than X-ray. Not only do radiocarpal fractures appear to be more common than suspected, but the CBCT is revealing a much wider spectrum of anatomical locations of fractures. It appears that radiocarpal fractures have been underdiagnosed in the past due to the limitations of X-ray imaging. Integrating CBCT into acute care settings has the potential to improve diagnostic accuracy and patient outcomes. Establishing standardised imaging guidelines could help clinicians determine when CBCT should be prioritised over traditional X-rays, optimising diagnostic efficiency.

Fewer than ten studies were included in this review, all of which were conducted in Europe. This highlights the need for New Zealand based research to determine if results are transferable to our patients and health system. It also highlights a dearth of data regarding the ethnicity of patients who are accessing CBCT imaging. This research aims to investigate both aspects. The results may provide valuable information on radiocarpal fracture incidence in our population, by evaluating the comparative diagnostic value of X-ray and CBCT imaging at identifying radiocarpal fractures. This information could be used to guide imaging protocols and improve diagnosis of occult fractures. Addressing gaps in ethnicity data may prompt healthcare providers to examine whether certain groups face barriers to advanced imaging and could open conversation around the impacts of this on health equality.

# Chapter 3
# Methodology and Methods

## 3.1 Methodology and positionality

I am a New Zealand registered physiotherapist with 25 years of experience. For the past 17 years I have been working as a registered hand therapist in private practice, assessing, and treating hand and upper limb injuries. I work within the Western biomedical model of health care and am part of a team in an acute fracture clinic service. I work with Emergency Medicine Specialists, doctors, nurses, and radiographers. High-tech imaging is available on site, so with a wealth of resources at hand, my expectations of what patient care should look like is very different than it would be if I were working rurally.

Over the years, I have encountered cases of undiagnosed fractures, often presenting well after the initial injury. These cases, and the challenges of managing the downstream effects (prolonged recovery, non-union requiring subsequent surgery, delayed return to work and/or sport, and the emotional toll this has on patients), have heightened my sensitivity to the limitations of standard diagnostic pathways. These factors have combined to influence my positionality and shape my approach to clinical care and research.

Hand therapy is guided by evidence-based practice. The biomedical model that I work within favours a positivist approach to research. Therefore, a quantitative methodological approach was taken for this retrospective observational study. The primary data collected included fracture detection rates, for which a quantitative approach ensures that fractures are classified based on measurable imaging outcomes. In addition to fracture identification, this study examined patient demographics such as age, sex, ethnicity, and access to imaging. Quantitative methods allow for structured comparisons and statistical relationships to be drawn between these variables.

While this study adheres to the positivist biomedical framework, it also acknowledges the critical realist perspective, recognising the complex interplay of social and biological factors in health and injury. The research does not merely quantify fractures but explores the demographics of the patients presenting to our clinic, as well as access to imaging. By employing a quantitative approach, the study maintains scientific rigor while allowing for meaningful interpretation of the systemic influences on patient outcomes.

## 3.2 Study Aims

The purpose of this study was to ascertain the current detection rate of occult radiocarpal fractures using CBCT imaging, and to compare the fractures found on CBCT with those found on initial X-ray. Additionally, it sought to investigate the relationship between patient demographics, access to imaging, and final outcomes.

## 3.3 Study Questions

1. How many radiocarpal fractures are not visible on initial X-ray imaging, but are subsequently detected by CBCT imaging, and is there a significant difference in the location of fractures detected by each modality?
2. Is there a significant difference in the fractures detected between adult and paediatric populations?
3. Are there observed differences in age, sex, ethnicity or distance travelled to treatment on patient outcomes or access to imaging?

## 3.4 Null Hypotheses

1. CBCT and initial X-ray imaging show no significant difference in fracture detection or in the locations of identified fractures.
2. There is no significant difference between radiocarpal fractures identified in adult versus paediatric populations.
3. Patient age, sex, ethnicity, and travel distance to treatment do not influence patient outcomes or access to imaging.

## 3.5 Study Design

A retrospective review was conducted of patient records for individuals presenting with wrist injuries to a specialist fracture clinic operating within a 24-hour acute medical care facility in a metropolitan area. This facility is a major urgent care clinic capable of managing high patient volumes. It offers walk-in services for urgent medical and accident-related care, including minor injuries, acute illnesses, and after-hours support when general practices are unavailable. Located centrally within the city, the clinic is easily accessible to residents and plays a vital role in the local healthcare network. It receives referrals from general practices for fracture management and complements emergency services provided by the nearby public hospital.

The clinic is part of a privately operated organisation that supports primary healthcare across the region. Patients are charged for services, with fees varying depending on the nature of the visit (injury-related consultations, general medical care, or after-hours treatment). These fees are publicly listed on the organisation's website, and children aged 13 years and under receive free medical care. Radiology is located on site. Patient co-payments are charged for X-ray imaging, but there is no cost the patient for CBCT imaging, which is ordered by specialist referral only.

The review covered a six-month period from 1 December 2023 to 30 May 2024, inclusive. This multidisciplinary service, comprising emergency medicine specialists, nurses, radiographers, and a registered hand therapist, managed all 316 patients who met the inclusion criteria. Each patient received an initial X-ray as part of standard protocol. Decisions regarding subsequent imaging were made by the attending emergency specialist, following established clinical guidelines that considered the mechanism of injury, clinical assessment, and relevant risk factors (Appendix A). This inclusive sampling approach reduces the likelihood of selection bias, as all eligible patients within the specified timeframe were reviewed.

## 3.6 Sample size estimation

A retrospective sample size calculation was undertaken using OpenEpi, Version 3, open-source calculator to determine the number of participants needed to detect a clinically relevant treatment effect. A population size of 3000 (based on 2021 ACC published data for active wrist fracture claims (n= 2,927)) and a default % frequency of 50% was used. Confidence limits were set at 5% and the design effect was set at 1.0 for a random sample. Results in Table 6 indicate that this study provides a near 95% confidence level, suggesting that the sample size is one that accurately represents the population and allows for reliable statistical analysis.

Table 6

*Sample size for frequency in a population*

| | |
|---|---|
| Population size (for finite population correction factor or fpc)(*N*): | 3000 |
| Hypothesized % frequency of outcome factor in the population (*p*): | 50%+/-5 |
| Confidence limits as % of 100 (absolute +/- %)(*d*): | 5% |
| Design effect (for cluster surveys-*DEFF*): | 1 |

**Sample Size (*n*) for Various Confidence Levels**

| **Confidence Level (%)** | **Sample Size** |
|---|---|
| 95% | 341 |
| 80% | 156 |
| 90% | 249 |
| 97% | 408 |
| 99% | 544 |
| 99.9% | 796 |
| 99.99% | 1007 |

Equation

Sample size $n = [DEFF*Np(1-p)]/ [(d^2/Z^2_{1-\alpha/2}*(N-1)+p*(1-p)]$

Results from OpenEpi, Version 3, open-source calculator

## 3.7 Ethics

Ethical approval was gained from Auckland University of Technology's Ethics Committee (AUTEC) on 27th November 2024. Reference 24/344 (Appendix B).

## 3.8 Consultation

Prior to commencement of the study, Māori consultation was undertaken with Sandra Kettle (New Zealand registered Physiotherapist and New Zealand registered hand therapist). Sandra is a physiotherapy Kaitiaki for Tae Ora Tinana and is a member of the Māori Advisory Group for Hand Therapy New Zealand. She resides North of Auckland. The researcher acknowledges the inclusion of Māori data in this research and recognises Māori sovereignty over that data. While this research is not a Kaupapa Māori project, the author is respectful of Māori rights and interests. This study aims to prompt broader reflection within the medical community by drawing attention to possible unconscious biases in clinical practice and research. Thought will be given to how any relevant findings can be translated into practical, culturally responsive guidance for Māori communities.

Organisation consultation and consent was obtained from the healthcare facility where the specialist fracture clinic is based, ensuring that the research was undertaken with their full knowledge and agreement (Appendix C). These steps ensured that the research project was conducted in a transparent and ethical manner.

A consultation was conducted with the Accident Compensation Corporation (ACC), requesting access to their data on wrist injuries lodged in the Canterbury region during the study period (1st December 2023 – 30th May 2024). The request specifically sought information that included patient ethnicity, aiming to evaluate the representativeness of the study sample. The dataset supplied included ACC codes for S234 distal radius fracture, 2341 Colles fracture, S2401 scaphoid fracture, S24z fracture carpal bone, S520 wrist sprain.

## 3.9 Inclusion Criteria

Records of all patients, of any age, presenting with suspected radiocarpal fracture, to the specialist fracture clinic service. Radiocarpal fractures are defined as fractures to the distal radius and carpal bones (scaphoid, lunate, trapezium, trapezoid, triquetrum, pisiform, capitate and hamate).

## 3.10 Exclusion Criteria

There were no exclusion criteria applied to the study.

## 3.11 Data Collection and Processing

Prior to the commencement of the study a Data Management Plan was created which conformed to both AUT's Research Data guidelines and site requirements (Appendix D). Data collection began in January 2025 and finished in March 2025. All data were collected retrospectively from patient files. This plan detailed data storage procedures, version control, and methods for ensuring data integrity throughout the research process. A code book was created to focus data collection, ensuring that only data relevant to the study were collected and appropriately coded (Appendix E).

Data were gathered from patient electronic health records (Gensolve Practice Manager) and from electronic imaging records (Inteleviewer, Pacific Radiology Group). A total of 1,011 patients presented to the specialist fracture clinic for treatment over the course of the six-month inclusion period. Of these, 325 wrist injuries were identified in 316 individuals. Patient sex, ethnicity and age (at the time of initial X-ray) were identified from patient health records. Participants were further categorised into paediatric (aged <16 years and under) and adult (aged ≥16 years) groups. This aligns with Te Whatu Ora's service structure, in which children's wards typically accommodate patients up to and including 15 years of age. It also corresponds with a broader social threshold in New Zealand, where age 16 marks the earliest legal point for school leaving and obtaining a driver's licence. While not a direct indicator of biological maturity, this division represents a practical boundary that aligns with healthcare delivery and social transitions relevant to the New Zealand context. Distance travelled to attend appointment was determined by calculating the shortest route from the patient's home address to the 24HR clinic via Google Maps.

Imaging records were accessed to collect data on the type of imaging performed (X-ray, CBCT, MRI), fracture presence (none, fracture, occult fracture) and fracture location. Occult fracture was defined as fracture not visible on X-ray but showing on CBCT or MRI. In patients sustaining more than a single fracture, each fracture was recorded individually. For scaphoid fracture, the type of fracture (distal pole/scaphoid tubercle, waist, proximal pole) was also noted.

Data were entered into an Excel spreadsheet and once completed, patient NHIs were removed, and a clean data sheet created. Patient identifying characteristics (NHI numbers) were stored separately from the clean data sheet and the correlation tool was not accessible to anyone other than the researcher. Patient names were not collected at any stage of the research process. Patient privacy and confidentiality were respected throughout the research process.

Data were then filtered according to variables, this allowed errors to be identified and corrected. Thirteen coding errors were identified; patient files were reviewed and the data amended accordingly. One patient had been entered twice in error, and the duplicate was removed.

## 3.12 Data Audit Procedure

An audit was undertaken of the collected data. The purpose of the audit was to ensure the accuracy, consistency, and reliability of the collected data in the research study. By systematically reviewing a representative sample (10%) of the dataset, the audit aimed to identify any potential errors, discrepancies, or inconsistencies that could affect the integrity of the findings.

The data sample audit was undertaken by a research assistant (RA). The RA is a New Zealand-registered physiotherapist and hand therapist with postgraduate qualifications, as knowledge of the research topic was required to enable accurate interpretation of the information collected from patient files. A confidentiality agreement was signed by the RA to protect patient and data privacy (see Appendix F).

Every tenth patient was audited, giving an audit sample size of n= 32 (317 patients in the dataset). An Excel spreadsheet was created with patient ID and variables to be collected. A code book was created containing dataset names and coding instructions (Appendix E). This ensured that only data relevant to the study was extracted from patient files. Training was provided to ensure that the research assistant was familiar with the data extraction and recording processes.

Comparison of the audit data with the original dataset revealed a 96% agreement rate. Fourteen discrepancies (4% error rate, 14/352 entered) were identified. On reviewing the discrepancies, it was determined (by both the researcher and the RA) that ten coding errors were made by the RA and three coding errors were made by the researcher. The researcher coding errors were corrected on the clean and raw datasets.

The remaining discrepancy related to a disagreement on diagnosis. The researcher believed the ulnar styloid fracture evident on X-ray imaging was historical, from a 2022 injury (non-union). Therefore, the X-ray was coded as "no (new) fracture". The RA believed the fracture was acute and that the patient should be excluded from the study. A third opinion was sought from the reporting radiologist, and patient data were retained and included in the study, as it was the opinion of the radiologist that the ulnar styloid fracture represented an old injury (ununited apophysis ulnar styloid process ossicle).

## 3.13 Imaging Techniques

All X-ray and CBCT imaging was performed on-site at the 24-hour Clinic by Pacific Radiology Group. MRI was not available on-site and was outsourced to an alternative Pacific Radiology Group provider.

**Radiography**

Projections for all patients included posteroanterior (PA), oblique, and lateral views of the wrist in the neutral position with an additional scaphoid PA view with 20–30° tube angulation to the head in ulnar deviation. Digital images were obtained with a flat panel detector (Philips Diagnost 4) using voltage of 55 kV, tube current of 2 mAs, and a 110-cm film to focus distance.

**Cone-beam CT**

All CBCT images were obtained using a Planmed Verity extremity CBCT scanner (Planmed Oy). The examination was conducted using a voltage of 96 kV and tube current of 5 mA. Slice reconstruction thickness was 0.2 mm High Definition. FOV was 150 mm × 150 mm. Total scan acquisition time is approximately 25 seconds, with approximately 30 minutes of image processing time after the scan. Seven reconstructions (axial 0.6mm, coronal 0.6mm, sagittal 0.6mm, coronal oblique 0.2mm, sagittal oblique 0.2mm and 3D rotate and 3D roll) were sent to the picture archiving and communication system (PACS).

**MRI**

Images were obtained with a 3-T unit (Magnetom Skyra, Siemens Healthcare) and a 16-channel wrist coil (Hand/wrist 16, Siemens Healthcare). The protocol consisted of coronal and sagittal slices with two sequences: T1-weighted spin-echo (TR/TE, 553/12; slice thickness, 2mm) and T2 with fat saturation (TR/TE, 3000/56; slice thickness, 2 mm). A 100-mm FOV with a 512 × 512 matrix was used for each sequence. No gadolinium was injected. Examinations were carried out in the Superman position (prone with arm extended into the gantry).

## 3.14 Data Analysis

Descriptive statistics (frequencies, percentages, median, range, and ratios) were used to summarise and present the key characteristics of the cohort. Categorical data (age, sex, ethnicity, or imaging received) were summarised by frequency and percentage. Continuous data was analysed by measures of central tendency (median) and measures of variability (range). Graphical representation was used to visually illustrate patient flow, data trends and distributions.

Initial categorical variables, including sex, ethnicity and imaging received, were defined according to the study codebook. Patient age, initially a continuous variable, was categorised into age groups, allowing for easier identification of patterns, trends, and distributions within the dataset. Categorical data (age, sex, distance, ethnicity, imaging modality, age group) were analysed using Pearson's chi-square test. Fisher's exact test was used to analyse small sample sizes, particularly for ethnicity, due to the under-representation of non-European groups. Since age and distance travelled were not normally distributed (positive skew), the Mann-Whitney U test compared differences between these variables and the others.

Logistic regression analysis was conducted to examine key variables. Initially, each variable was assessed individually using binary logistic regression. Age was categorised both by decade and broadly into paediatric versus adult groups to facilitate analysis.

Due to the predominance of European patients and the relatively small representation of other ethnic groups, the Māori, Pasifika, Asian, 'Other,' and 'Not Specified' categories were combined into a single non-European group for analysis. Similarly, travel distance was dichotomized into two categories for analysis: less than 20 km and over 20 km. This adjustment was necessary as the limited number of patients in certain groups restricted statistical analysis, but combined groups provided sufficient numbers for meaningful evaluation.

Finally, multinomial logistic regression was employed to investigate factors influencing fracture diagnosis using initial X-ray (IXR) versus CBCT imaging as the dependent variable. Predictor variables included age, gender, travel distance, and ethnicity.

Data were analysed using IBM SPSS Statistics Software Version 30.0.0.0 (172). An alpha level of .05 was used for all statistical tests.

# Chapter 4

# Results

## 4.1 Overview of patient pathway

In this study, 325 injuries were identified in 316 patients. At the time of injury, eight patients had either fractured two separate bones in the same wrist or had sustained injuries to both wrists, while one patient was treated for two separate injuries during the six-month period.

Figure 3 displays the flow of patients through the fracture clinic. All patients received initial X-ray imaging. Of the 325 injuries assessed, 41% (n= 134/325) were diagnosed with a fracture based on the initial X-ray. The remaining 59% (n= 191/325) showed no fracture and required further evaluation.

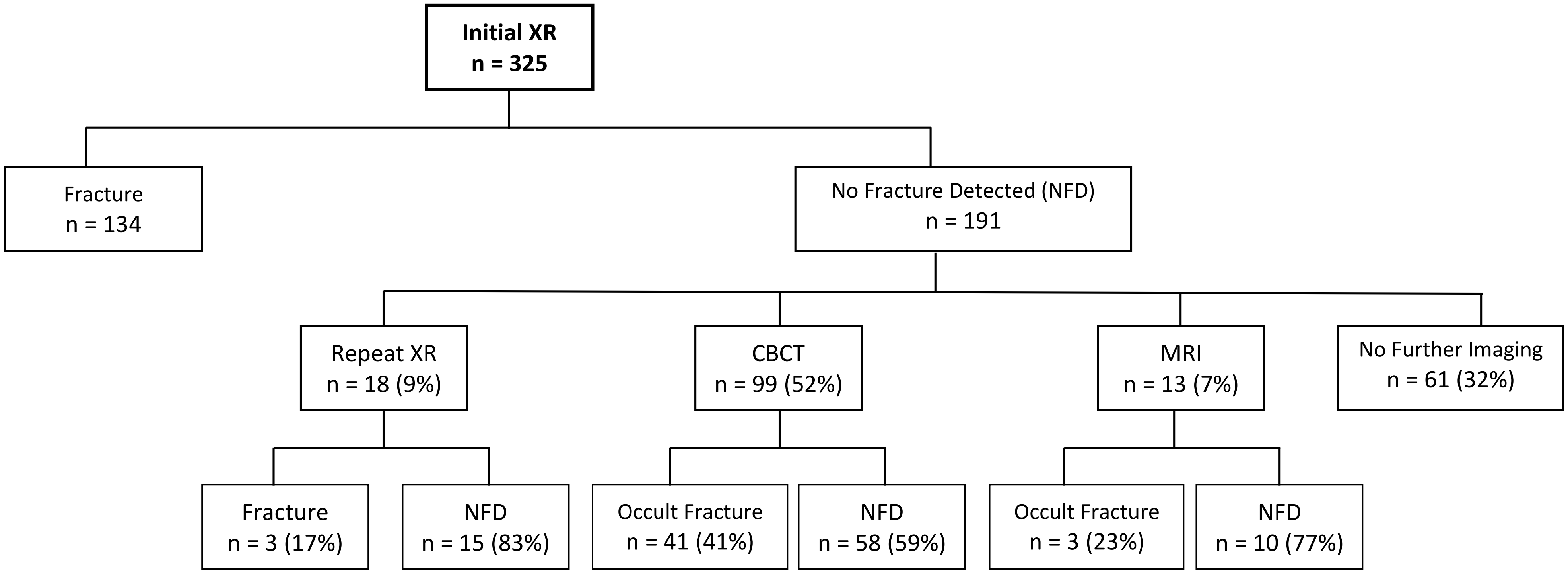
In total, 191 patients had a normal initial X-ray and underwent additional assessment. Following assessment, over half were referred for CBCT (n= 99/191), nine per cent were referred for repeat X-ray (n= 18/191), seven per cent were referred for MRI (n= 13/191), and the remaining 32% (n= 61/191) received no further imaging. Altogether, 130 patients received repeat imaging (68%, n= 130/191).

Despite a negative initial X-ray, over a third of patients (36%, n= 47/130) who received further imaging were later diagnosed with a radiocarpal fracture. Magnetic resonance imaging and repeat X-rays each identified three additional fractures. Among patients referred for CBCT, 41% (n= 41/99) were diagnosed with radiographically occult fractures. This means that two out of every five CBCT referrals ultimately revealed a previously undetected fracture.

While CBCT, MRI, and repeat X-rays successfully identified fractures missed on the initial imaging, 32% of patients (n= 61/191) with a negative first X-ray were assessed as low risk of fracture and received no further imaging. It is not possible to determine if there were undiagnosed fractures in this group.

Figure 3

*Suspected radiocarpal fracture patient pathway*



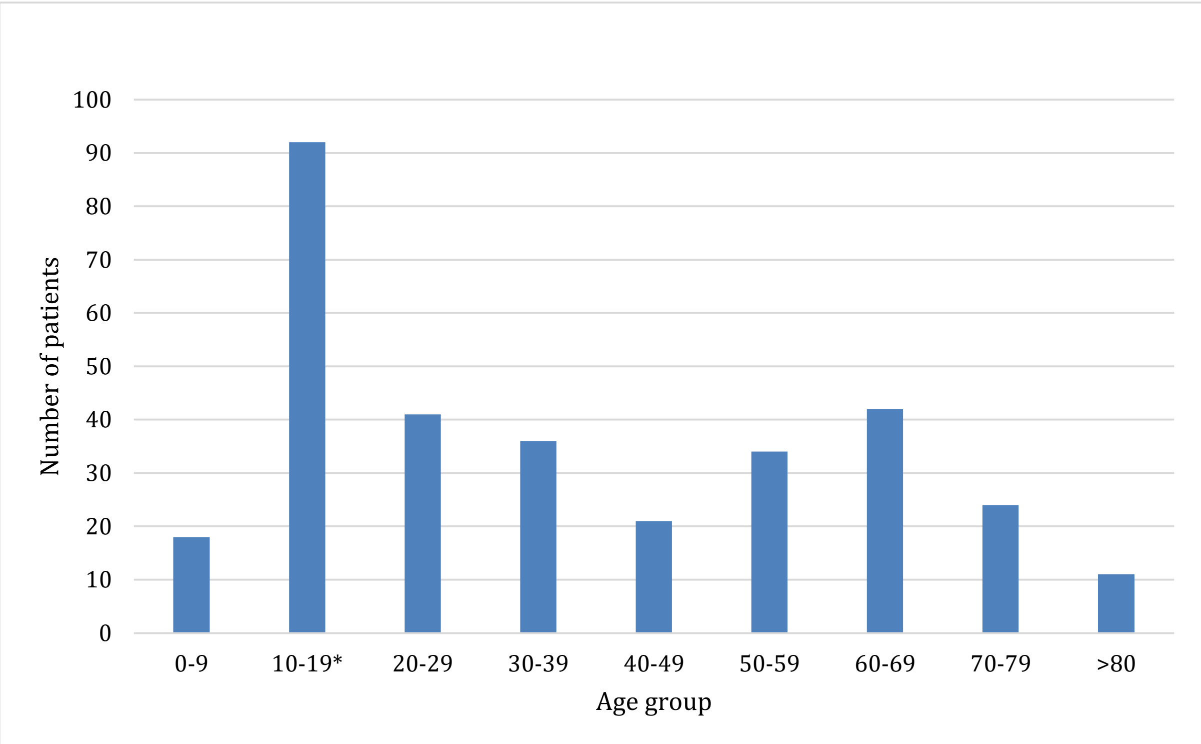
## 4.2 Cohort characteristics by age, sex and ethnicity

### 4.2.1 Age

The patient cohort presenting to the fracture clinic had an age range from 5 to 95 years, with a median age of 37 years. To better understand trends, the data were categorised into 10-year age bands and examined. Figure 4 illustrates a bimodal distribution, highlighting two distinct populations that exhibit higher presentation rates to the fracture clinic. The first peak is in the age 10-19 years cohort, who make up the largest group presenting to fracture clinic for assessment (n= 92/316, 29%). The second occurs in the 60-69 group (n= 43/316, 14%).

Figure 4

*Breakdown of cohort age representation, grouped by decade*



### 4.2.2 Sex

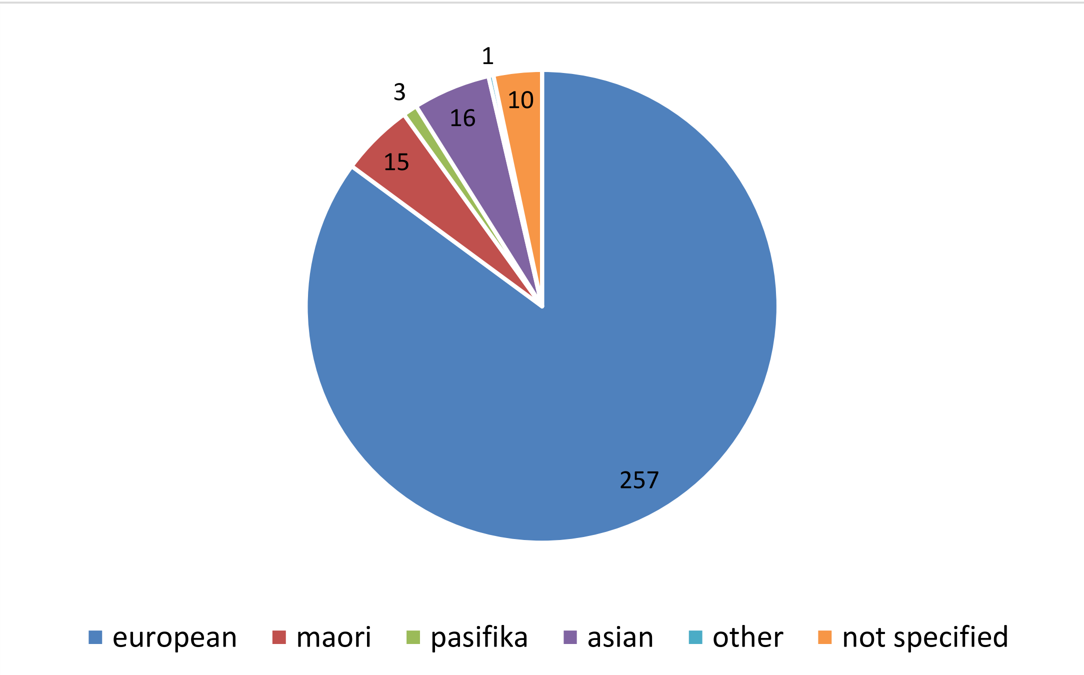
In the total cohort, the male-to-female ratio was 41% (n= 133/325) to 59% (n= 192/325), indicating a higher representation of female patients. The paediatric group showed a near 50/50 male-to-female split (male: n= 45/88, female: n= 43/88). In contrast, the adult population followed the overall trend, with a 37/63 distribution (male: n= 88/237, female: n= 149/237), highlighting the greater proportion of female patients in older age groups.

### 4.2.3 Ethnicity

The patient cohort was predominantly European, comprising 86% (n= 280/325) of the total population. Māori (5%, n= 15/325) and Asian patients (5%, n= 16/325) had equal representation, while 3% (n= 3/325) were categorised as undefined. Few Pasifika patients presented for assessment, representing 0.9% (n= 3/325) of the population, with other ethnicities making up just 0.1% (n= 1/325). The ethnic composition of the study cohort is presented in Figure 5, below.

Figure 5

*Ethnic composition of study cohort*



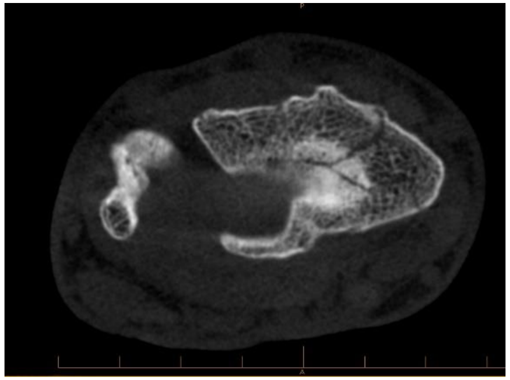
## 4.3 Cohort characteristics and method of detection - by fracture location

All patients in the cohort with diagnosed fractures on either initial X-ray or CBCT were extracted from the dataset and analysed separately (Table 7). While 90% of distal radius fractures and 80% of scaphoid fractures were detected on initial X-ray, no fractures of the trapezium, capitate, or lunate were identified. However, CBCT revealed nine trapezium fractures, three capitate fractures, and one lunate fracture. The trapezoid is rarely fractured; no cases were recorded during the six-month study period.

The results highlight significant variations in fracture location depending on cohort characteristics (Figure 6). Females were twice as likely as males to sustain distal radius fractures, whereas the opposite trend was observed for scaphoid fractures. The median age for scaphoid fracture was 30 years, a decade younger than for distal radius fractures (40 years), while patients with triquetral fractures had a median age of 51 years, making them a decade older on average. The highest median age was observed in patients with trapezium fractures (56 years), whereas the lowest was found in patients with capitate fractures (15 years). Additionally, women were more likely to be diagnosed with trapezium fractures, whereas men were more frequently diagnosed with hamate fractures.

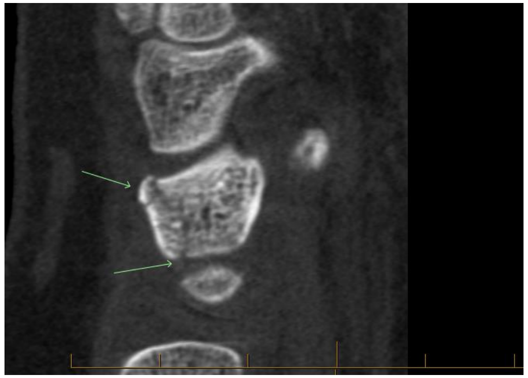
Further examination of scaphoid fracture data revealed a total of 46 fractures: 24 to the scaphoid waist, an area at risk of non-union, and 22 to the distal pole or scaphoid tubercle. No proximal pole fractures were identified in this cohort. The average time to diagnosis was 10 days. In total, 20% of scaphoid fractures (n= 9/26) were occult. While the median age of injury for the two fractures sites was identical (29 years), children appear to be more likely to fracture the scaphoid tubercle/distal pole (n= 8/22, 36%) and less likely to sustain fractures to the scaphoid waist (n= 1/24, 4%).

Figure 6 *Cohort Characteristics and method of detection - by fracture location*

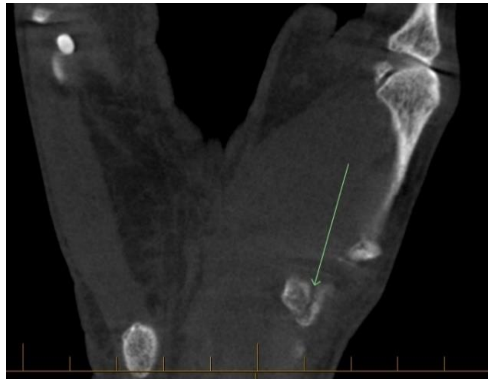


**A. Distal radius (n=101)**
Male to female ratio = 1:2
Median age in years (range) = 40 (5-95)
10% occult, 90% visible on initial X-ray

**B. Scaphoid (n=41)**
Male to female ratio = 2:1
Median age in years (range) = 30 (9-78)
20% occult, 80% visible on initial X-ray

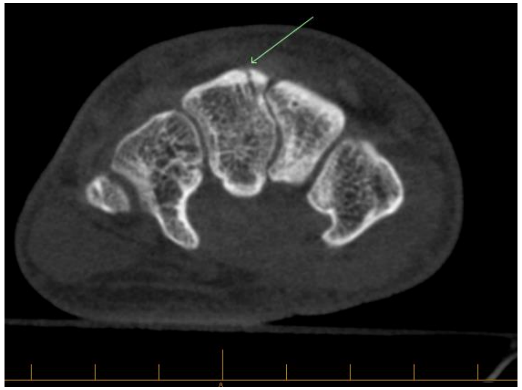


**C. Triquetrum (n=13)**
Male to female ratio = 6:7
Median age in years (range) = 51 (19-73)
38% occult, 62% visible on initial X-ray

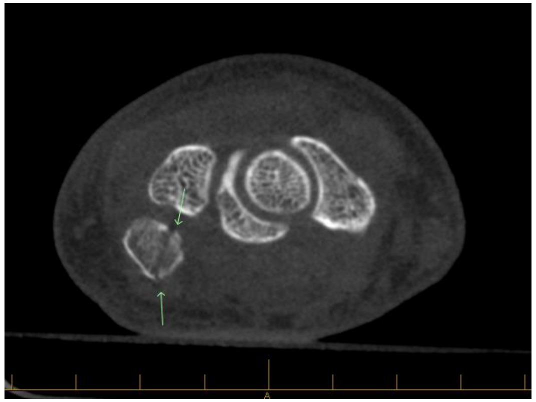


**D. Trapezium (n=9)**
Male to female ratio = 2:7
Median age in years (range) = 56 (27-75)
100% occult

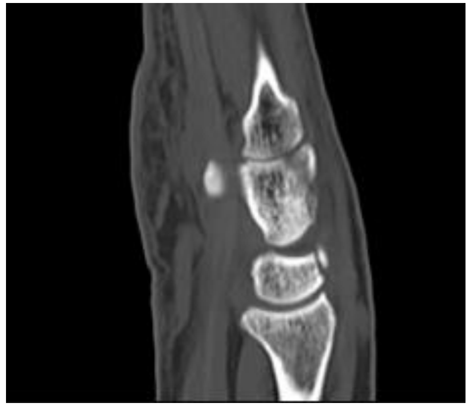
**E. Hamate (n=5)**
Male to female ratio = 4:1
Median age in years (range) = 31 (22-55)
80% occult, 20% visible on initial X-ray



**F. Capitate (n=3)**
Male to female ratio = 1:2
Median age in years (range) = 15 (10-20)
100% occult



**G. Pisiform (n=2)**
Male to female ratio = 1:1
Median age in years (range) = 49 (34-64)
50% occult, 50% visible on initial X-ray



**H. Lunate (n=1)**
Female
Age in years = 75
100% Occult

## 4.4 Null hypothesis 1: CBCT and initial X-ray imaging show no significant difference in fracture detection or in the locations of identified fractures.

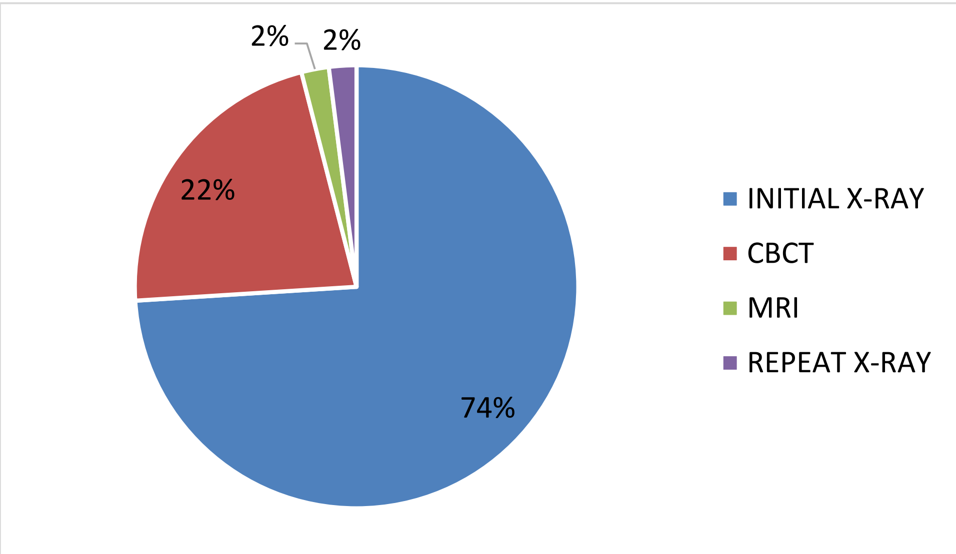
To test this hypothesis, both components (fracture presence and fracture location) were examined separately. Descriptive statistics were used to summarise detection patterns and anatomical sites identified by each imaging modality. Following this, non-parametric statistical tests (such as the Chi-square or Fisher's exact test, depending on sample size and distribution) were applied to determine whether any observed differences between CBCT and X-ray were statistically significant.

### 4.4.1 'How many fractures are not visible on initial X-ray imaging but are subsequently detected by CBCT imaging?'

Examining overall fracture identification by imaging modality (Figure 7) showed that of the 181 total diagnosed fractures, 74% (n= 134/181) of fractures diagnosed were identified on initial X-ray, and 22% (n= 41) were identified only through CBCT. The remaining 4% (n= 6) were diagnosed via MRI or repeat X-ray.

Figure 7

*Overall fracture identification by imaging modality*



### 4.4.2 'Is there a significant difference in the type of fractures detected by each modality?'

The percentage of fractures identified on X-ray was compared with those identified on CBCT (Figure 8). Results show that while X-rays primarily detected distal radius and scaphoid fractures (93%), CBCT revealed a greater diversity of carpal bone fractures. Fractures of the other carpal bones constituted 66% of all fractures identified by CBCT but only 7% on X-ray.

Fractures identified on initial X-ray imaging were compared with those detected via CBCT imaging (Table 7). A comparison was made of cohort and fracture characteristics. The effect of imaging modality (X-ray versus CBCT) on fracture location was investigated, with strong evidence found of significant difference in fracture detection between methods ($p < 0.001$, Table 7). Specifically, there was a higher prevalence of occult non-scaphoid carpal fractures identified with CBCT. Based on these results, the null hypothesis cannot be accepted. These findings demonstrate that CBCT and initial X-ray imaging differ significantly in both their ability to detect fractures, and the anatomical locations of the fractures identified.

Figure 8

*Percentage of fracture types diagnosed on initial imaging versus occult fractures diagnosed on CBCT*

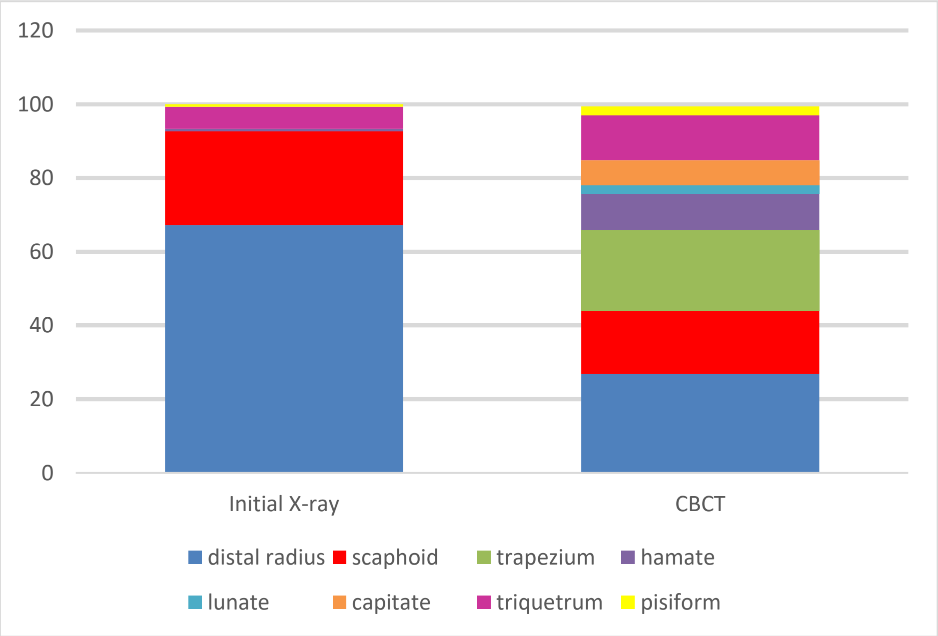


Table 7

*Cohort and fracture characteristics of fractures identified on initial X-ray imaging versus CBCT*

| | Fracture on initial X-ray imaging | Occult fracture detected on CBCT | P value |
|---|---|---|---|
| **N** | 134 | 41 | |
| **Sex** (%) | | | |
| Male | 55 (41%) | 19 (46%) | 0.57[1] |
| Female | 79 (59%) | 22 (54%) | |
| **Age** (median [range]) | 38.00 [5.00, 95.00] | 44.00 [10.00, 75.00] | 0.156[1] |
| **Ethnicity** (%) | | | 0.90[2] |
| European | 118 (88.2) | 37 (90.2) | |
| Māori | 4 (3.0) | 2 (4.9) | |
| Asian | 7 (5.2) | 1 (2.4) | |
| Pasifika | 1 (0.7) | 0 (0.0) | |
| Middle East/Latin America/African | 1 (0.7) | 0 (0.0) | |
| not defined | 3 (2.2) | 1 (2.4) | |
| **Fracture Location** (%) | | | **<0.001[1] *** |
| distal radius | 90 (67.2) | 11 (26.8) | |
| scaphoid | 34 (25.4) | 7 (17.1) | |
| trapezium | 0 (0.0) | 9 (22.0) | |
| hamate | 1 (0.7) | 4 (9.8) | |
| lunate | 0 (0.0) | 1 (2.4) | |
| capitate | 0 (0.0) | 3 (6.7) | |
| triquetrum | 8 (6.0) | 5 (12.2) | |
| pisiform | 1 (0.7) | 1 (2.4) | |
| trapezoid | 0 (0.0) | 0 (0.0) | |
| time (median [range]) | N/A | 12.00 [3.00, 42.00] | N/A |
| **Distance travelled in km** (median [range]) | 14.5 [1.1, 181.0] | 17.0 [1.6, 114.0] | |

[1]Chi-square Test [2] Fisher Exact Test [*]significant result

## 4.5 Null Hypothesis 2: There is no significant difference between radiocarpal fractures identified in adult versus paediatric populations.

The study cohort included all patients, regardless of age, who presented to the fracture clinic with a suspected radiocarpal fracture. In total, 325 injuries were assessed, with 181 confirmed fractures, yielding a cohort fracture rate of 56%. Adult fractures (n= 131) constituted 72% of all cases, while paediatric fractures (n= 50) accounted for the remaining 28%.

A detailed summary of cohort and fracture characteristics, stratified by age, is provided in Table 8. The diagnosed fracture rates were identical between the two groups, with 56% of cases confirmed in both the paediatric (50/89) and adult (131/236) cohorts. Given the identical fracture rates between paediatric and adult populations the findings do not indicate a significant difference in radiocarpal fracture occurrence based on age group. Similarly, demographic analysis revealed that both cohorts were predominantly European, with 90% of adult fractures and 92% of paediatric fractures occurring in European patients.

However, differences in sex distribution were evident across age groups. Among paediatric fractures, there was an equal split between males and females (50/50), whereas in adults, the proportion shifted to 40% male and 60% female (Figure 9). Furthermore, the median age at the time of fracture differed between sexes. In the adult cohort, females were, on average, 17 years older than males at the time of fracture, whereas in the paediatric cohort, this difference was only one year.

Table 8

*Cohort and fracture characteristics (diagnosed fractures only), stratified by age (child vs adult)*

| | | **Adult (age 16+)** | **Paediatric (age ≤ 15 years)** | **p** |
|---|---|---|---|---|
| **N** | | 131 | 50 | |
| **Sex** (%) | male | 52 (39.7) | 25 (50.0) | 0.369 |
| | female | 79 (60.3) | 25 (50.0) | |
| **Ethnicity** (%) | European | 118 (90.1) | 46 (92.0) | 0.199 |
| | Māori | 3 (2.3) | 1 (2.0) | |
| | Asian | 6 (4.6) | 0 (0.0) | |
| | Pasifika | 0 (0.0) | 2 (4.0) | |
| | Middle East/Latin America/African | 0 (0.0) | 0 (0.0) | |
| | not defined | 4 (3.0) | 1 (2.0) | |
| **Outcome** (%) | fracture on XR | 90 (68.7) | 43 (86.0) | **0.001*** |
| | fracture on CBCT | 38 (29.0) | 2 (4.0) | |
| | fracture on MRI | 1 (0.8) | 2 (4.0) | |
| | fracture on repeat XR | 2 (1.5) | 3 (6.0) | |
| **Fracture** (%) | distal radius | 64 (48.8) | 38 (76.0) | **0.01*** |
| | scaphoid | 36 (27.5) | 10 (20.0) | |
| | trapezium | 9 (6.9) | 0 (0.0) | |
| | hamate | 5 (3.8) | 0 (0.0) | |
| | lunate | 1 (0.8) | 0 (0.0) | |
| | capitate | 1 (0.8) | 2 (4.0) | |
| | triquetrum | 13 (9.9) | 0 (0.0) | |
| | pisiform | 2 (1.5) | 0 (0.0) | |
| **Diagnosis** (%) | fracture | 92 (70.2) | 46 (92.0) | **0.01*** |
| | occult fracture | 39 (29.8) | 4 (8.0) | |
| **Distance travelled in km** (median [range]) | | 15.2 [1.6, 181.0] | 14.5 [1.8, 118.0] | 0.791 |

*significant result

Figure 9

*Adult and paediatric fractures by sex, age and detection on X-ray imaging*

**Adult**
Male/Female = 40/60
Median age (years) = 35.7/52.8
70% of fractures visible on initial x-ray

**Paediatric**
Male/Female = 50/50
Median age (years) = 11.6/10.5
90% of fractures visible on initial x-ray

Statistical analysis revealed a significant difference in the diagnostic modality for fractures (**p = 0.001**, Table 7). Among paediatric fractures, 92% were identified through X-ray imaging, with 86% diagnosed on initial X-ray and an additional 6% detected via follow-up imaging. In contrast, only 70% of adult fractures were diagnosed using X-ray imaging, while the remaining 30% were classified as occult fractures. Of these, 29% were identified through CBCT imaging. The statistically significant difference suggests that paediatric fractures are predominantly diagnosed via initial X-ray imaging, whereas adult fractures exhibit a higher likelihood of being occult and requiring alternative imaging modalities for detection.

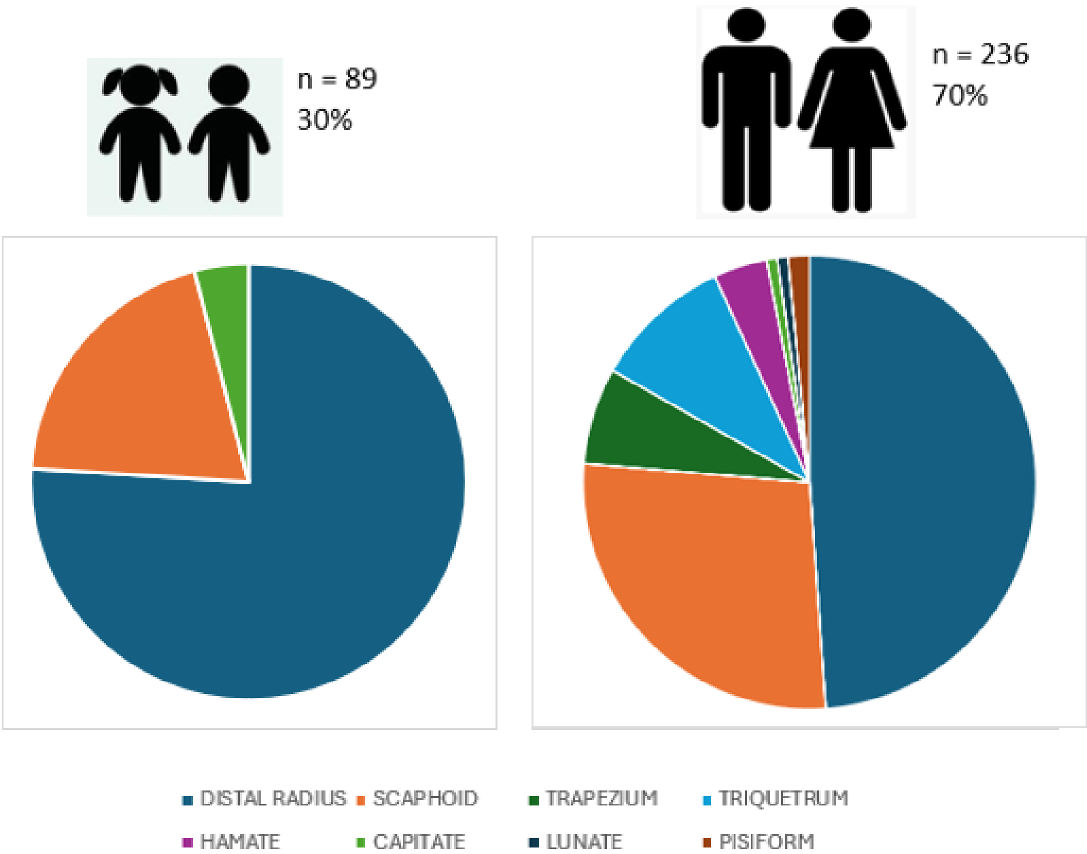
It is noted that adults had higher referral rates for CBCT than children, and higher diagnostic rates of occult fracture. There were 236 adults in the cohort, 90 of whom had fracture on initial X-ray (n= 90/236, 38%). This left 146 adults with no apparent bone injury. Sixty percent of adults with negative initial X-ray were subsequently referred for CBCT imaging (n= 87/146). Of these, 44% (n= 38/87) were diagnosed with occult fracture. In comparison, there were 89 paediatric cases in the cohort, 48% of which had fracture on initial X-ray (n= 43/89). This left 46 children with no apparent bone injury. Twenty-four percent of children with negative initial X-ray were subsequently referred for CBCT imaging (n= 11/46). Of these, 18% (n= 2/11) were diagnosed with occult fracture.

Analysis indicates that while all patients underwent initial X-ray imaging, the likelihood of referral for additional imaging differed between paediatric and adult populations. A total of 27% of paediatric patients (n= 24/89) received no further imaging beyond the initial X-ray, compared to only 16% of adult patients (n= 37/238). These findings suggest that paediatric patients were less likely to be referred for supplementary imaging and may have been at a higher risk of undiagnosed fractures.

Statistically significant differences in the fracture type were identified (**p = 0.01**, Table 8). Within the paediatric cohort fractures were observed in only three bones: the distal radius (76%), the scaphoid (20%) and the capitate (4%) bones. In comparison, distal radius fractures accounted for only 49% of adult fractures, with the scaphoid the next most broken bone at 27.5%. As shown in Figure 10, the remaining fractures involved a variety of carpal bones including: the triquetrum (9.9%), trapezium (6.9%), hamate (3.8%), pisiform (1.6%), lunate and capitate bones (0.8% each).

Figure 10

*Comparison of paediatric and adult fractures*



**Aspects Supporting the Null Hypothesis**

Fracture Rates: The overall fracture rates in paediatric and adult populations were identical (56% in both groups), indicating no statistically significant difference in radiocarpal fracture occurrence based on age.

Demographics: Both cohorts were predominantly European (90% of adult fractures and 92% of paediatric fractures), suggesting that ethnicity did not significantly influence fracture prevalence between age groups.

**Aspects Contradicting the Null Hypothesis**

Sex Distribution: The proportion of male and female fractures varied significantly between age groups. Paediatric fractures had an equal distribution (50/50), whereas adult fractures showed a gender disparity (40% male, 60% female).

Age at Fracture: Within adults, females were, on average, 17 years older than males at the time of fracture, whereas in paediatric cases, the difference was only one year.

Diagnostic Modality: Statistically significant differences (**p = 0.001**) were observed in fracture detection methods. Paediatric fractures were predominantly diagnosed via initial X-ray (92%), while adult fractures had a higher rate of occult fractures (30%), requiring CBCT imaging for diagnosis.

Referral for Additional Imaging: Paediatric patients were significantly less likely to undergo follow-up imaging (27% had no additional imaging, versus 16% of adults).

Fracture Type and Location: Significant differences were identified in fracture location (**p = 0.01**). Paediatric fractures primarily involved three bones (distal radius, scaphoid, capitate), whereas adult fractures affected a broader range of carpal bones, highlighting distinct injury patterns between the two populations.

## Conclusion

While overall fracture rates were identical between paediatric and adult groups, there were several differences, particularly in sex distribution, diagnostic modality, fracture location, and referral patterns, suggesting significant variations in radiocarpal fractures between these age groups. Therefore, the null hypothesis cannot be accepted, as these findings demonstrate distinct differences in fracture presentation and management between paediatric and adult populations.

## 4.6 Null hypothesis 3: Patient age, sex, ethnicity, or distance travelled to treatment do not influence patient access to imaging.

To effectively assess this hypothesis, each variable (patient age, sex, ethnicity, and travel distance) will be analysed individually to determine its influence on access to imaging. Subsequently, simple and multiple regression analysis will be employed to explore the interrelationship between these variables.

While previous sections focused on X-ray versus CBCT imaging findings, this section broadens the scope to include patients who did not undergo further imaging beyond the initial X-ray. Table 11 presents cohort and fracture characteristics based on final diagnosis.

### 4.6.1 Ethnicity

Of the 316 individual patients presenting to the fracture clinic, the ethnic distribution was as follows: 86% European (n= 272), 5% Māori (n= 15), 5% Asian (n= 16), 1% Pasifika (n= 3), and 2% (n= 6) did not specify their ethnicity. To assess representativeness, comparisons were made with Christchurch's latest census data (StatsNZ, 2023) and ACC wrist injury claims (Analytics & Reporting ACC, 2025) lodged during the study period (Table 9). Proportions suggest that Māori, Pasifika, and other ethnicities are less likely than Europeans to present to fracture clinic for assessment. Despite differences in presentation rates, non-parametric hypothesis testing (Table 8) found no significant association between ethnicity and patient referral for CBCT imaging (p = 0.86).

Table 9

*Comparative table of the ethnic breakdown of population*

| (%) | **Census data Christchurch 2023** | **ACC Data New Wrist Injury Claims Canterbury (1/12/23 – 31/5/24)** | **Patients Presenting to Fracture Clinic (study sample)** |
|---|---|---|---|
| European | 75.9 | 76.4 | 86.1 |
| Māori | 11.2 | 6.8 | 4.7 |
| Pasifika | 4.3 | 1.9 | 1 |
| Asian | 17.1 | 4.5 | 5.0 |
| Other | 1.9 | 6.8 | 0.3 |
| Unknown | 1.1 | 4.5 | 1.9 |

Table 10 presents the ethnic distribution of patients receiving CBCT follow-up imaging and those who received no additional imaging beyond their initial X-ray. Findings show that proportionally more Māori and Pasifika patients receive no further imaging compared to their European and Asian counterparts. However, given that 85% of the patient cohort was European, the small number of Māori and Pasifika patients in the study impacts the reliability of these results.

Table 10

*Comparison of those receiving CBCT follow-up imaging versus those receiving no further imaging by patient ethnicity*

| | **European** | **Māori** | **Pasifika** | **Asian** |
|---|---|---|---|---|
| Received CBCT imaging n/total (%) | 86/159 (54%) | 5/11 (45%) | 1/2 (50%) | 5/8 (63%) |
| No further imaging n/total (%) | 51/159 (32%) | 6/11 (55%) | 1/2 (50%) | 2/8 (25%) |

To address the reliability of the findings, Māori and Pasifika patient numbers were combined, and a 95% confidence interval analysis was conducted. Of the 13 Māori and Pasifika patients, seven (54%) did not receive further imaging. Based on the total study sample of 325 patients, a confidence interval of 0.54 [0.26–0.82] was established, indicating a wide margin of error. This suggests that the potential difference between the observed sample results and the true population value could be considerable. Repeating the same process for European patients resulted in a much narrower confidence interval of 0.32 [0.25–0.40], attributed to the significantly larger patient sample size.

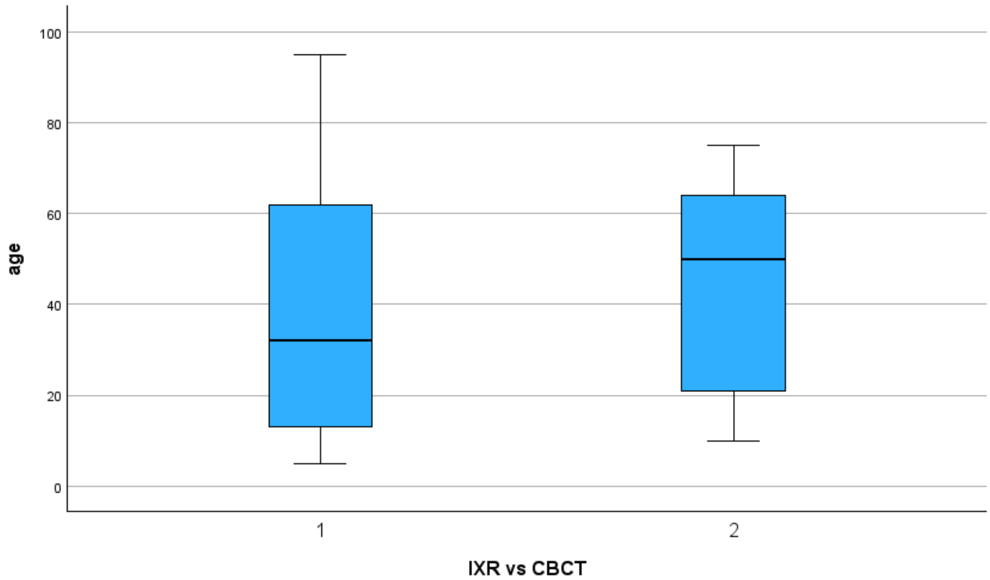
Conclusion: Although no significant association between ethnicity and CBCT referral was found (p = 0.86), the small sample size of Māori and Pasifika patients limits the power to detect differences. The wide confidence interval for this group (54% [0.26–0.82]) suggests substantial uncertainty around this estimate. While the null hypothesis cannot be rejected, observed disparities in both presentation for treatment and referral for follow-up imaging warrant further investigation in larger, more representative samples.

### 4.6.2 Age

The patient cohort exhibited a broad age range, spanning 5 to 95 years. Among those assessed by initial X-ray (n= 325), the median age was 37 years (range: 5-95 years), while patients undergoing CBCT imaging had a slightly higher median age of 42 years (range: 10-75 years). Although the CBCT group displayed a narrower age range, as visualised in the box plot below, non-parametric testing revealed no statistically significant difference in the median age between groups (p = 0.16), Table 7. However, graphical representation of the data appears to show that both older and younger patients are less likely to be referred for further imaging evaluations (see Figures 11 and 12).

Figure 11

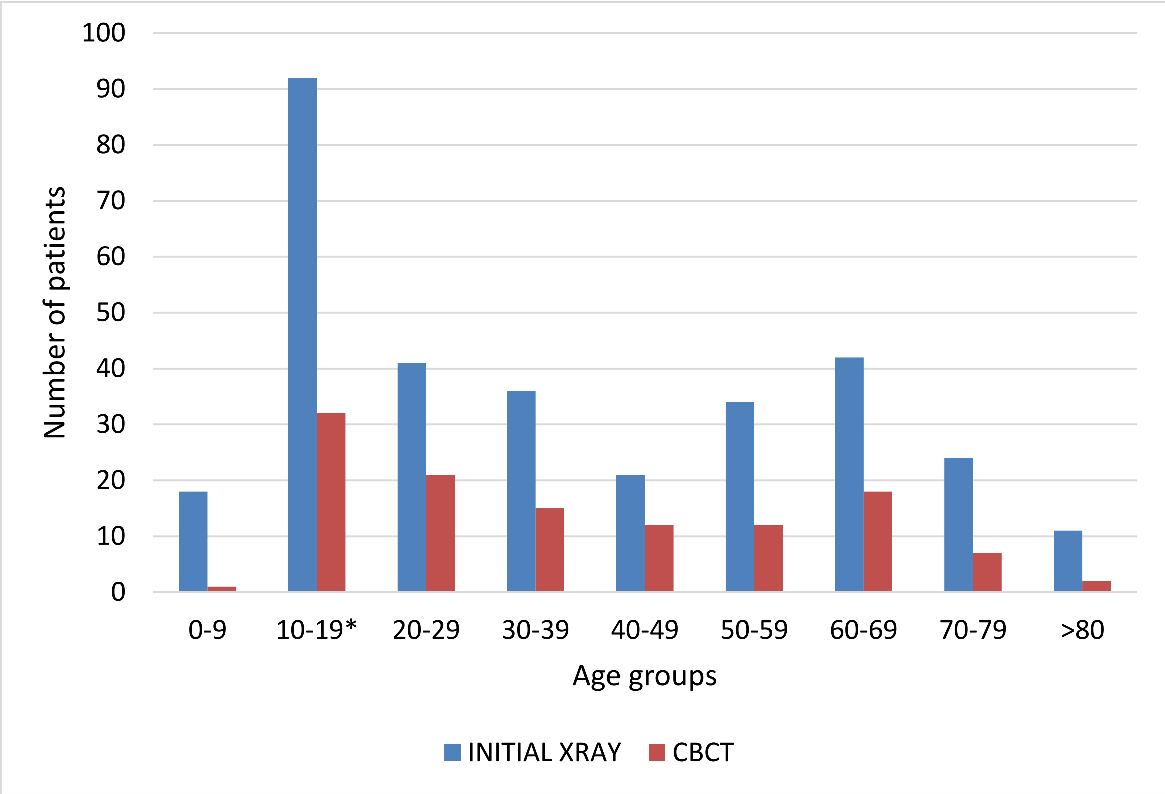
*Age Distribution of patients who received initial X-ray versus CBCT imaging*




1 = initial X-ray, 2 = CBCT imaging

Figure 12

*Imaging received by patient age groups*



### 4.6.3 Sex

Among the 316 individuals included in this study, 129 (41%) were male and 187 (59%) were female.

No significant association between sex and imaging received was found on non-parametric testing (Chi-squared test, p = 0.57, Table 7). However, descriptive data suggest potential sex-based differences in imaging referrals. When analysing imaging referral patterns by sex (Figure 13), differences were observed. Males were less likely than females to be referred for CBCT imaging (41% vs. 60%) and were more likely to receive no further imaging beyond their initial X-ray (39% vs. 26%). Conversely, men were nearly twice as likely as women to be referred for MR imaging. These findings indicate possible sex-based variations in imaging referral decisions, highlighting the need for further investigation.

Figure 13

*Imaging referral differences by sex, excluding patients with fractures confirmed on initial X-ray*

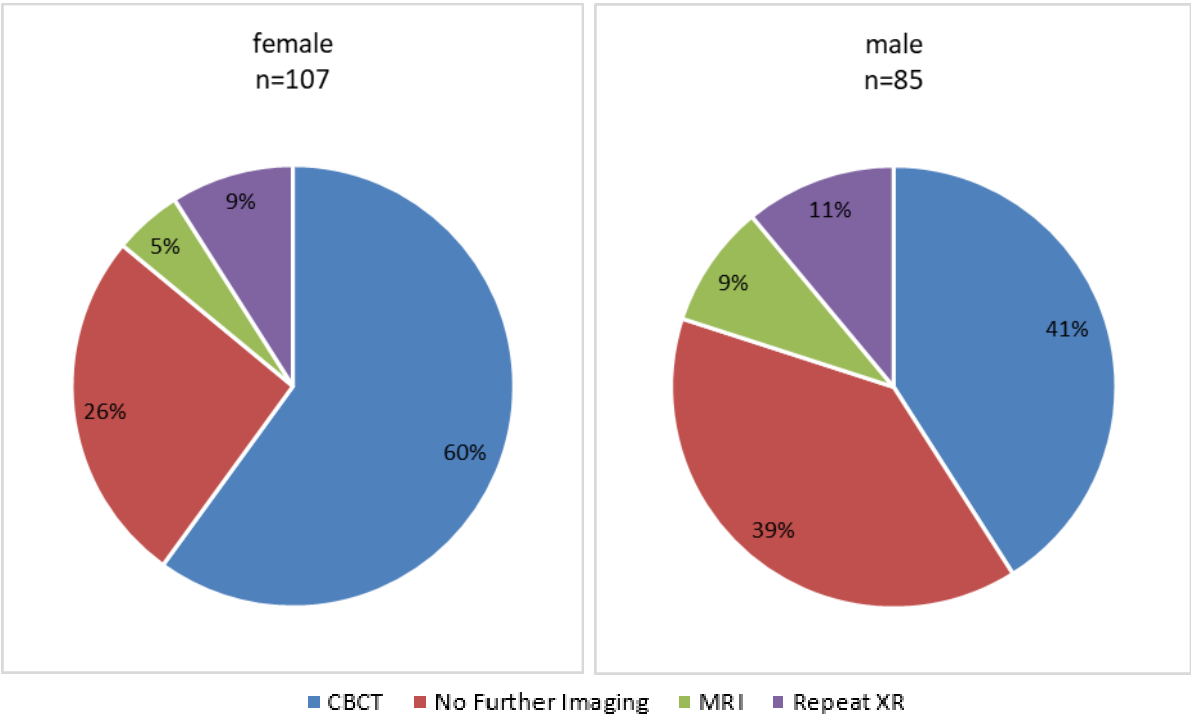


Table 11

*Cohort and fracture characteristics according to final diagnosis*

| | Fracture on X-ray imaging | Occult fracture on follow-up imaging | No fracture detected on follow-up imaging | No follow-up imaging |
|---|---|---|---|---|
| **N** | 137 (42%) | 44 (14%) | 83 (25%) | 61 (19%) |
| **Sex** (%) | | | | |
| male | 57 (41.6) | 20 (45.5) | 27 (32.5) | 28 (45.9) |
| female | 80 (58.4) | 24 (54.5) | 56 (67.5) | 33 (54.1) |
| **Age** (median [range]) | 37.00 [5.00, 95.00] | 42.00 [10.00, 75.00] | 33.00 [8.00, 83.00] | 32.9 [6.00, 93.00] |
| **Ethnicity** (%) | | | | |
| European | 121 (88.3) | 39 (88.6) | 69 (83.1) | 51 (83.6) |
| Māori | 4 (2.9) | 2 (4.5) | 3 (3.6) | 6 (9.8) |
| Asian | 7 (5.1) | 1 (2.3) | 6 (7.2) | 2 (3.3) |
| Pasifika | 1 (0.7) | 0 (0.0) | 1 (1.2) | 1 (1.6) |
| Middle East/Latin America/African | 1 (0.7) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| not defined | 3 (2.2) | 2 (4.5) | 4 (4.8) | 1 (1.6) |
| **Image** (%) | | | | |
| initial XR | 134 (97.8) | 0 (0.0) | 0 (0.0) | 61 (100.0) |
| CBCT | 0 (0.0) | 41 (93.2) | 58 (69.9) | 0 (0.0) |
| MRI | 0 (0.0) | 3 (6.8) | 10 (12.0) | 0 (0.0) |
| repeat XR | 3 (2.2) | 0 (0.0) | 15 (18.1) | 0 (0.0) |
| **Outcome** (%) | | | | |
| fracture on XR | 134 (100) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| fracture on CBCT | 0 (0.0) | 42 (93.3) | 0 (0.0) | 0 (0.0) |
| fracture on MRI | 0 (0.0) | 3 (6.7) | 0 (0.0) | 0 (0.0) |
| fracture repeat XR | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| no fracture repeat XR | 0 (0.0) | 0 (0.0) | 15 (18.1) | 0 (0.0) |
| no fracture CBCT | 0 (0.0) | 0 (0.0) | 58 (69.9) | 0 (0.0) |
| no fracture MRI | 0 (0.0) | 0 (0.0) | 10 (12.0) | 0 (0.0) |
| no fracture, no further imaging | 0 (0.0) | 0 (0.0) | 0 (0.0) | 61 (100.0) |
| **Fracture location** (%) | | | | |
| No bone injury | 0 (0.0) | 0 (0.0) | 83 (100.0) | 61 (100.0) |
| distal radius | 90 (65.7) | 12 (27.3) | 0 (0.0) | 0 (0.0) |
| scaphoid | 37 (27.0) | 9 (20.5) | 0 (0.0) | 0 (0.0) |
| trapezium | 0 (0.0) | 9 (20.5) | 0 (0.0) | 0 (0.0) |
| hamate | 1 (0.7) | 4 (9.0) | 0 (0.0) | 0 (0.0) |
| lunate | 0 (0.0) | 1 (2.3) | 0 (0.0) | 0 (0.0) |
| capitate | 0 (0.0) | 3 (6.8) | 0 (0.0) | 0 (0.0) |
| triquetrum | 8 (5.8) | 5 (11.4) | 0 (0.0) | 0 (0.0) |
| pisiform | 1 (0.7) | 1 (2.3) | 0 (0.0) | 0 (0.0) |
| **Diagnosis (%)** | | | | |
| Fracture | 137 (100.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| no fracture | 0 (0.0) | 0 (0.0) | 83 (100.0) | 61 (100.0) |
| Occult fracture | 0 (0.0) | 44 (100.0) | 0 (0.0) | 0 (0.0) |

### 4.6.4 Distance Travelled

Results indicate that most patients (58%, n= 186/321) lived within 10km of the 24-hour clinic (Figure 14). In total, almost three quarters of patients (72%, n= 237/321) travelled less than 20km to access treatment. The greatest distance travelled was 181km, by a patient who came from Kaikoura to Christchurch specifically for fracture clinic treatment, while the shortest was 600m, by a local resident. The median travel distance was 15.2km.

Four visitors to Christchurch (from Palmerston North, Tūrangi, Blenheim, and Twizel) were excluded from the dataset.

Figure 15 suggests a trend in imaging referral based on travel distance. Among local patients, 30% were referred for CBCT imaging, whereas this percentage rose to 40% for those traveling over 50km. There appears to be a trend toward higher CBCT referral rates among patients who travel further, but this did not reach statistical significance (p = 0.09). Similarly, the probability of receiving no further imaging appears to decline with increased travel distance. While 19% of local residents were not referred for additional imaging, this proportion dropped to 13% among rural Canterbury patients.

Figure 14

*Distance travelled from patient home to 24-hour clinic*

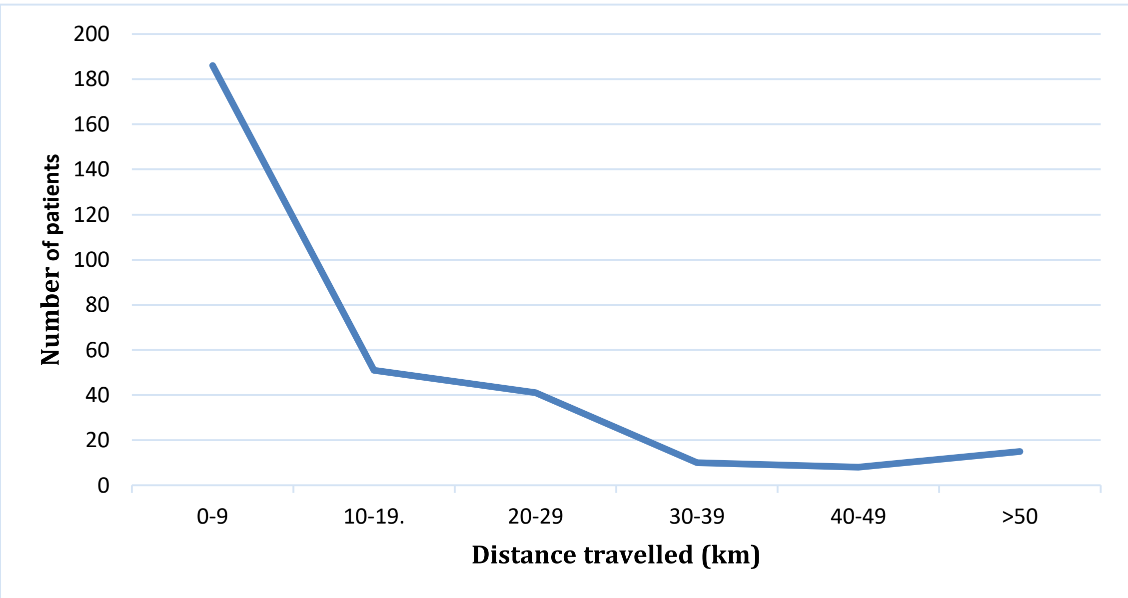
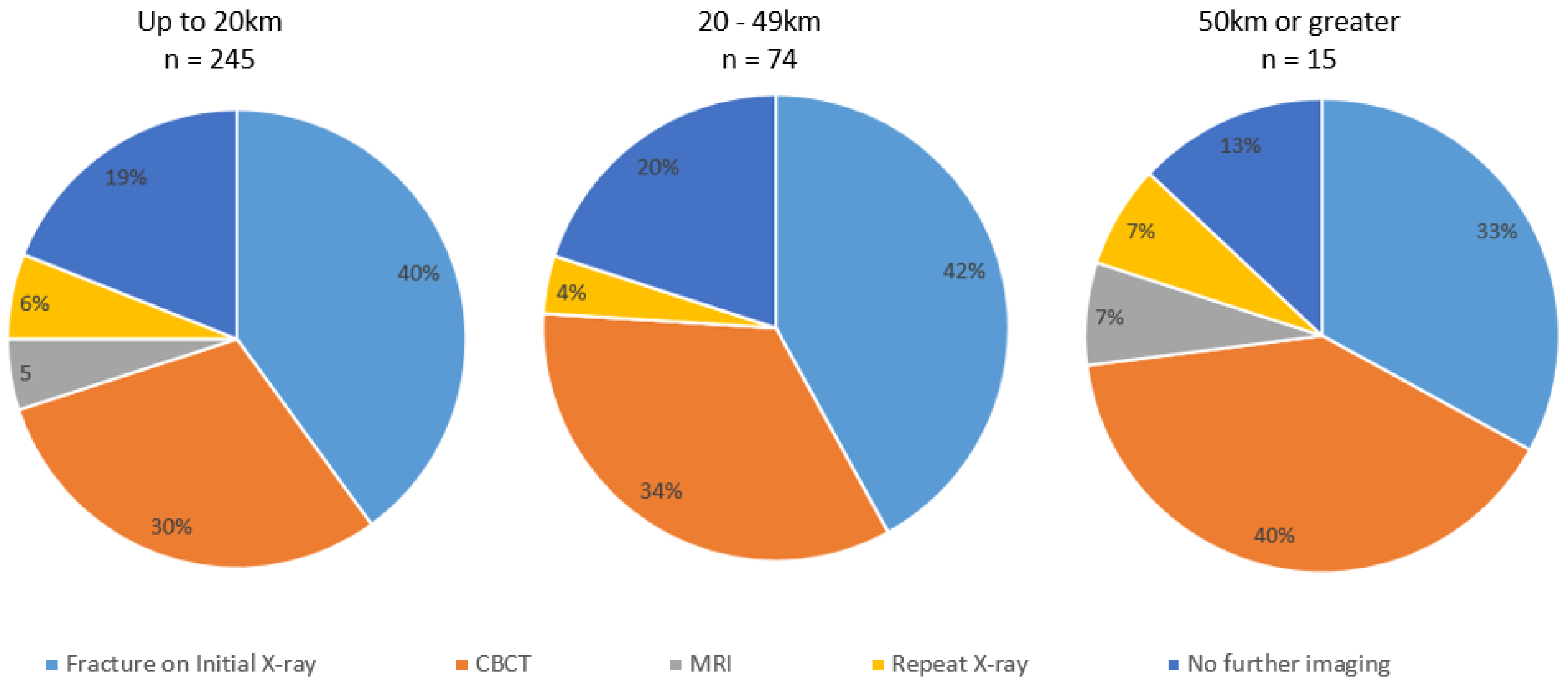


Figure 15

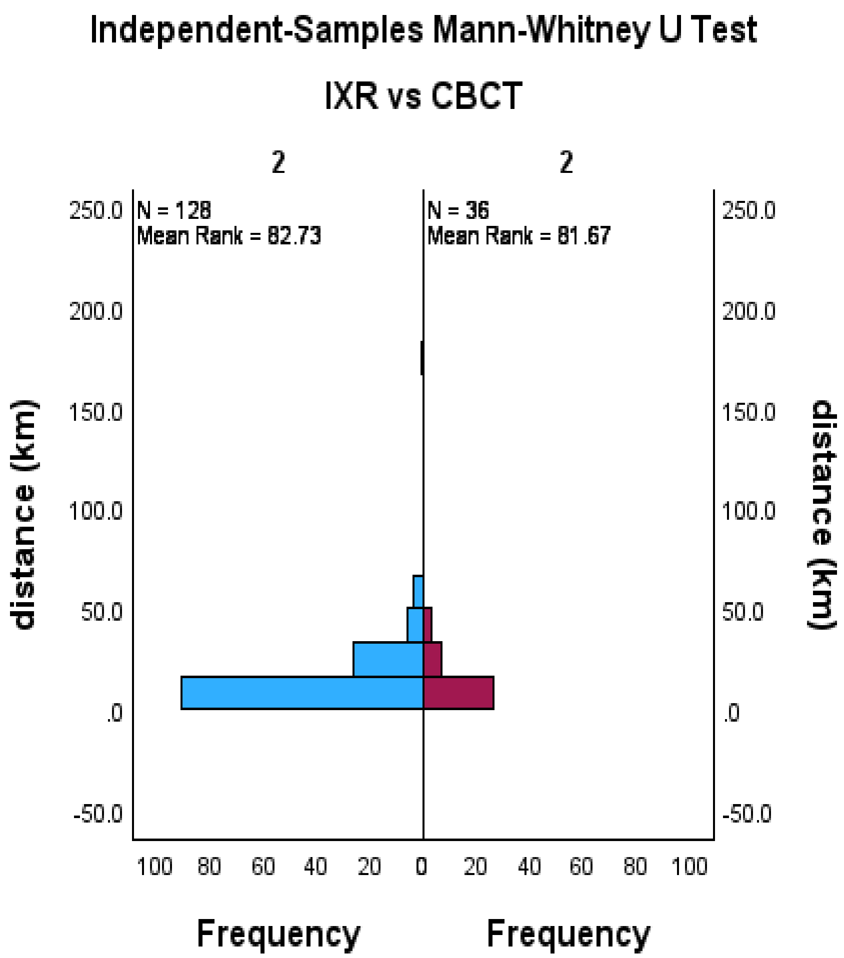
*Comparison of imaging received by distance travelled to fracture clinic*



However, further statistical analysis (p = 0.09, Figure 16) found no significant association between median travel distance and CBCT referral. Therefore, despite observable trends suggesting greater imaging referrals for distant travellers, the data supports the null hypothesis, indicating that travel distance does not significantly impact access to imaging. A larger sample size could help clarify whether the observed trend represents a real but subtle effect or just variability within the data. Potential confounding factors are addressed in the discussion.

Figure 16

*Independent-Samples median test comparing distance travelled by initial X-ray and CBCT*



### 4.6.5 Binary Logistic Regression

Explanatory variables were first considered individually, with binary logistic regression for the dependant variable (being referred for CBCT imaging). Following this, the variables were combined and analysed using multiple regression analysis. Variance inflation factor (VIF) was used to assess the collinearity among the independent variables, and no significant collinearity was found.

**Ethnicity**

Given the predominance of European patients and the relatively small numbers of individuals in other ethnic groups - Māori, Pasifika, Asian, Other, and Not Specified categories were combined for analysis (European vs non-European). Binary logistic regression revealed an odds ratio below one (Exp(B) = 0.791, [95% CI: .249-2.513]), indicating that individuals from non-European ethnic groups may have a slightly lower likelihood of being referred for CBCT imaging. However, the p-value (0.690) is not statistically significant, meaning this cannot be interpreted as a meaningful difference.

**Age**

Binary logistic regression was conducted to examine the influence of patient age on fracture diagnosis, comparing initial X-ray findings with CBCT imaging. The categorical covariate, paediatric vs adult, was assessed in relation to the dependent variable.

The results indicate a significant effect of age, with an odds ratio of 6.052 (**Exp(B) > 1,** [95% CI: 1.786-20.711]) and a low p-value **(p = 0.004)**. This suggests that paediatric patients are six times more likely to have fractures diagnosed on X-ray imaging compared to adults, a statistically significant finding that highlights age as a key factor in diagnostic outcomes.

**Sex**

While males were found to have a slightly lower odds ratio (Exp(B) = 0.816, [95% CI: 0.404–1.651]) compared to females, suggesting they may be marginally less likely to be referred for CBCT imaging, this difference was not statistically significant ($p = 0.573$).

**Distance travelled**

Binary logistic regression assessed the impact of travel distance on the outcome, comparing individuals traveling less than 20km to those traveling more than 20km. While shorter travel distance showed a slight positive association (Exp(B) = 1.154, [95% CI: .502-2.651]), the effect was weak and not statistically significant ($p = 0.736$, $p > 0.05$). Therefore, travel distance does not meaningfully influence the outcome.

### 4.6.6 Multiple Regression Analysis

The multinomial logistic regression model (Table 12) examines factors influencing fracture diagnosis using initial X-ray (IXR) versus CBCT imaging as the dependent variable. The predictors include age, sex, travel distance, and ethnicity. Key findings show:

Table 12

*Multiple regression analysis of factors affecting fracture diagnosis: IXR vs CBCT*

| IXR vs CBCT[a] | B | Std. Error | Wald | df | Sig. | Exp(B) | 95% Confidence Interval for Exp(B) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower Bound | Upper Bound |
| Intercept | 1.111 | .734 | 2.290 | 1 | .130 | | | |
| Paediatric | 2.141 | .757 | 8.001 | 1 | **.005** | **8.506** | 1.930 | 37.492 |
| Adult | 0b | . | . | 0 | . | . | . | . |
| Male | -.648 | .453 | 2.044 | 1 | .153 | .523 | .215 | 1.271 |
| Female | 0[b] | . | . | 0 | . | . | . | . |
| Less than 20km | .141 | .436 | .104 | 1 | .747 | 1.151 | .490 | 2.705 |
| 20km or more | 0[b] | . | . | 0 | . | . | . | . |
| European | -.129 | .624 | .043 | 1 | .836 | .879 | .259 | 2.987 |
| Non-European | 0[b] | . | . | 0 | . | . | . | . |

a. The reference category is: CBCT

b. This parameter is set to zero because it is redundant.

**bold** indicates a significant result

**Age**

Age group is the only significant predictor (p = 0.005) of the imaging modality by which a fracture was diagnosed, with paediatric patients being 8.5 times [95% CI: 1.930-37.492] more likely to receive an IXR diagnosis compared to adults (Exp(B) = 8.506).

**Sex (Male vs Female)**

Males had a lower likelihood of being referred for CBCT compared to females, with an odds ratio of 0.816 (95% CI: .404–1.651). However, this was not statistically significant ($p = 0.573$).

**Travel Distance (Less than 20km vs greater than 20km)**

The odds ratio (Exp(B) = 1.151, [95% CI: .490-2.705]) suggests a slight increase in likelihood of CBCT imaging for those traveling less than 20km, but this is not statistically significant ($p = 0.747$).

**Ethnicity (European vs non-European)**

European participants had slightly lower odds of having fractures diagnosed on IXR compared to CBCT (Exp(B) = 0.879, [95% CI: .259-2.987]). However, $p = 0.836$ indicates no statistical significance, suggesting ethnicity is not a relevant factor in fracture diagnosis. These results should be interpreted with caution due to the small number of non-European participants, which limits the ability to detect significant differences, potentially affecting the reliability of the findings.

In summary, patient age was the only factor that significantly influenced the type of imaging used to diagnose their fracture (**p = 0.005**), with paediatric patients being 8.5 times [95% CI: 1.930-37.492] more likely to receive an IXR diagnosis compared to adults. The null hypothesis that there is no significant difference in IXR vs CBCT usage based on age group is rejected, as paediatric patients are far more likely to receive an IXR diagnosis. However, the null hypothesis cannot be rejected for ethnicity, travel distance, or sex, as no significant differences were observed ($p > 0.05$).

# Chapter 5
# Discussion

## 5.1 Summary of findings

This study highlights the value of CBCT in diagnosing acute radiocarpal fractures, particularly where X-ray fails to detect bone injury. Cone beam computed tomography demonstrated a high detection rate in patients with persistent clinical suspicion of fracture despite negative X-ray results, with a substantial proportion subsequently diagnosed with occult fractures. Without access to CBCT, many of these injuries would likely have gone undiagnosed.

Across the study cohort, most fractures were visible on X-ray, but a significant portion were radiographically occult. Notably, while X-rays primarily identified distal radius and scaphoid fractures, CBCT revealed a markedly different distribution of fracture sites. Most fractures identified by CBCT involved carpal bones other than the scaphoid and distal radius, highlighting the limitations of X-ray imaging. Statistical analysis confirmed a significant difference between the two imaging modalities, with CBCT more effectively identifying occult non-scaphoid fractures. These findings reinforce the risk for diagnostic error when relying solely on X-ray, and support the importance of advanced imaging, particularly in cases where clinical suspicion persists despite normal radiographs.

In addition to differences in fracture distribution between CBCT and X-ray imaging, this study also identified notable variations between paediatric and adult fracture patterns. Although both groups had identical overall fracture detection rates, adults were referred for CBCT more frequently and had a higher incidence of occult fractures. This suggests a greater tendency toward escalation to advanced imaging in the adult cohort. Whereas most paediatric fractures were identified via X-ray alone, many adult fractures were diagnosed only after further imaging. This difference was statistically significant.

No significant differences in referral for imaging were observed based on sex, ethnicity, or distance travelled. However, the small sample size of non-European participants and of those travelling longer distances to the clinic limits the strength of these conclusions and may have masked possible disparities.

## 5.2 Interpretation of results and comparison with existing literature

This study provides valuable insights that can enhance clinical practice and inform imaging referral decisions for detecting radiocarpal fractures.

### 5.2.1 X-ray as the Primary Screening Tool

Given its affordability, rapid availability, and diagnostic efficiency, X-ray continues to be the preferred initial modality for evaluating suspected wrist fractures (Pallaver & Honigmann, 2019; Snaith et al., 2021). In this study, 40% of patients presenting to the fracture clinic had fractures that were identifiable on their initial X-ray, which accounted for 74% of all confirmed fracture diagnoses. These findings underscore the value of X-rays in the initial assessment of acute wrist fractures, though limitations remain, especially in detecting carpal fractures, which often require advanced imaging for definitive diagnosis.

### 5.2.2 CBCT for Occult Fracture Detection

Cone beam computed tomography is highly effective in detecting fractures not visible on initial X-ray imaging. In this study, 41 additional fractures were identified among 99 patients who had normal X-rays but were subsequently referred for CBCT, resulting in an occult fracture detection rate of 41%. These findings reinforce the diagnostic value of CBCT in improving fracture detection and guiding appropriate management.

Published research supports this view, with some advocating CBCT as the new standard of care for investigating suspected radiocarpal fractures (Edlund et al., 2016; Gibney, Smith, et al., 2019; Krayem et al., 2021; Vitez et al., 2021), while others recommend it be used as a supplement to conventional X-ray imaging (Borel et al., 2017; Fitzpatrick et al., 2022; Snaith et al., 2022).

Comparing detection rates of radiographically occult fractures across international CBCT studies helps to situate our findings within a broader clinical context. Studies differ in their reported detection rates. Those reporting higher detection rates include Gibney, Murphy, et al. (2019), who found a 50% rate among 166 patients with acute trauma and negative X-rays, and Borel et al. (2017), who reported a 45% rate in a smaller cohort of 49 patients with suspected scaphoid fractures. These figures are consistent with our own study's detection rate of 41%, suggesting that when guided by careful clinical judgment, CBCT has a high diagnostic yield for occult radiocarpal fractures.

In contrast, other studies have demonstrated lower detection rates. Snaith et al. (2022) reported a rate of 16.2% in a study disrupted by the COVID-19 pandemic, which limited recruitment and reduced sample size. Vitez et al. (2021) reported a 28% rate among 56 patients, also noting sample size as a limiting factor. These lower rates reflect variability across studies, which may be influenced by differences in study design, patient numbers, and clinical workflows, rather than CBCT performance.

Colville et al. (2022), found a 25% detection rate in 100 CBCT scans, though their cohort was restricted to adult patients (≥18 years of age), which may have influenced diagnostic outcomes. Paediatric patients are generally considered more likely to present with radiographically occult fractures due to incomplete ossification and cartilaginous structures, factors that increase the diagnostic yield of advanced imaging modalities such as CBCT (Jørgsholm et al., 2016; Weber et al., 2023), however, this explanation does not align with our findings. In our study, paediatric patients had low referral rates for CBCT imaging and consequently, low diagnostic rates of occult fracture. A more plausible explanation for our high overall detection rate may lie in our pre-radiological referral process, where strict clinical selection criteria and greater referrer experience could have led to a higher proportion of clinically justified scans and, consequently, a greater diagnostic hit rate.

Overall, these comparisons reinforce the notion that CBCT's effectiveness is not solely dependent on the technology itself, but also on how and when it is deployed within clinical workflows.

### 5.2.3 MRI – how does it compare?

To contextualise the diagnostic strengths of CBCT, it is important to evaluate its performance relative to MRI, which is widely recognised as the gold standard due to its superior soft tissue evaluation and ability to detect fractures that may not be visible on X-ray or CBCT (Fitzpatrick et al., 2022). However, its significantly higher cost, longer scanning times, and limited availability make routine use impractical in many clinical settings. CBCT, on the other hand, provides fast, targeted imaging at a lower cost, while still demonstrating excellent sensitivity and specificity.

We compared our findings with those reported by Burton et al. (2025), who evaluated MRI detection rates in 197 patients with normal X-ray results. Their study identified 43 scaphoid fractures and 59 non-scaphoid occult fractures, yielding a total of 102 occult fractures and a detection rate of 53%, which is slightly higher than that observed in our cohort. However, this difference may not be statistically significant, as detection rates across studies vary widely due to factors such as sample size, referral patterns, and imaging protocols. These variables complicate direct comparisons between imaging modalities like CBCT and MRI.

While MRI remains the benchmark for identifying radiographically occult fractures, our findings suggest that CBCT may offer a viable alternative. Its high spatial resolution, rapid acquisition time, and lower cost make it particularly attractive in settings where MRI is unavailable or contraindicated.

### 5.2.4 Effective Referral Process for CBCT

In our study, the fracture clinic demonstrated an effective pre-radiological assessment and referral process for CBCT imaging. Among those who underwent CBCT, a substantial proportion were diagnosed with occult fractures, demonstrating that referrals were appropriate and based on solid clinical judgment. An efficient referral system ensures that CBCT is used appropriately, optimising resource allocation while improving diagnostic accuracy for patients with suspected fractures. By using CBCT appropriately based on clinical judgment, healthcare providers can avoid unnecessary scans, thereby reducing costs associated with imaging and radiation exposure. These findings underscore the importance of carefully weighing the cost-benefit of CBCT utilisation, striking a balance between thorough diagnostic evaluation and the careful use of healthcare resources.

It can be difficult to quantify the full costs of missed injuries, a study by Karl et al. (2015) looked at the cost-effectiveness of immediate advanced imaging (MRI and CBCT) for suspected occult scaphoid fractures. They found that imaging costs were similar to the combined costs of cast immobilisation, repeat X-rays, and follow-up visits. When factoring in potential loss of earnings and the impact of prolonged immobilisation, the study concluded that early advanced imaging was a favourable option.

While specific qualitative studies on missed carpal fractures are limited, a study by Simonsen-Lentz et al. (2020) offers a qualitative perspective on how delayed insufficiency fracture diagnoses affect patients. Findings showed that patients experienced significant pain without a clear diagnosis, leading to frustration and emotional distress, and that loss of function was a major concern. The delayed diagnosis was perceived as a major burden, impacting daily activities and independence. A broader health economics viewpoint from Fautrel et al. (2020) discusses intangible, non-monetary costs, such as pain and suffering, as a critical but often overlooked component in cost assessments. Their study emphasises that intangible costs should be considered alongside direct and indirect costs when evaluating diagnostic strategies.

### 5.2.5 Time to Diagnosis

Variation in the timing of imaging across studies reflects differing clinical approaches to diagnosing occult fractures. Borel et al. (2017) conducted CBCT within seven days of injury while other studies, including Gibney, Murphy, et al. (2019), Gibney, Smith, et al. (2019), and Vitez et al. (2021), reported imaging within 14 days. Krayem et al. (2021) did not specify the time to diagnosis.

In our study data, the average time from injury to diagnosis for CBCT or MRI was 10 days, which is relatively fast compared to the longer wait times typically associated with specialist appointments in the community. This reflects the efficiency of the fracture clinic in delivering timely diagnoses for patients with suspected occult fractures, enabling definitive diagnosis and management planning within a clinically reasonable timeframe. However, during this interval, only a quarter of patients received appropriate immobilisation, while the remainder were immobilised unnecessarily. This has important implications: unnecessary immobilisation can impair hand function, delay return to work or sport, and increase healthcare utilisation, while inadequate immobilisation risks exacerbating the injury or contributing to poor healing outcomes.

Immobilisation has well-documented physiological and functional consequences, particularly in the wrist where fine motor control is essential for daily activities. Muscle atrophy occurs rapidly, primarily due to a reduction in muscle fibre size and number, leading to a measurable decline in strength, most notably within the first week of immobilisation (Appell, 1990; Lundbye-Jensen, 2008). Musculoskeletal adhesions, or scar tissue formation, can begin within a few days of an injury and continue to develop over several weeks (Dubois & Esculier, 2020; Fernández-Guarino et al., 2023). While the initial inflammatory phase is crucial for healing, excessive or uncontrolled scar tissue formation can lead to adhesions, which may restrict movement and cause pain

In the wrist, these changes are especially impactful. The combined loss of strength, coordination, and joint flexibility can significantly impair hand function, affecting tasks that require precision and dexterity. Beyond peripheral effects, immobilisation also influences central nervous system function. Even short periods of disuse have been shown to induce cortical reorganisation, diminishing movement representations and disrupting efficient motor control (Lundbye-Jensen, 2008; Singh et al., 2018; Zanettea et al., 2004). Research indicates that disuse atrophy and impaired proprioception contribute to these neuroplastic changes (Canu et al., 2019; Hagert & Rein, 2024; Marini et al., 2017), underscoring the importance of early intervention to preserve both physical and neurological aspects of motor function.

Although the current system offers faster access to definitive diagnosis, opportunities remain to streamline the diagnostic process further and reduce unnecessary immobilisation. Earlier triage and referral for imaging, or direct access to CBCT in acute care settings could help reduce diagnostic delays and minimise inappropriate immobilisation. Future research is needed to evaluate whether protocol-driven early imaging pathways can streamline diagnosis and support faster recovery and return to function.

### 5.2.6 CBCT Detects a Wider Range of Fractures

CBCT proved to be significantly more effective in detecting fractures across multiple wrist bones compared to X-ray imaging. While CBCT identified fractures in eight out of nine wrist bones, X-ray primarily detected fractures in the distal radius and scaphoid. Notably, X-ray failed to visualize fractures in the trapezium, capitate, and lunate bones, highlighting its diagnostic limitations. These findings suggest that carpal fractures are more prevalent than previously recognised, with historical underdiagnosis largely due to the restricted capabilities of X-ray imaging. This is supported by Krayem et al. (2021) whose study showed a threefold increase in carpal fracture detection during the CBCT imaging period compared to the X-ray-only period.

In this study, the trapezium was the second most fractured carpal bone after the scaphoid. Notably, no fractures of the trapezium were visible on X-ray imaging. The median age of affected patients was 56 years, and the demographic was predominantly female. Historically, patients in this group presenting with tenderness at the first carpometacarpal joint following a fall on an outstretched hand have been reassured that their symptoms reflect age-related joint changes. However, it is likely that some of these individuals had sustained trapezium fractures, injuries that went undetected due to the limitations of standard X-ray imaging. These findings align with those of Gibney, Murphy, et al. (2019), who identified the trapezium as the most commonly radiographically occult carpal bone fracture. The authors found that even when the specific bone and location of the fracture site were known, only one of 19 trapezium fractures could be confidently retrospectively identified on initial X-ray imaging. Non-displaced trapezium fractures can be managed conservatively, while surgery is recommended in displaced cases. Injury to the joint surface between the trapezium and the base of the first metacarpal or the scaphoid can lead to pain and limited mobility. Therefore, it is important to diagnose and treat the fracture at an early stage, so that articular congruence is restored (Beekhuizen et al., 2020). Trapezium fractures are also associated with Bennett's fractures and ulnar-sided carpal injuries (Sharpe et al., 2023). These combined injuries can obscure diagnosis, particularly when more obvious fractures draw clinical focus. Because trapezium fractures are often subtle and easily missed, clinicians should maintain a high index of suspicion and use advanced imaging when assessing trauma to the thumb CMC joint.

Routine integration of CBCT into clinical practice is therefore essential, not only to improve diagnostic accuracy but also to ensure a more comprehensive understanding of fracture incidence, ultimately leading to better patient outcomes.

### 5.2.7 Scaphoid Waist Fractures

Missed scaphoid fractures can lead to serious long-term complications due to the bone's unique anatomy and retrograde blood supply. One of the most common sequelae is non-union, where the fracture fails to heal, resulting in persistent pain and instability; reported non-union rates range from 5–12% (Dinah & Vickers, 2007). Avascular necrosis is another major concern, particularly with proximal pole fractures, as disruption of the blood supply can lead to bone death and collapse, severely impairing wrist function (Berber et al., 2020). Over time, untreated fractures can alter wrist biomechanics, leading to post-traumatic osteoarthritis, characterised by joint degeneration, stiffness, and reduced range of motion. Carpal instability may also develop, especially in cases of scapholunate dissociation, compromising grip strength and coordination (Haerle et al., 2016).

These complications are often exacerbated by delayed or missed diagnoses, especially given that scaphoid fractures are frequently radiographically occult in the early stages. In our study, a substantial proportion of scaphoid waist fractures were not visible on initial X-ray imaging, underscoring the limitations of relying solely on this modality. Notably, 20% of scaphoid fractures identified were occult, a figure consistent with previously published rates by Bäcker et al. (2020) and Burton et al. (2025), both reporting 22%, and Karl et al. (2015), who reported 15%. This consistency across studies reinforces the reliability of occult fracture detection rates and highlights the importance of early, targeted imaging in patients with high clinical suspicion of radiocarpal injury. Early diagnosis and appropriate management are essential to prevent these complications and preserve long-term wrist function.

### 5.2.8 Differences in Fracture Detection Between Adults and Children

Paediatric fractures differ significantly from those in adults due to the unique anatomical and biomechanical characteristics of children's bones. In the paediatric carpus, the predominance of cartilage and the presence of a thick, elastic periosteum help resist displacement and promote healing (Goddard, 2005; Light, 2000). These properties lead to distinct fracture patterns and more favourable outcomes compared to adults, whose fractures, particularly scaphoid waist fractures, carry a greater risk of non-union (Williams & Lochner, 2013).

Scaphoid fractures are the most common carpal injuries across all age groups (Fitzpatrick et al., 2022). However, children also sustain fractures to other carpal bones, most frequently the capitate, followed by the trapezium, triquetrum, and pisiform (Weber et al., 2023). These injury patterns are closely related to the sequential ossification of carpal bones, which begins with the capitate during infancy and continues throughout adolescence (Al-Khater et al., 2020; Oestreich et al., 2020). In our study, aside from the scaphoid, the capitate was the only other carpal bone fracture identified in paediatric patients.

Although X-ray remains the standard initial imaging modality, its sensitivity, particularly for non-scaphoid fractures, is limited. Studies have demonstrated that X-rays can miss half of all carpal fractures in both adults and children (Krayem et al., 2021; Pan et al., 2016; Weber et al., 2023). One comparative study found that radiographs detected fewer than half of paediatric carpal fractures confirmed by MRI, whereas CBCT offered substantially higher diagnostic accuracy (Jørgsholm et al., 2016)

It is important to note that age criteria for paediatric classification vary between studies. While Jørgsholm et al. (2016) define paediatric patients as individuals under 18 years of age, both Weber et al. (2023) and our study adopt a narrower threshold of under 16 years. This variation may influence how diagnostic outcomes and fracture prevalence are interpreted and compared.

Despite the well-documented limitations of X-ray imaging, paediatric patients in our study were referred for CBCT far less frequently than adults. Although X-rays demonstrated a higher initial detection rate for fractures in children, this apparent effectiveness may create misplaced clinical confidence. As a result, fewer referrals for advanced imaging may occur, increasing the risk of occult fractures going undetected in paediatric patients.

Encouragingly, the prognosis for paediatric scaphoid fractures is generally excellent, with a low reported non-union rate of approximately 1.5% (Oestreich et al., 2020; Suh et al., 2014). Nonetheless, undiagnosed fractures, particularly in non-scaphoid bones, can delay treatment and compromise recovery. Given these insights, there is a compelling argument for using CBCT imaging more readily in children, especially when X-rays are inconclusive. Doing so may significantly improve diagnostic accuracy and ensure more timely and effective treatment of paediatric wrist injuries.

### 5.2.9 Age

The studies included in our literature review reported a median patient age ranging from 40 to 46 years (Borel et al., 2017; Colville et al., 2022; Edlund et al., 2016; Gibney, Murphy, et al., 2019; Gibney, Smith, et al., 2019; Krayem et al., 2021; Snaith et al., 2022). In contrast, the median age in our cohort was lower, at 35 years, which likely reflects the higher proportion of paediatric patients in our study population. Notably, individuals aged 10–19 years accounted for 35% of patients presenting to the fracture clinic for assessment. The broader age range (5–95 years) in this study suggests a more diverse patient population, encompassing both paediatric and elderly patients. This variability may provide a more comprehensive understanding of fracture patterns across different age groups, potentially influencing clinical management and resource allocation.

The 10–19 years age group represents the highest proportion of patients presenting to the fracture clinic for assessment, indicating a higher incidence of wrist injuries in adolescents. This peak is likely due to increased activity levels, participation in sports, and risk-taking behaviours that raise the likelihood of injury (Dinh et al., 2025). A secondary peak appears in older adults aged 60–69 years, which aligns with known patterns of bone fragility in aging populations. This trend is likely influenced by a combination of factors including maintained activity levels, declining bone density, and a higher risk of falls (International Osteoporosis Foundation, 2025; Padilla-Colón et al., 2018). Patients over the age of 80 account for a small proportion of those assessed. Although this group remains at risk for fragility fractures, factors such as shorter life expectancy, population distribution, and reduced physical activity contribute to their lower representation in the data (Ravindrarajah et al., 2018; Zhou et al., 2021). In New Zealand rest homes, the policy regarding falls generally involves an initial assessment by the most senior staff member on duty, followed by contacting the resident's family and doctor, and potentially calling an ambulance for hospital transfer if necessary (Te Tāhū Hauora Health Quality & Safety Commission, 2023). This approach may result in a greater proportion of elderly patients being referred directly to public hospitals for assessment and treatment, potentially bypassing private fracture clinics and further contributing to their lower level of representation in this dataset.

### 5.2.10 Sex

The male-to-female ratio in this study, of 40:60, aligns with the findings of Snaith et al. (2022). This suggests a similar demographic pattern, which may be relevant for understanding sex-related differences in injury prevalence and healthcare utilisation. Women generally exhibit higher health-seeking behaviours than men, often seeking medical attention more promptly after an injury. This tendency may contribute to the higher proportion of female patients presenting with possible wrist fractures, as they are more likely to recognise symptoms, prioritise care, and engage with healthcare services (Deeks et al., 2009). Also, women may be more likely to present with possible wrist fractures due to factors such as lower bone density, particularly in postmenopausal women, making them more susceptible to fractures from falls. In Caucasian women, the lifetime risk of a fractured wrist is about 16%, versus 2.5% for men (Crockett et al., 2019).

### 5.2.11 Disparities in Access to Services

An analysis of patient demographics highlighted significant disparities in access to fracture clinic services. The vast majority of patients identified as European (86%), while Māori and Pasifika individuals represented only a small proportion of cases. This underrepresentation, particularly when contrasted with ACC wrist injury claim statistics, suggests that these communities may face barriers to accessing care. Contributing factors could include financial constraints, referral practices, transport difficulties, and limited awareness of available services. The clinic is set in a privately operated facility in the central city, where treatment co-payments are required. Patients who seek care in private urban clinics often differ socioeconomically from those in public or rural settings, which may lead to the exclusion of lower-income or underserved populations (Nixon et al., 2023). Consequently, the fracture patterns and treatment approaches observed in this study may reflect the needs and preferences of a more financially resourced demographic, rather than offering a representative view of the wider community.

Notably, only three Pasifika patients with suspected radiocarpal injury attended the clinic over a six-month period, all of whom were aged 13 years-old or under and therefore eligible for free care. This suggests that cost may be a limiting factor for adult Pasifika patients seeking treatment. Research by Jeffreys et al. (2024) found that across all age groups, 22% of Māori (compared with 13% of non-Māori) experienced cost-related barriers to accessing GP services.

These findings align with broader research on ethnic disparities in healthcare access within Aotearoa New Zealand. Studies consistently show that Māori and Pasifika populations face greater obstacles to timely and appropriate care. For example, transport costs were identified as a disproportionately higher barrier for Māori and Pacific peoples, affecting 19% of these groups compared to around 8% of Asian and Other ethnicities (Te Tāhū Tauora, 2024). The Pacific Health Review (Grey, 2013) recommended locating healthcare facilities in areas with reliable transport options to reduce these barriers, while more recently, Tevita Funaki, chief executive of The Fono, emphasised the need for after-hours services within Pasifika communities to improve access. Additionally, health literacy, especially in navigating the healthcare system, remains a key factor in achieving equitable care (Persico, 2025).

However, access is also shaped by deeper issues of trust and cultural alignment. Many Māori patients and their whānau report feeling that their spiritual and cultural practices are undervalued or ignored within mainstream healthcare settings (Graham & Masters-Awatere, 2020). This disconnect contributes to a lack of confidence in the Western medical model, which has historically failed to adopt a more holistic view of health. Narratives from Māori experiences in clinical environments reveal that patients value meaningful rapport with clinicians (Walker et al., 2008; Willams et al., 2003). When this relational connection is absent, it is often perceived as a barrier to care (Graham & Masters-Awatere, 2020; Kidd et al., 2013; Penney et al., 2011). Walker et al. (2008) highlighted the often-overlooked role of whānau support, noting that family members frequently bear the burden of providing transport to and from healthcare appointments. These responsibilities impose additional financial and time pressures on whānau which may further deter engagement with health services.

Additionally, there is a lack of cultural representation across medical professions. In Aotearoa New Zealand, Māori comprise 18% of the population, while Pasifika account for 9% (StatsNZ, 2024). Hand Therapy New Zealand (HTNZ) does not collect or publish data on the ethnic composition of its members. However, data from the Occupational Therapy Board of New Zealand and the Physiotherapy Board of New Zealand reveal a notable underrepresentation of Māori and Pasifika within these professions. Māori represent just 4% of registered occupational therapists and 5% of registered physiotherapists, while Pasifika make up only 2% of the occupational therapy workforce and 1% of the physiotherapy workforce (Physiotherapy Board of New Zealand, 2020; Timmins et al., 2023). Similarly, in the medical profession, Māori doctors account for 4.7% of the workforce, while Pasifika doctors represent just 2.3% (Medical Council of New Zealand, 2023). This persistent lack of cultural representation across health professions may contribute to reduced access and engagement with services by Māori and Pasifika communities. When healthcare providers do not reflect the cultural identities of the populations they serve, it can undermine trust, limit cultural safety, and reduce the relevance of care, factors that are essential for equitable health outcomes. Collectively, these challenges may help explain the lower presentation rates of Māori and Pasifika patients to our clinic.

### 5.2.12 Distance Travelled

There appear to be no previous studies examining the impact of travel distance on access to CBCT imaging for assessing radiocarpal injury. The findings of this study indicate that most patients (58%) resided within 10 km of the 24-hour clinic, while nearly three-quarters (72%) travelled less than 20 km to receive treatment.

Although it is well known that rural residents must travel long distances to access healthcare services, the extent to which distance affects their willingness to seek care is less well understood. Distance decay refers to the decrease in healthcare access as travel distance or time increases (Wang et al., 2021) and is recognised as a factor affecting the utilisation of healthcare services. However, the threshold at which distance begins to deter healthcare access is not well defined.

Kelly et al. (2016) found that distance decay in healthcare access can occur at distances as short as 21.4 km. In contrast, Burge et al. (2008) reported that distance does not become a significant barrier to cancer treatment until at least 51 km. Similarly, Brustrom and Hunter (2001) found that even free healthcare services, such as mammography, may go unused if they are more than 32.2 km from a person's residence.

Findings of this study reinforces the idea that travel distance plays an important role in healthcare access decisions, particularly for urgent care settings. Mseke et al. (2024) suggest that travel time may be a more meaningful measure than distance. For example, in rural or remote areas where terrain, road conditions, and transportation infrastructure can significantly affect journey duration. Even in urban settings, public transportation can introduce substantial delays due to indirect routes, transfers, and scheduling gaps, meaning that short geographic distances may still translate into long travel times. Patients may be influenced not only by how far they must travel but also by how long the journey takes, which can shape their decisions about whether to seek care. This distinction between distance and time is crucial for understanding access barriers and designing interventions that address them effectively.

Beyond patient behaviour, this study also suggests that travel distance may influence clinical decision-making. A trend was observed where patients who travelled farther had higher CBCT referral rates, rising from 39% to 60%, although this difference did not reach statistical significance ($p = 0.09$). Additionally, the likelihood of receiving no further imaging decreased as travel distance increased. This suggests that travel distance not only influences patients' healthcare decisions but also affects clinical decision-making. The trend toward higher CBCT referral rates among those who travel farther may reflect healthcare providers' consideration of patients' difficulty in returning for follow-up. Similarly, the decline in cases receiving no further imaging with increased travel distance suggests that clinicians may opt for more definitive diagnostic measures when follow-up is uncertain. This reinforces the broader impact of distance decay on both patient behaviour and provider decision-making, highlighting the need for further research on how travel distance shapes healthcare utilisation.

Although the trend toward higher CBCT referral rates among patients travelling further appears notable (rising from 39% to 60%), the p-value of 0.09 indicates that this observation did not meet traditional thresholds for statistical significance. This could be due in part to a limited sample size or variability within the groups (for example, those travelling greater distances may present with more severe injury mechanisms). A larger study might reveal whether these trends hold when adequately powered, or if they are largely a product of random variation. While the observed trend is of interest, it is important to account for these potential confounders when drawing conclusions. In summary, travel distance may impact both patient access to treatment and health provider clinical decision-making and warrants further investigation.

## 5.3 Implications of the study's findings on clinical practice

The study's findings offer valuable insights to enhance clinical practice and inform decisions regarding referrals for imaging to detect radiocarpal fractures. These results have practical, real-world implications, some of which are outlined below.

### 5.3.1 X-ray as an effective initial screening tool

*40% of patients presenting to fracture clinic had fractures visible on initial X-ray. In total, 97% of fractures detected by X-ray were detected on the initial X-ray.*

Therefore, X-ray remains the best option for initial fracture screening due to its low cost and ease of accessibility. There is a strong consensus across major clinical guidelines that X-ray remains the preferred initial imaging modality for wrist trauma. The UK's National Institute for Health and Care Excellence (NICE), in its guideline NG38 on non-complex fractures (2016) recommends X-ray as the first-line investigation for suspected fractures, including those of the wrist. While MRI may be considered in cases of suspected scaphoid fractures when initial X-rays are negative but clinical suspicion remains high, X-ray is still the standard initial step in most presentations.

Similarly, the American College of Radiology (ACR) Appropriateness Criteria for acute hand and wrist trauma (2018) supports the use of X-ray as "usually appropriate" for initial imaging. The guidelines note that advanced imaging modalities such as MRI, CT, or ultrasound should be reserved for cases where X-ray findings are inconclusive or when soft tissue injuries are suspected. Repeat X-rays after 10–14 days may also be appropriate if initial imaging does not confirm a fracture, but clinical suspicion persists.

In New Zealand, the Ministry of Health's National Criteria for Access to Community Radiology (2015) and the Community Referred Radiology Programme (Health New Zealand Te Whatu Ora, 2025a) both endorse X-ray as the first-line imaging tool for wrist trauma. These guidelines ensure that primary care providers have access to wrist radiographs as part of standard diagnostic services, reinforcing the role of X-ray in initial fracture assessment.

Taken together, these guidelines from NICE, ACR, and New Zealand health authorities affirm that X-ray is the most appropriate initial imaging modality for wrist trauma due to its diagnostic reliability, low cost, and widespread availability.

### 5.3.2 The role of CBCT in diagnosing occult radiocarpal fractures

*Of the 60% of patients with a negative first X-ray, one in four subsequently had a fracture diagnosed on repeat imaging. In total, 93% of the occult fractures identified, were diagnosed by CBCT imaging.*

Cone beam computed tomography appears to be highly effective in identifying radiocarpal fractures that are not visible on standard X-ray imaging. This finding is consistent with previous research, which highlights CBCT's superior spatial resolution for bony anatomy. Its ability to produce high-resolution, three-dimensional images makes it particularly valuable for detecting occult carpal fractures that may be missed on conventional radiographs. Studies by Krayem et al. (2021) and Vitez et al. (2021) support this, demonstrating that CBCT significantly improves diagnostic accuracy, especially in cases where conventional X-rays appear normal or inconclusive.

### 5.3.3 Effective referral and triage for CBCT imaging

*Two out of every five patients referred for CBCT imaging had an occult fracture diagnosed.*

41% of patients referred for CBCT imaging were diagnosed with an occult fracture, demonstrating an effective pre-radiological assessment and referral process within the fracture clinic service. However, the selective nature of CBCT imaging introduces a critical limitation: occult fractures may go undetected in patients who are not referred for scanning. This reflects the broader challenge of clinical decision-making in musculoskeletal trauma. Walenkamp et al. (2016) found that although emergency department physicians could reasonably distinguish between patients with and without distal radius fractures based on physical examination, they expressed complete diagnostic confidence in only 19% of cases, emphasising the uncertainty that often accompanies initial clinical assessments.

### 5.3.4 Age-related differences in fracture detection and imaging referral

*Paediatric fractures were most likely to be diagnosed on X-ray imaging, with 90% of fractures diagnosed using this method. In comparison, only 70% of adult fractures were visible on X-ray imaging. It should be noted that referral for CBCT imaging for the paediatric population was significantly lower than that for adults (25% referral rate versus 60% referral rate for adults); therefore, results should be interpreted with caution.*

Given the high incidence of occult fractures in adults, a proactive approach to CBCT referrals is recommended to enhance diagnostic accuracy and facilitate timely detection. Studies have demonstrated CBCT's superior spatial resolution and diagnostic performance in identifying subtle cortical fractures that are often missed on conventional radiographs (Grassi et al., 2023). This aligns with the ACR Appropriateness Criteria, which support advanced imaging modalities such as CT or CBCT when clinical suspicion persists despite negative radiographs (Torabi et al., 2023).

In contrast, the lower referral rate for CBCT in children suggests that a proportion of radiographically occult fractures may go undiagnosed in this population. This discrepancy may stem from concerns about radiation exposure, as highlighted in paediatric imaging guidelines that advocate for cautious use of CT modalities in younger patients (Royal College of Radiologists, 2014). The New Zealand Code of Practice for Diagnostic Radiology (ORS C1) similarly emphasises justification and optimisation of imaging, reinforcing the need for careful clinical decision-making (Ministry of Health New Zealand, 2024). The Starship Hospital guidelines further note that many paediatric scaphoid fractures are not visible on initial radiographs, supporting the need for follow-up imaging or splinting based on clinical signs (Starship, 2022).

Adjusting referral thresholds for paediatric patients could improve fracture detection and provide a clearer understanding of the true incidence of occult injuries in this group. Further research is needed to evaluate whether current imaging protocols sufficiently capture paediatric fractures or if modifications are required to ensure more effective and timely diagnosis.

### 5.3.5 Timeliness of diagnosis and the impact of unnecessary immobilisation

*The average time to diagnosis for CBCT/MRI was ten days. Practically, this means that while one in four patients were diagnosed with occult fracture and were appropriately immobilised during this period, three out of four patients were unnecessarily immobilised.*

In our study, the average time from injury to diagnosis using CBCT or MRI was just 10 days, significantly faster than the typical wait for specialist appointments in the community. This accelerated pathway not only improves patient outcomes but also reduces the burden on traditional referral systems. This model could be successfully implemented in other major cities across New Zealand, helping to alleviate the burden on Emergency Departments initially and specialist services subsequently. However, there remains opportunity to enhance efficiency within the current framework.

At present, 25% of patients genuinely benefit from correct immobilisation, while 75% experience unnecessary restrictions. Additionally, delays in ACC claim processing impact timely access to specialist imaging, with priority processing of claims requiring three days for acceptance. Another significant concern is the effect of immobilisation on daily life, as patients wearing casts often experience limitations that prevent them from driving safely, limiting their capacity to work and perform routine tasks.

Currently, there are no universally standardised international guidelines that specify an exact timeframe for performing CBCT in cases of suspected occult radiocarpal fractures. However, clinical practice and emerging evidence suggest several reasonable approaches. In many settings, CBCT is performed approximately 7 to 14 days after the initial trauma, particularly when radiographs are negative but clinical suspicion remains high (Borel et al., 2017; Gibney, Smith, et al., 2019). This interval allows for reassessment once initial swelling subsides and may improve visualisation of subtle cortical disruptions that were not apparent on plain films. Some institutions advocate for immediate CBCT at the time of presentation in the emergency department when radiographs are inconclusive and clinical concern is significant. This approach aligns with broader trends in emergency medicine, where rapid triage and imaging are prioritised to reduce diagnostic delays and improve patient outcomes (Colville et al., 2022; Snaith et al., 2022)

Taking all these factors into consideration, several key improvements are proposed. Establishing a rapid triage system would enable the early identification of high-risk cases, ensuring timely imaging referrals. Enhancing ACC claim processing efficiency would accelerate the acceptance of suspected occult fracture cases, reducing unnecessary delays. Furthermore, implementing a fast-track referral pathway for imaging would streamline diagnostic procedures and enhance overall patient care.

### 5.3.6 Diagnostic advantages of CBCT for non-scaphoid carpal fractures

*Cone beam computed tomography (CBCT) provides a significantly broader detection of radiocarpal fractures, identifying eight out of nine bones in the wrist. In contrast, X-ray imaging primarily detected fractures in only two bones (65% in the distal radius and 27% in the scaphoid). Notably, X-ray failed to visualise fractures in the trapezium, capitate, or lunate bones, highlighting its diagnostic limitations.*

These findings suggest that carpal fractures are more prevalent than previously recognised, with historical underdiagnoses largely due to the restricted capabilities of X-ray imaging. A more routine integration of CBCT in clinical practice is essential to accurately assess the true incidence of these fractures within the population. Our findings support those of Krayem et al. (2021) whose CBCT-based analysis revealed a broader and distinct spectrum of carpal fractures compared to earlier radiographic studies.

### 5.3.7 Missed scaphoid fractures and the case for advanced imaging

*Twenty percent of scaphoid waist fractures were not visible on X-ray imaging.*

One in five scaphoid waist fractures may go unnoticed without access to CBCT in the acute setting. This underscores the importance of early and accurate diagnosis, as timely identification is essential for the effective management and optimal recovery of these injuries. Integrating CBCT into routine clinical practice could significantly reduce the risk of missed fractures, leading to improved patient outcomes.

Clinical guidelines from the UK, USA, and New Zealand increasingly emphasise the limitations of plain radiography in detecting scaphoid fractures. The NICE guidelines (UK) recommend MRI as the first-line imaging modality for suspected scaphoid fractures, citing its superior sensitivity and cost-effectiveness compared to CT or repeat radiographs (NICE National Institute for Health and Care Excellence, 2016). However, access to MRI directly from emergency departments remains limited in many UK centres. In the United States, the American College of Radiology (ACR) suggests that while initial radiographs are appropriate, MRI without contrast is preferred when radiographs are inconclusive, with CT also considered suitable for evaluating fracture displacement or staging (American College of Radiology, 2018). In New Zealand, Starship Children's Hospital and the RNZCUC advocate for early advanced imaging when clinical suspicion persists despite negative X-rays (Asim, 2021; Starship, 2022). These guidelines typically recommend MRI or CT within 10–14 days, aiming to prevent complications such as non-union or avascular necrosis. While MRI remains the dominant modality across these guidelines, there is limited awareness and integration of CBCT, despite emerging evidence supporting its diagnostic accuracy, lower radiation dose, and accessibility. As CBCT technology becomes more widely available, its potential role in musculoskeletal imaging, particularly for small bone fractures like those of the scaphoid, warrants greater recognition and inclusion in future clinical pathways.

### 5.3.8 Addressing ethnic and socioeconomic disparities in access to imaging

*Most patients (86%) accessing the fracture clinic service identified as European, while other ethnic groups were represented in significantly smaller numbers. Their representation was lower than what would be expected based on ACC statistics for wrist injury claims lodged, suggesting potential disparities in service accessibility or referral patterns.*

This discrepancy highlights the need for further investigation into whether barriers to access exist and how equitable care can be ensured for all demographic groups. Formalising partnerships with local community health providers such as Etu Pasifika and Piki Te Ora could significantly improve access and awareness. These organisations already play a trusted role within their communities and could serve as key conduits for education on the risks of missed fractures, as well as the availability of CBCT imaging and fracture clinic services. Targeted initiatives, such as pop-up fracture assessment days hosted at these centres, could help bridge gaps in service utilisation and build trust in clinical pathways. Additionally, there is a pressing need to explore subsidised access to imaging and fracture care for low-income or high-risk groups, ensuring that financial barriers do not prevent timely diagnosis and treatment.

The discrepancy between ethnic representation in fracture clinic attendance and ACC wrist injury claim data suggests potential systemic issues in referral patterns, clinical decision-making, or community awareness. Education plays a pivotal role. Targeted campaigns for GPs, physiotherapists, and urgent care providers should highlight the limitations of relying solely on X-ray imaging and promote the advantages of CBCT and timely fracture clinic referrals. These materials should be culturally appropriate and, where possible, translated to ensure accessibility. Community engagement in health education is a proven strategy for improving health outcomes, building trust, and addressing inequities. Research consistently shows that when communities are actively involved in designing and delivering health education, the impact is deeper, more sustainable, and more culturally relevant (Gomez et al., 2024; Plessas et al., 2024; Restini et al., 2024).

Improving access to fracture care requires a well-rounded approach that deals with cost barriers, supports education for both providers and patients, and fixes system-level problems, while also working closely with the communities most affected.

## 5.4 Implications of the study for hand therapists

Occult radiocarpal fractures, which are not immediately visible on standard X-rays, present significant challenges for hand therapists. Since these fractures often go undetected initially, patients may begin rehabilitation with an incorrect diagnosis, leading to inappropriate treatment plans and delayed recovery. Hand therapists, with their expertise in wrist assessment, treatment, and expected recovery timelines, are uniquely positioned to identify inconsistencies in a patient's presentation that may indicate a missed fracture. Regular patient follow-up allows hand therapists to identify atypical healing patterns, persistent pain, or unexpected functional limitations. This close monitoring enables them to raise concerns about a potential undiagnosed fracture and advocate for further investigation.

Confirmation of occult radiocarpal fractures requires advanced imaging, such as MRI or CBCT. However, referrals for these imaging modalities typically fall within the domain of sports medicine specialists, and hand and wrist surgeons. This creates a bottleneck in the diagnostic process, as patients often face long wait times for specialist appointments before imaging can be ordered. The resulting delay in diagnosis can lead to improper healing, increasing the risk of complications such as non-union, chronic instability, or avascular necrosis. These complications not only prolong rehabilitation but may also necessitate surgical intervention, further impacting patient outcomes.

Hand therapists are often the first point of contact for patients with acute wrist injury. Given their advanced training and direct involvement in wrist injury rehabilitation, hand therapists may be in an ideal position to expand their scope of practice to include ordering CBCT imaging for suspected occult radiocarpal fractures. By integrating imaging referrals into their practice, hand therapists could streamline the diagnostic process, reduce delays, and facilitate earlier intervention, ultimately improving patient outcomes. This potential expansion of their role would require additional training and regulatory approval but could significantly enhance the efficiency of care for patients with subtle but clinically significant wrist injuries.

## 5.5 Strengths of the study

This study's relatively large sample size, approaching the 95% confidence level supports accurate population representation and robust statistical analysis. Since the study was not limited to radiographically occult fractures, its results can be generalised to the wider wrist trauma population, making the findings more relevant for clinical practice.

The data audit, conducted on 10% of the sample, demonstrated a 96% agreement rate, indicating strong consistency and accuracy in data collection and analysis. This high level of agreement further supports the rigour of the study's methodology and enhances confidence in the validity of the reported outcomes.

By considering social determinants of health, this study moves beyond purely clinical factors and acknowledges the broader influences on patient care. Including ethnicity as a variable allowed for the identification of potential biases or inequalities in access to imaging services. This insight can inform policies aimed at reducing healthcare disparities and ensuring equitable treatment for all patients. Similarly, examining the impact of travel distance on imaging access has highlighted potential geographic disparities, particularly for rural communities.

## 5.6 Limitations of the study

This study is limited by its retrospective design and single centre data collection. Patients with ongoing clinical suspicion of radiocarpal fracture, with negative initial X-ray were referred for CBCT, which introduced selection bias and may have affected the true representativeness of the study population. A prospective study assessing all patients using both X-ray and CBCT would provide more accurate incidence rates. Ideally, MRI would be employed as the definitive reference standard for fracture detection. However, conducting a prospective study of this scale, with a sample size equivalent to the current retrospective analysis, would be very costly to implement and beyond the scope of a master's-level research project.

A further limitation of this study is the underrepresentation of minority ethnic groups, particularly Māori, Pasifika, and Asian populations. The small sample sizes within these groups limited their representation, restricting the ability to draw robust conclusions and potentially affecting the generalisability of the findings. To strengthen future research, oversampling of these populations should be incorporated into study design to ensure adequate representation and sufficient statistical power for subgroup analysis. With a larger sample of non-European participants, meaningful subgroup analyses could be undertaken to examine whether patterns or outcomes differ across ethnic groups, contributing to more culturally responsive insights.

## 5.7 Recommendations for future research

This study provides valuable insights into the characteristics of people presenting to fracture clinic with potential radiocarpal fracture, and the current detection rate of occult radiocarpal fractures using CBCT imaging. Replicating this study in other major cities, especially Auckland, which has the country's largest and most diverse population, would allow for meaningful comparisons, identifying both similarities and differences in data outcomes. A larger sample size would further enhance the validity and reproducibility of findings.

Several areas for further research have emerged from this study, particularly regarding healthcare accessibility for ethnicities other than European, the impact of travel distance on access to treatment and imaging, and differing referral rates for CBCT imaging between children and adults.

Most patients accessing fracture clinic services (86%) identified as European, with other ethnic groups represented in small numbers. Their representation falls below expected levels based on ACC statistics for wrist injury claims, suggesting potential disparities in service accessibility or referral patterns. Additionally, findings suggest that cost may serve as a barrier for some individuals, underscoring the need to investigate obstacles to healthcare access. To explore these issues in greater depth, a qualitative study could be designed to recruit Māori and Pasifika patients presenting to emergency departments or private fracture clinics. Through interviews or focus groups, the study could explore patient experiences, perceived barriers to access, decision-making regarding seeking care, and the role of cost or cultural factors. This would provide insight into how systemic or socioeconomic factors may influence engagement with diagnostic and treatment pathways for wrist injuries.

Regarding travel distance, this study found that most patients (58%) lived within 10 km of the 24-hour clinic, while almost three-quarters (72%) travelled less than 20 km for treatment. Rural Canterbury residents travelled longer distances to access healthcare. Higher CBCT referral rates were observed among patients who travelled longer distances, while the likelihood of receiving no further imaging decreased as travel distance increased. These findings, while not statistically significant, indicate that travel distance may shape both patients' healthcare choices and influence clinical decision-making. A larger sample size could help clarify whether the observed trend represents a real but subtle effect or just variability within the data. Further research is needed to explore this dynamic in greater detail.

Consideration should be given to the relevance of these findings to healthcare access in Aotearoa New Zealand, where factors such as geographic isolation, workforce limitations, and unequal distribution of imaging technology may affect the feasibility and equity of implementing advanced diagnostic modalities. Exploring these factors will help assess whether CBCT can be realistically integrated into clinical pathways across urban, rural, and underserved communities, and will contribute to a more informed conversation around imaging resource allocation and equitable healthcare delivery for all population groups, including Māori and Pacific peoples.

Most paediatric fractures were diagnosed using X-ray imaging, with 90% of cases identified through this method, compared to 70% for adults. CBCT referral rates varied significantly between age groups, with only 25% of paediatric patients referred for CBCT versus 60% of adults. Adjusting referral thresholds for paediatric patients could improve fracture detection and provide a clearer picture of the true incidence of occult fractures in this group. Further research is needed to assess whether X-ray imaging effectively detects paediatric radiocarpal fractures or if revisions to imaging referral protocols are necessary.

# Chapter 6

# Conclusion

Cone beam computed tomography has emerged as a highly effective imaging modality for identifying carpal fractures, particularly those that are subtle or occult, and which often go undetected on standard X-ray imaging. Integrating CBCT into acute care and emergency settings would significantly improve diagnostic accuracy, facilitating earlier and more confident detection of fractures. This, in turn, would support informed clinical decision-making regarding treatment strategies, whether conservative management (splinting and hand therapy), cast immobilisation, or surgical intervention. By reducing the risk of missed diagnoses and inappropriate treatment plans, early use of CBCT could contribute to better patient outcomes, including faster recovery times, reduced complications, and improved long-term function.

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# Appendices

# Appendix A Clinical Guidelines

Policy 1357

| | | | | |
|---|---|---|---|---|
| **Clinical Scaphoid Fracture** | Most commonly occurs in skeletally mature people up to the age of 60<br><br>High impact injury<br><br>Assess pain anatomical snuff box, thumb loading and ventral aspect scaphoid. Tenderness in these 3 areas, indicate clinical scaphoid injury<br><br>Needs immobilisation<br><br>Check for scapho-lunate widening on x-ray (see below for Rx) | Apply BE POP scaphoid cast (slight radial deviation, minor extension, wrist in pronation). Split if injury <24 hours old<br><br>Fulltime employed or parent of young children - review in SFC/ORTHO clinic allowing a minimum of 3 working days for reassessment and consideration of further investigation - ACC claim must be accepted before further investigations can be ordered<br><br>Those not applicable for ACC funding for further investigation - review in SFC/ORTHO at 12-14 days<br><br>Patient to perform own circulation check if nil clinical concern. | Review in SFC/ORTHO at 12-14 days.<br><br>Parent/caregiver to complete own circulation check if nil clinical concern. Ensure good patient education re: circulation and cast cares | Those returning for consideration of further imaging – ROP and assess. MRI/Cone CT arranged usually same day<br><br>Apply wrist splint – complete orthotic form<br><br>Ensure follow up appointment arranged before patient leaves – next available clinic or seen acutely if nurse rostered on who can apply FG<br><br>At next appointment if # present in FG for 5/52 (total time in cast 6/52)<br><br>Those returning at 12-14/7 – ROP and assess Xray if indicated<br><br>If # present – see below |
| **Definite Scaphoid Fracture** | Assess level of # - waist of scaphoid OR proximal/distal pole of tubercle<br><br>**Any displacement** refer to hand surgeon or OAC due to increased incidence of non-union | Apply BE POP scaphoid cast (slight radial deviation, minor extension, wrist in pronation). Split if injury <24 hours old<br><br>Review in SFC/ORTHO 1/52<br><br>Patient to perform own circulation check if nil clinical concern. | As per adult | Undisplaced Scaphoid tubercle – CHOP in FG for 3/52 (total time in cast 4/52 – 6/52 if intra-articular)<br><br>Undisplaced Scaphoid Waist - CHOP in FG for 5/52 (**MINIMUM** total cast time 6/52) then ROP and xray<br><br>Undisplaced proximal pole – CHOP in FG for 7/52 (**MINIMUM** total cast time 8/52) ROP and CBCT to assess union |

*This Guideline was last reviewed August 2023 / Date for next review August 2025*

Policy 1198

# CLINICAL GUIDELINE

# Fractured Scaphoids (Suspected)

24 HOUR SURGERY
Pegasus

**Suspicion raised if:**

- Skeletally mature (patient older than 10)
- mechanism of injury
- tender in anatomical snuff box, dorsally and upon loading of thumb

**DAY 1 - at presentation**

- X-ray – initially NAD but clinical suspicion of possible fractured scaphoid. Check **scapho-lunate** area – see note 1.
- If injury < 24hrs old apply a **split be-pop in radial deviation + slight extension**
- If injury >24hrs old – no need to split the plaster
- Organise Fracture Clinic follow-up (SFC or Specialist – not MO):
  - In 3 working days to allow for ACC acceptance in Specialist Fracture Clinic/Specialist if patient is currently in the workplace or has significant issues in a cast (e.g. care of young children). These patients will be reassessed and MAY be referred for MRI if appropriate.
  - In Specialist F
  - No circulation

**DAY 10-14**

- Remove POP, assess clinically and re-X-ray if necessary
- If no fracture start to mobilise unless <u>very</u> suspicious of a problem
- MRI requested if indicated
- Advise review at 1 week if any ongoing problems
- If fracture present re-plaster for the appropriate time (6 weeks minimum) with specialist review at completion of this period to reassess and repeat xray - see Notes below.

**NOTES**

- Look at the scapho-lunate area and refer to SFC if the joint space appears widened. This may indicate a significant ligamentous injury.
- Definite fractured scaphoids are to be in a cast for a minimum of 6 weeks. Follow-up is to be at a Specialist Fracture Clinic or an Ortho Consultant Clinic - NOT an MO Fracture Clinic to assess clinical and radiological union.
- Ideally all scaphoids - both suspected and confirmed - should be followed up at a Specialist Fracture Clinic or an Ortho Consultant Clinic rather than an MO Fracture Clinic.
- Fractured scaphoid tubercle - treat symptomatically (e.g. TCT for 3 – 4 weeks and review)

# Appendix B  Ethics approval

## Auckland University of Technology Ethics Committee (AUTEC)

27 November 2024
Julia Hill
Faculty of Health and Environmental Sciences

Dear Julia

Re Ethics Application: **24/344 Diagnosing occult radiocarpal fractures in Aotearoa: What is the current detection rate, and which patients are accessing early CBCT imaging?**

Thank you for your responses to AUTEC's conditions.
Your ethics application has been approved for three years until 26 November 2027.

**Standard Conditions of Approval**

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics
For any enquiries, please contact the Secretariat at ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)
The AUTEC Secretariat
**Auckland University of Technology Ethics Committee**
Cc: johbly11@autuni.ac.nz; nsaywell@aut.ac.nz

# Appendix C Permission for researchers to access organisation data

*Project title:*

***Diagnosing occult radiocarpal fractures in Aotearoa: What is the current detection rate of occult radiocarpal fractures using cone beam computed tomography (CBCT) imaging, and which patients have access to early imaging?***

*Project Supervisor:* ***Dr Julia Hill & Dr Nicola Saywell***
*Researcher:* ***Johanna Buick***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 19th October 2024.
- ○ I give permission for the researcher to undertake research within Pegasus Health 24HR Clinic.
- ○ I give permission for the researcher to access patient lists from Senior Fracture Clinics dated 1st December 2023 – 31st May 2024 inclusive.

Clinical Director's signature:

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Clinical Director's name:

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Clinical Director's Contact Details (if appropriate):

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Date:

***Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number***

## Appendix D Data Management Plan

***<u>Project title and brief description:</u>***

Ethics Application: 24/344

Diagnosing occult radiocarpal fractures in Aotearoa: What is the current detection rate, and which patients are accessing early CBCT imaging?

**What is the purpose of this research?**

In New Zealand, access to high tech imaging (cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI)) is by specialist referral only - but long wait times to access surgeons or sports medicine specialists limit patient access to imaging in the acute phase of injury. This research explores early access to high tech imaging, made available through the fracture clinic service, thus expediting the diagnosis of occult fracture. If results corroborate with published international studies, ways of improving the accessibility of CBCT in the acute setting can be explored.

The questions to be addressed in this paper are: *What is the current detection rate of occult radiocarpal fractures using CBCT imaging? What are the characteristics of patients who are accessing early CBCT?*

The findings of this research may be used for academic publications and presentations.

**What will happen in this research?**

*Design*: A retrospective audit of patient records.

*Participants:* All patients of any age presenting with suspected radiocarpal fracture.

*Timeframe*: Six-month period from 1st December 2023 to 30th May 2024

Fracture clinic lists over the six-month period will be manually, retrospectively reviewed. Patients presenting with wrist injury will have data extracted from their electronic health records. Data collected will include:

- Age (at time of injury), sex and ethnicity
- Time between initial XR and CBCT
- Diagnosis (fracture on initial XR/occult fracture/no bone injury) and bone fractured (e.g. scaphoid, trapezium, distal radius etc.)

Data collection for imaging will be from the radiology information system (Inteleviewer). Data will be collected on whether patients were determined to have no bone injury, fracture, or occult fracture based on imaging outcomes, as well as the type of imaging performed. If a fracture, or occult fracture are identified, the location of the fracture will be noted. In patients sustaining more than a single fracture, the location of each fracture will be noted. Data collection is focused on method of identification of fracture, not on the range of imaging a patient has had.

**Primary Researcher**

Johanna Buick

**Supervisors or other researchers**

Dr Julia Hill, Dr Nicola Saywell

**Who will have the primary responsibility for the data at the different stages of its life cycle?**

There are multiple stages in the research data lifecycle. The lifecycle of research data is categorised into two broad phases:

• Active: this is the phase in which data is collected, modified, analysed, and reported on/published. The researcher will have primary responsibility for data during this time.

• Post-analysis retention: this is the phase in which the above activities have been completed, and the data is stored for the specified retention period. AUT's default position is that in this phase data is to be stored on AUT premises and data will be the responsibility of the researcher's supervisor.

***<u>What is the nature of the data being collected and produced?</u>***

*What type of data will be produced, used, or generated (both physical and digital)?*

Electronic data will be collected, generated, and analysed. There will be no hard copy of data.

*How will data be collected and in what formats?*

The data will be gathered (retrospectively) from patient electronic health records (Gensolve Practice Manager) and from electronic imaging records (Inteleviewer, Pacific Radiology Group). Data will be entered into an excel spreadsheet and once completed, patient NHIs will be removed, and a clean data sheet will be created. Patient identifying characteristics (NHI numbers) will be stored separately from the clean data sheet and will not be accessible to anyone other than the researcher. A small sample of data (10%) will be audited by a research assistant to check the accuracy and reproducibility of data. This will require the research assistant to have access to the NHIs of this 10% sample and a confidentiality agreement will be required.

*How will the data collection be documented so that others can work out what is involved? Is there a data dictionary?*

There is a code book for data collection to ensure that all data relevant to the study is collected and sorted into appropriate categories, and no data irrelevant to the study will be accessed. (see appendix 1)

*Will the data be reproducible?*

If permission to access organisational data was granted to another party, the data itself would be reproducible.

*How much data will it be, and at what rate will it grow? How often will it change?*

The data file is anticipated to have a sample size of 250-350 patient files. The collection period is limited to a six-month period (1st December 2023 – 31st May 2024 inclusive). This will be a retrospective audit of patient files.

*Are there tools or software needed to create or process or visualize the data?*

Once the clean data sheet has been completed in excel, the data will be transferred to data processing software to allow easier processing and visualisation.

*What costs, training, or resources are needed to implement this?*

This will require the researcher to have access to data processing software and guidance in its use.

*Will pre-existing data be used and if so, from where will it be sourced?*

Data will be retrospectively collected from a specialist fracture clinic service located in Christchurch, New Zealand. Data will be sourced from patient electronic health records (Gensolve Practice Manager) and from electronic imaging records (Inteleviewer, Pacific Radiology Group). Organisational permission to access data has been granted.

***Where are you collecting data?***

*Where are you collecting data?*

Data will be retrospectively collected from a community based specialist fracture clinic service located in Christchurch, New Zealand.

*What jurisdiction requirements apply to the collection of data?*

This is under New Zealand jurisdiction and will comply with the Privacy Act 2020.

***What are the data storage plans?***

*What are the data storage and backup strategies? What would happen if it got lost or became unusable later?*

Data will be stored on a secure folder on Microsoft Teams, which only the researcher and her supervisors have access to. This is in accordance with AUT guidelines.

*Will any data be stored on portable devices (e.g. audio files on a mobile phone)?*

No.

*How will the security of any temporary storage be assured?*

Data will be stored in accordance with AUTEC's guidline.

*Will the data be securely stored or transferred to a secure data repository?*

The data will be securely stored on AUT managed cloud storage or processing platforms.

*What data will you keep and what data will be destroyed?*

All data collected will be stored for at least ten years as required by section 5 of the Health (Retention of Health Information) Regulations 1996. Key identifiers (NHI numbers) will be stored separately to the clean data sheet.

*When and how will data be destroyed?*

A secure data wiping program will be used to destroy the data stored on the external hard drive after it has been stored for ten years.

***What are the ethical requirements for your data?***

*How will the undertakings about consent, confidentiality, deidentification, and other ethical considerations given to participants be assured?*

*How sensitive is your data?*

The sensitivity classification of the data is 'Private' as it contains re-identifiable/ de-identified research data (should the key identifier tool be provided, or the research repeated).
Classification

*How identifiable is your data (Will it be directly or indirectly identifiable? Will it be deidentified though potentially re-identifiable? Will it be permanently unidentifiable?) Will this alter? When?*

On collection the data will be identifiable as patient NHIs will be linked to patient ID numbers. Following the initial collection of data, key identifiers will be removed from the data to create a clean data sheet (deidentification of data). Only the researcher will have access to the correlation tool which matches patient NHI with patient ID numbers. Data will remain permanently deidentified during analysis, write up and publication.

*What will happen to the identifiable information?*

Patient NHI numbers and correlation tool will be stored separately from the data sheet on a secure, password protected, AUT server.

*Should some data be destroyed or returned? When and how? By whom?*

A secure data wiping program will be used to destroy the data stored on the external hard drive after it has been stored for ten years in accordance with policy (Health (Retention of Health Information) Regulations 1996).

*Incidental Findings*

In the event that a study assessment returns a result of potential clinical significance, the participant will be informed. The participant's usual doctor and / or an appropriate specialist will be notified, and follow-up will be arranged.

***<u>What consultation has occurred around the management of your data?</u>***

*With which communities or stakeholders has consultation occurred?*

Māori consultation has been undertaken with Sandra Kettle (New Zealand registered Physiotherapist and New Zealand registered hand therapist). Sandra is based North of Auckland and is part of the Māori Advisory Group for Hand Therapy New Zealand, as well as a physiotherapy Kaitiaki for Tae Ora Tinana. Sandra supports the proposed research, considering the information collected to be a taonga for the Māori people, and has expressed her availability for further consultation once the research data has been analysed.

Organisation consultation and consent has been obtained from the healthcare facility where the specialist fracture clinic is based

*How are any Māori data sovereignty issues being managed (please refer to* https://www.temanararaunga.maori.nz*)?*

Māori Data Sovereignty

During the study, data may be collected from participants identifying as Māori.

Personal and health information is a taonga (treasure) and will be treated accordingly.

Formal Māori consultation for this study will be completed as part of the Locality Approval Process for New Zealand study site(s). Any recommendations for additional measures to improve Māori rights and interests in relation to data will be acted upon.

Data collected in this research may display inequity in access to imaging following wrist injury. Therefore, results could be utilised in informing and driving Māori/Iwi development at national and local levels.

*How are the principles of whakapapa, whanaungatanga, rangatiratanga, kotahitanga, manaakitanga, and kaitiakitanga being implemented?*

Te ao Māori emphasises the importance of relationships between nature and people. It is a holistic worldview that focuses on interconnections and is grounded in tikanga customary values and mātauranga knowledge. The researcher acknowledges our obligations to our Māori partners under Te Tiriti o Waitangi. Consultation aims to recognise the rights of Māori and to ensure that their voice is heard, and their views are considered, both in the research planning and in the discussion of results.

***How is your data being organised and what documentation and metadata is being used?***

Data will be stored and organised according to the project name, data type and general data source.

Files will be named according to the identification number allocated, data type and general data source.

Data will be entered into an Excel spreadsheet under predetermined dataset names as documented in the Research Code Book.

No metadata will be used in this study.

***<u>What are the plans for data sharing and access?</u>***

Identifiable data may be accessed by the following groups:

- The researcher, her supervisor and designated study staff, to fulfil protocol requirements.
- Local radiology staff, to process, analyse and report images if any discrepancies are found.
- The research assistant, for audit purposes.
- The Health and Disability Ethics Committee, for legal and regulatory purposes.
- Health, regulatory, or government agencies, for legal and regulatory purposes.
- The patient, their GP or appropriate specialist, in the event of an incidental finding of potential clinical significance.

De-identified data may be accessed and used by the following groups:

- The researcher, her supervisors and suitably trained and experienced study staff, to conduct the study.
- The Health and Disability Ethics Committee, to comply with legal and regulatory duties.
- Health, regulatory, or government authorities, to comply with legal and regulatory duties.

De-identified data may be included in published study results including, but not limited to, peer-reviewed publications, clinical trial registry websites, scientific meetings, and regulatory / marketing submissions.

*Is a data sharing agreement needed?*

A data sharing agreement will not be required. While it is envisioned that the research results will be widely shared, the data itself will remain private and confidential. AUT's intellectual property rights policy will be adhered to.

*When will you publish and where?*

The research will be submitted for publication within 6 months of completion of the master's thesis.  Submission will be made to the Journal of Hand Therapy, or Journal of Hand Surgery.

*What level of data access is the publisher likely to require and how will participants consent to sharing their data with publishers?*

A non-data sharing statement will be selected when submitting the research for publication.

*What tools or software are needed to work with the data?*

Microsoft Excel will be required to work with the data.

***What are the plans for managing any breaches of privacy or confidentiality?***

*What processes are in place to prevent breaches?*

Data will be deidentified and stored on a secure AUT server.  Data will be collected and stored in accordance with AUT guidelines and procedures.

*Who will be responsible for notifying breaches to AUTEC and to the Privacy Commissioner when they are notifiable breaches under the Privacy Act 2020?*

Dr Julia Hill is the applicant on the application for ethics approval through AUTEC (when the research is part of the requirements for a qualification at AUT, the applicant is always the primary supervisor), therefore Julia will be responsible for notifying breaches to AUTEC and to the Privacy Commissioner should they occur.

***What are the plans for data preservation and archiving***

*How will the data be archived for preservation and long-term access?  How long should it be retained (e.g., 6 years, 10 years, permanently) and how is this being assured?*

All data collected will be stored for at least ten years as required by section 5 of the Health (Retention of Health Information) Regulations 1996.  Key identifiers (NHI numbers) will be stored separately to the clean data sheet. A secure data wiping program will be used to destroy the data stored on the external hard drive after it has been stored for ten years

*What file formats are involved for electronic data? How will future accessibility be assured?*

Raw data will be formatted on a Microsoft Excel spreadsheet. Data processing will be conducted on Microsoft Excel and data processing software). Data will be stored on AUT servers, ensuring future accessibility.

*Are there existing data archives that are appropriate for your data, whether subject based, institutional, public?*

This has not been explored.

*Who will maintain the data for the long-term?*

In the active phase data will be maintained by the researcher in accordance with AUT guidelines. In the post-analysis retention phase, data will be maintained (stored) on AUT servers by the supervisor (Dr Julia Hill).

***<u>What are your main data challenges? Who can help?</u>***

*What training or support do you need and what is available?*

AUT Library Research Data Management

AUT Library Research Support

Support with data analysis will be provided.

*What University policies are relevant to your project? Have you read and understood them?*

AUT Research Data Storage Guidelines

AUTEC Guidelines and Procedures

# Appendix E Code book for data collection

| Full variable name | Dataset name | Coding instructions |
|---|---|---|
| Identification number | id | Subject identification number |
| Sex | sex | 1 = male<br>2 = female |
| Age | age | In years |
| Distance | distance | Distance in km from home to fracture clinic |
| Ethnicity | ethnicity | 1 = European<br>2 = Māori<br>3 = Asian<br>4 = Pasifika<br>5 = Middle East/Latin America/African<br>6 – not defined |
| Imaging taken | image | 1 = initial XR<br>2 = CBCT<br>3 = MRI<br>4 = repeat XR |
| Outcome | outcome | 1 = fracture on XR<br>2 = fracture on CBCT<br>3 = fracture on MRI<br>4 = fracture on repeat XR<br>5 = no fracture repeat XR<br>6 = no fracture CBCT<br>7 = no fracture MRI<br>8 = no fracture no further imaging |
| Bone fractured | fracture | 0 = No bone injury<br>1 = distal radius<br>2 = scaphoid<br>3 = trapezium<br>4 = hamate<br>5 = lunate<br>6 = capitate<br>7 = triquetrum<br>8 = pisiform |
| Scaphoid | scaphoid | 1 = waist<br>2 = proximal pole<br>3 = distal pole/tubercle |
| Final diagnosis | diag | 1 = fracture<br>2 = no fracture<br>3 = occult fracture |
| Time to final diagnosis | time | In days |

## Appendix F  Confidentiality Agreement

*For an intermediary or research assistant.*

*Project title:*
*Diagnosing occult radiocarpal fractures in Aotearoa: What is the current detection rate of occult radiocarpal fractures using cone beam computed tomography (CBCT) imaging, and which patients have access to early imaging?*

*Project Supervisor:* ***Dr Julia Hill & Dr Nicola Saywell***
*Researcher:* ***Johanna Buick***

- ○ I understand that all the material I will be asked to record is confidential.
- ○ I understand that the contents of the Consent Forms, tapes, or interview notes can only be discussed with the researchers.
- ○ I will not keep any copies of the information nor allow third parties access to them.

Intermediary's signature : ..............................................................................................
Intermediary's name : ....................................................................................................
Intermediary's Contact Details (if appropriate) :
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Date:

Project Supervisor's Contact Details (if appropriate):
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***Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number***
*Note: The Intermediary should retain a copy of this form*