

The Effect of Lateral Wedging on Foot Function in Walking and Running Gait

Aaron Jackson

A research component submitted to Auckland University of Technology in
fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

2025

School of Allied Health

Abstract

A lateral wedge is an underfoot intervention often added to foot orthoses by sloping material so that the lateral side is higher or thicker compared to the medial side. Podiatrists prescribe foot orthoses, which often incorporate lateral wedges, to alter foot function and reduce symptoms in the lower limb. Despite the anecdotally reported frequent use of lateral wedges in podiatric practice, there is limited evidence concerning their clinical application or biomechanical outcomes in healthy populations. To address this gap, this thesis had two aims: first, to understand how lateral wedges are applied clinically, including their frequency of use, the diagnoses they are used to address, and how they are fabricated and positioned; and second, to evaluate how lateral wedges affect foot function, specifically first metatarsophalangeal joint motion and centre of pressure during walking and running gait. To meet these aims, a series of four studies was developed, which have been presented in this thesis.

Firstly, to develop an understanding of the prescription habits of New Zealand (NZ) podiatrists 1000 custom foot orthosis prescriptions were obtained and analysed to determine the frequency and symmetry of orthotic prescription characteristics. A lateral wedge was included in 22% of prescriptions and was more likely to be utilised for the management of plantar heel pain or ankle sprains.

Secondly, a scoping review was conducted to map existing research on the effect of lateral wedges in healthy adults. This review identified insufficient descriptions of wedge design, with many studies omitting details of the materials used to manufacture lateral wedges and their placement. Most included studies (95%) examined full-length, rearfoot, or sulcus-length wedges, with an average wedge inclination of 6°. No evidence was found contrasting the effects of lateral wedges for running versus walking gait.

Thirdly, an online survey found that 86% of NZ podiatrists believed lateral wedging increased first metatarsophalangeal joint extension during gait. This was also the most common reason for using lateral wedges, with shifting the centre of pressure medially being the second most common. Two-thirds of podiatrists fabricated their own lateral wedges, generally using three-millimetre (1.5°-3°) medium-density ethylene vinyl acetate, positioned under the forefoot. The forefoot positioning of lateral wedges favoured by NZ podiatrists differs from what is typically applied in research. Furthermore, NZ podiatrists used lower inclinations than those generally studied.

Finally, using three-dimensional gait analysis, a crossover trial was conducted in which 24 participants ran and walked in ten different insoles, including different placements (full length vs. forefoot) and inclinations (3° vs. 6°). Lateral wedges reduced first metatarsophalangeal joint extension. This effect was not influenced by wedge placement or inclination and was observed in both walking and running gait. The centre of pressure was shifted medially, although only when using the 6° or full-length wedges. The effect on the centre of pressure contradicts existing evidence.

Based on this data and the current habits of NZ podiatrists, lateral wedges used in practice are unlikely to achieve their intended outcomes. First MPJ extension is being reduced, not increased. Although the aim to shift the COP medially is valid, low wedge inclinations utilised by podiatrists may be too little to elicit the desired outcome. Therefore, this thesis calls for clinicians and industry partners to critically reflect on their expected outcomes of lateral wedging, particularly in relation to first MPJ kinematics, and to adopt a more nuanced approach to lateral wedge design, ensuring that the wedge is tailored specifically for the intended use and desired outcome.

Table of Contents

ABSTRACT	II
LIST OF FIGURES	VII
LIST OF TABLES	IX
ATTESTATION OF AUTHORSHIP	X
CO-AUTHORED WORKS ARISING FROM THE DOCTORAL THESIS	XI
ACKNOWLEDGEMENTS	XIV
CHAPTER 1: THESIS OVERVIEW	15
1.1 Rationale.....	15
1.2 Aims of the Thesis.....	18
1.3 Thesis Research Questions	18
1.4 Thesis Outline	19
CHAPTER 2: INTRODUCTION	22
2.1 Anatomy of the Foot.....	22
2.2 Podiatric Models of Foot Function	23
2.3 Walking and Running Gait	28
2.4 Foot Orthoses	33
CHAPTER 3: CUSTOM FOOT ORTHOSES: A RETROSPECTIVE ANALYSIS OF 1000 PRESCRIPTIONS FROM NEW ZEALAND PODIATRISTS	38
3.1 Preface.....	38
3.2 Abstract	39
3.3 Background.....	40
3.4 Methods.....	41
3.5 Results	44
3.6 Discussion	48
3.7 Conclusion	51
3.8 Novel Contributions of Chapter 3.....	51
CHAPTER 4: LATERAL WEDGING OF THE FOOT: A SCOPING REVIEW	52
4.1 Preface.....	52

4.2	Abstract	53
4.3	Background	53
4.4	Methods.....	54
4.5	Results	56
4.6	Discussion	62
4.7	Conclusion	65
4.8	Novel Contributions of Chapter 4.....	65
4.9	Update Since Publication.....	66
CHAPTER 5: BELIEFS ABOUT AND USE OF FOREFOOT LATERAL WEDGING IN PODIATRIC MEDICAL PRACTICE: A SURVEY OF PODIATRIC PHYSICIANS IN NEW ZEALAND.....		70
5.1	Preface.....	70
5.2	Abstract	71
5.3	Background	72
5.4	Methods.....	73
5.5	Data Analysis.....	74
5.6	Results	75
5.7	Discussion	81
5.8	Conclusion	85
5.9	Novel Contributions of Chapter 5.....	85
CHAPTER 6: THE IMMEDIATE EFFECT OF LATERAL WEDGING ON FIRST METATARSOPHALANGEAL JOINT KINEMATICS AND CENTRE OF PRESSURE.....		86
6.1	Preface.....	86
6.2	Abstract	87
6.3	Introduction	88
6.4	Methods.....	90
6.5	Results	96
6.6	Discussion	107
6.7	Conclusion	112
6.8	Novel Contributions of Chapter 6.....	113
CHAPTER 7: THESIS DISCUSSION.....		114
7.1	Main Findings.....	114
7.2	Implications of the Thesis	117
7.3	Strengths and Limitations of the Thesis.....	124
7.4	Future Research Directions.....	126
7.5	Thesis Conclusion.....	130
REFERENCES.....		131

CHAPTER 8: APPENDICES	147
8.1 Appendix 1: Diagnostic groupings applied in Chapter 3	148
8.2 Appendix 2: Diagnostic associations from Chapter 3	151
8.3 Appendix 3: Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist	161
8.4 Appendix 4: Kinematic and Kinetic Outcomes of the studies included in Chapter 4.....	165
8.5 Appendix 5: Clinician Survey administered in Chapter 5	169
8.6 Appendix 6: Checklist for Reporting Results of Internet E-Surveys (CHERRIES) relating to Chapter 5	180
8.7 Appendix 7: Ethical Approval for Chapter 5	185
8.8 Appendix 8: Participant information sheet relating to Chapter 6	188
8.9 Appendix 9: Ethical Approval for Chapter 6	192
8.10 Appendix 10: Participant Consent form used in Chapter 6	195

List of Figures

Figure 1.1: An example of lateral wedge shape and placement. They are often described as a rearfoot lateral wedge (A), forefoot lateral wedge (B), and full-length lateral wedge (C). In each example, these would be sloped so that the lateral side is thick and the medial side is thin.	15
Figure 1.2: Graphical overview of studies included in the thesis	19
Figure 2.1 Arches illustrated, in this case of the right foot from the lateral view [left image] and medial view [right image]. Adapted from Behling et al. (25).	22
Figure 2.2 Clinical assessment developed by Root et al. (7), identifying forefoot varus (left) and forefoot valgus (right), Both images depict the right foot. Adapted from Root et al. (7).	25
Figure 2.3 Theoretical depiction of how ground reaction force is applied to a foot with a medially deviated STJ axis [A], a neutral axis location [B], or a laterally deviated STJ axis [C]. Adapted from Kirby (46).	27
Figure 2.4 Overview of human walking gait cycle. Adapted from Pirker and Katzenschlager (52).	30
Figure 2.5 Comparison of COM relative height between walking and running gait.	31
Figure 3.1 Prescription characteristics extracted from data	42
Figure 4.1: Flowchart diagram of literature search, screening, and selection	56
Figure 4.2 Flowchart diagram of search and screening of relevant literature published since May 2021	66
Figure 5.1: Likelihood of FLW prescription, based on common lower limb diagnoses. Data above the line indicating the conditions where FLWs were more likely to be used. Data below the line indicates conditions where FLWs were more unlikely to be used.	77
Figure 5.2: Importance of various considerations when prescribing forefoot lateral wedging	78
Figure 5.3: The most common reasons respondents would prescribe FLWs for both running and walking gait (%)	79
Figure 5.4: Approximate FLW shape when placed from the calcaneo-cuboid joint to the sulcus of the foot	81
Figure 5.5: The relationship between material thickness and width means that at a consistent material thickness (C) the inclination angle (b) will be smaller than (a) due to the modification being wider (B > A)	84
Figure 6.1 Comparison of insole contour. The sham insole is shown in the foreground and the contoured insole behind.	92
Figure 6.2 Experimental setup	93
Figure 6.3: Marker placement on the shoe as per the model detailed by Weir et al. (231).	94
Figure 6.4 Model used in Visual3D for kinematics analysis	95
Figure 6.5: Centre of Pressure (COP) trace and Statistical Parametric Mapping (SPM) analysis of running gait. X axis represents 0-100% stance phase. Y axis represents COP normalised to foot width and presented the number of radii from the midline where a positive value indicates lateral deviation	

and negative values indicate medial deviations. Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue. 103

Figure 6.6: Centre of Pressure (COP) trace and Statistical Parametric Mapping (SPM) analysis of walking gait. X axis represents 0-100% stance phase. Y axis represents COP normalised to foot width and presented the number of radii from the midline where a positive value indicates lateral deviation and negative values indicate medial deviations. Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue. 104

Figure 6.7: First metatarsophalangeal joint (MPJ) kinematics and Statistical Parametric Mapping (SPM) analysis for running gait. X axis represents 0-100% stance phase. Y axis is first MPJ position (degrees extended). Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue. 105

Figure 6.8 First metatarsophalangeal joint (MPJ) kinematics and Statistical Parametric Mapping (SPM) analysis for walking gait. X axis represents 0-100% stance phase. Y axis is first MPJ position (degrees extended). Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue. 106

Figure 7.1 Typical placement of a lateral wedge by NZ podiatrists 116

List of Tables

Table 3.1: Foot orthoses prescription characteristics	45
Table 3.2: Prescription symmetry	46
Table 3.3: Significant associations between clinical diagnosis and prescription characteristics	47
Table 4.1: Search strategy used for Medline via EBSCO*	55
Table 4.2: Demographic and study design details of the included studies	57
Table 4.3: Wedge design specifications as reported in the included studies	58
Table 4.4: Demographic and study design details of updated literature	67
Table 4.5: Wedge design specifications within updated research	67
Table 4.6: Method used to gather COP data in the existing literature	69
Table 5.1: Demographic data of participants	75
Table 6.1: Insole conditions used in the study	91
Table 6.2: Participant demographic and clinical data	97
Table 6.3: Main effect and pairwise comparison of design factors on COP	101
Table 6.4: Main effect and pairwise comparison of design factors on first MPJ extension	102
Table 7.1: CFO design characteristics associated with common clinical diagnoses	114

Attestation of Authorship

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

Aaron Jackson

Co-authored Works Arising from the Doctoral Thesis

This thesis has been presented in ‘manuscript format’ and includes several studies that have been published. Chapter 3 has been published in the Journal of Foot and Ankle Research, and chapters 4 and 5 have been published in the Journal of the American Podiatric Medical Association. All published chapters are made available under the CC BY-NC-ND 4.0 deed. Finally, Chapter 6 will be submitted for publication in Gait and Posture.

Chapter Number:	3
Manuscript Title:	Custom foot orthoses: a retrospective analysis of 1000 prescriptions from New Zealand podiatrists
Publication Status:	Published
Reference if published:	Jackson A, Sheerin K, Reid D, Ganley T, Lamb B, Carroll M. Custom foot orthoses: a retrospective analysis of 1000 prescriptions from New Zealand podiatrists. J Foot Ankle Res. 2025;18(2). doi:10.1002/jfa2.70044
AUTHOR SURNAME:	CONTRIBUTION
Jackson	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Sheerin	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Reid	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Ganley	Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge.
Lamb	Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge.
Carroll	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.

Chapter Number:	4
Manuscript Title:	Lateral Wedging of the Foot: A Scoping Review
Publication Status:	Published
Reference if published:	Jackson A, Sheerin K, Reid D, Molyneux P, Carroll MR. Lateral wedging of the foot: a scoping review. J Am Podiatr Med Assoc. 2023;113(5). doi:10.7547/21-180
AUTHOR SURNAME:	CONTRIBUTION
Jackson	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Sheerin	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Reid	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Molyneux	Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge.
Carroll	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.

Chapter Number:	5
Manuscript Title:	Beliefs About and Use of Forefoot Lateral Wedging in Podiatric Medical Practice: A Survey of Podiatric Physicians in New Zealand
Publication Status:	Published
Reference if published:	Jackson A, Sheerin K, Reid D, Carroll M. Beliefs about and use of forefoot lateral wedging in podiatric medical practice: a survey of podiatric physicians in New Zealand. J Am Podiatr Med Assoc. 2025;115(1). doi:10.7547/22-022
AUTHOR SURNAME:	CONTRIBUTION
Jackson	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Sheerin	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Reid	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Carroll	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.

Chapter Number:	6
Manuscript Title:	The immediate effect of lateral wedging on first metatarsophalangeal joint kinematics and centre of pressure.
Publication Status:	Unpublished/Ready for submission for Publication
Reference if published:	
AUTHOR SURNAME:	CONTRIBUTION
Jackson	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Sheerin	Conception and design of the project or output; Acquisition of research data where the acquisition has required significant intellectual judgement, planning, design, or input; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Reid	Conception and design of the project or output; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.
Yoon	Contribution of knowledge; Analysis or interpretation of research data.
Wyatt	Contribution of knowledge; Analysis or interpretation of research data.
Carroll	Conception and design of the project or output; Contribution of knowledge; Analysis or interpretation of research data; Drafting significant parts of the research output or critically revising it so as to contribute to its quality and interpretation.

Acknowledgements

I am profoundly grateful to all those who have supported and encouraged me throughout my PhD journey. This transformative process has been immensely enjoyable thanks to the many people who have been involved along the way.

Ehara taku toa i te toa takitahi, engari he toa takitini

My strength is not that of an individual, but that of the collective

I would first like to express my deepest appreciation to Professor Matthew Carroll. Matt, you have been instrumental throughout this journey. With your expertise, eye for detail and relaxed manner, you have provided me all the support I could have possibly asked for at every stage of the process. Thanks to your guidance I am finishing this chapter a much more confident and competent academic than when I began. I couldn't have asked for a better mentor. I look forward to many more collaborative projects and have no doubt that this was just the first. Sincerely, thank you.

I am also incredibly thankful for the guidance and mentorship provided to me by Associate Professor Kelly Sheerin and Professor Duncan Reid. Kelly, you have taken me from a complete beginner to someone confident applying and discussing motion capture technology. You have ensured that every step has felt collegial, friendly and supported. Duncan, I value your experience, expertise, and input; your involvement in my supervision team has always given me confidence and assurance. Thank you to both of you.

I would also like to acknowledge academic colleagues who have contributed to this work and my sanity: Dr Hannah Wyatt, Dr Mike Frecklington, Dr Prue Molyneux, and members of the AUT podiatry team. The support, ribbing, and guidance I have received from this group have always been appreciated.

Finally, I could not have undertaken this journey without the love and support I received at home. Anna, you have been my cheerleader, sounding board and welcome distraction when required. I'm sure you know more about lateral wedges than you ever imagined or desired to. Thank you for everything you have done and continue to do to support me. Toby and Wilbur, you will not understand why dad spent so much time in 'the hut'. You also probably don't realise how much I value the time we spend playing together. You have taught me the importance of being fully present at home and at work. I love you both more than you will ever know.

Ethics Approval

The Auckland University of Technology Ethics Committee granted ethical approval for the research presented in this thesis (AUTEK 21/118 and AUTEK 22/121). I am grateful to all the participants, both podiatrists and members of the public, who generously shared their time and insights, making this research possible.

Artificial Intelligence

I would like to acknowledge that Microsoft Copilot was used to proofread components of this thesis.

Chapter 1: Thesis Overview

1.1 Rationale

A lateral wedge, also referred to as a valgus wedge, is a wedge placed under the foot. A lateral wedge is thicker on the lateral side than the medial side and is generally created by adding material to the lateral side of a foot orthosis or the insole of a shoe. In some cases, a lateral wedge may be incorporated intrinsically into the shell of a foot orthosis or added to the midsole of a shoe (1). Figure 1.1 displays several examples of common lateral wedge positions on an insole.

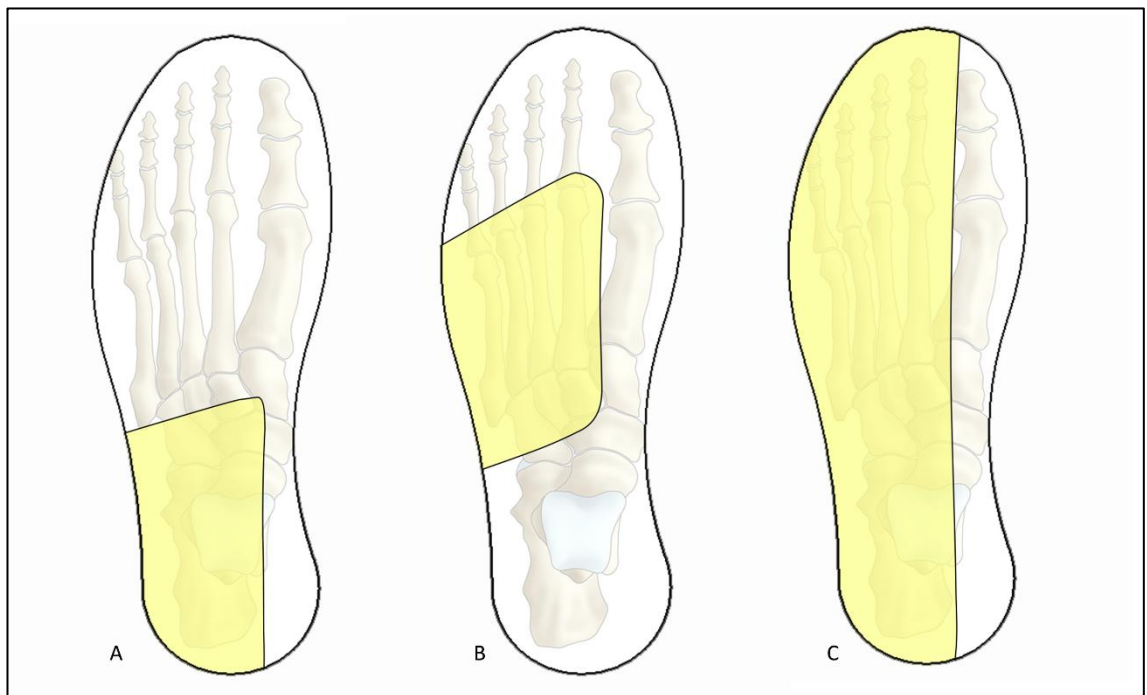


Figure 1.1: An example of lateral wedge shape and placement. They are often described as a rearfoot lateral wedge (A), forefoot lateral wedge (B), and full-length lateral wedge (C). In each example, these would be sloped so that the lateral side is thick and the medial side is thin.

Despite lateral wedging being a commonly used orthotic modification (2), there is limited evidence to guide clinical application. Currently, it is unclear how:

1. Clinicians apply lateral wedges in practice.
2. Lateral wedges affect lower limb and foot function in healthy adults during walking and running.
3. Lower limb function is affected by the location, positioning, and material choice of lateral wedges.

1.1.1 Application in Clinical Practice

It is unclear how clinicians utilise lateral wedges and for what purpose. Over the past 50 years, a range of ideas have been explored regarding the potential clinical outcomes of lateral wedging (3-7). Broadly speaking, these ideas can be categorised into three groups.

1. Historically, lateral wedges were thought to correct abnormal alignment of the foot. This relates to the belief that the foot is in an abnormal position if the rearfoot and forefoot are not aligned (6). Although this concept has faced rigorous challenges in recent years (8, 9), as detailed in Chapter 2, the concept presents one of the earliest theoretical explanations to guide the use of lateral wedges.
2. Lateral wedges have been shown to reduce strain on lower limb tissue, such as the plantar fascia (4) and alter the balance of forces around the ankle (10-12).
3. The largest body of research concerning lateral wedges relates to their purported benefits for people with medial knee osteoarthritis (OA). It is proposed that changing the loading patterns between the tibia and femur may produce beneficial effects in terms of symptom reduction (13, 14).

Despite these theoretical reasons underlying the prescription of a lateral wedge, how they are applied in podiatric practice remains unclear. There is limited evidence exploring the biomechanical objectives that drive podiatrists' clinical decisions when applying lateral wedges, the patient presentations that lead to their prescription, or how they are constructed and placed clinically. It is essential to develop a clear picture of current practice habits to enhance the translation of research into practice. This will allow future research to consider how clinicians utilise lateral wedges and thoroughly explore the validity of these modifications.

1.1.2 Effect of Lateral Wedging on Lower Limb and Foot Function in Walking and Running Gait

There are significant gaps in knowledge about how and when lateral wedges alter foot function in walking and running gait. Research has explored the effect of lateral wedging on a range of kinetic (10, 12, 15-17) and kinematic (18-21) outcomes. However, these studies have predominantly focused on the rearfoot and lacked consideration of wedge design. The lack of evidence on how clinicians use lateral wedges makes it challenging to determine if current research accurately reflects clinical practice. This necessitates a systematic approach to mapping the current evidence and identifying gaps, then prioritising these based on clinical relevance to generate the missing data.

Distinct differences in kinematics and kinetics exist when contrasting running to walking gait, the specifics of which will be covered in Chapter 2 (22). Differences in joint moments, muscle activation, and time under load may result in varying foot responses to a lateral wedge. This implies that a lateral wedge must function under various conditions with differing loads applied, depending on the wearer's activity. A significant gap in current knowledge is understanding how the effects of a lateral wedge differ between walking and running gait. While both gait types have been examined independently, there is no evidence comparing the impact of the same lateral wedge on walking and running. Addressing this gap is crucial for developing a comprehensive understanding of the biomechanical implications of lateral wedge use across different activities.

1.1.3 Effect of location, positioning and material choice

It is currently unclear how clinicians fabricate lateral wedges in practice and how this affects the biomechanical outcomes of lateral wedging as an intervention. Fabrication of lateral wedging refers to the construction process, including decisions such as wedge inclination, material selection and placement of the modification. There is limited evidence to guide optimal placement and material selection, leading to an array of designs being applied clinically.

Research commonly refers to lateral wedges that begin at the rearfoot and extend to the toes (13, 14). In the case of full-length wedges, there is little ambiguity regarding the placement of proximal and distal borders; these are the back and end of the insole. However, with forefoot lateral wedging, additional consideration must be given to where the proximal border is placed. For example, if a forefoot wedge begins close to the rearfoot, it sits underneath different joints and soft tissue structures compared to a wedge that begins more distally.

These changes in position may impact how the foot is affected by the wedge, which could alter the biomechanical outcome of the intervention. Van Gheluwe and Dananberg (3), as well as Kogler et al. (4), identified that lateral wedges placed solely under the forefoot elicit different biomechanical outcomes than those placed either under the rearfoot only or the full length of the foot. Clinicians are expected to have their own method of designing and fabricating lateral wedges, most likely founded on their educational and clinical experience. This necessitates the development of evidence-based guidance for lateral wedge design and placement.

1.2 Aims of the Thesis

This thesis explores two aims. First, NZ podiatrists' practical application of lateral wedges, examining the conditions under which they are utilised, the reasoning behind their use, and the design considerations involved. Second, the thesis aims to assess the impact of lateral wedges on the foot and ankle kinetics and kinematics in healthy individuals.

1.3 Thesis Research Questions

This thesis asks the following research questions:

1. When prescribing custom foot orthoses, what design characteristics are most frequently selected by NZ podiatrists?
2. Does the clinical diagnosis for which an orthotic is being prescribed predict characteristics included in the design?
3. What material properties (thickness, density, and hardness) are utilised in existing research regarding lateral wedges, and where on the insole are these placed?
4. What are the most common materials NZ podiatrists use when making lateral wedges, and where are these placed?
5. How do lateral wedges affect the foot and ankle kinetics and kinematics of healthy individuals?
6. How does lateral wedging placement influence the foot's kinetics and kinematics in walking and running gait?
7. Does the biomechanical effect of lateral wedging differ if placed on an otherwise flat or contoured insole?

1.4 Thesis Outline

This thesis comprises seven chapters and four studies (Figure 1.2) to answer the research questions outlined above. The specific aims of each chapter are detailed below.

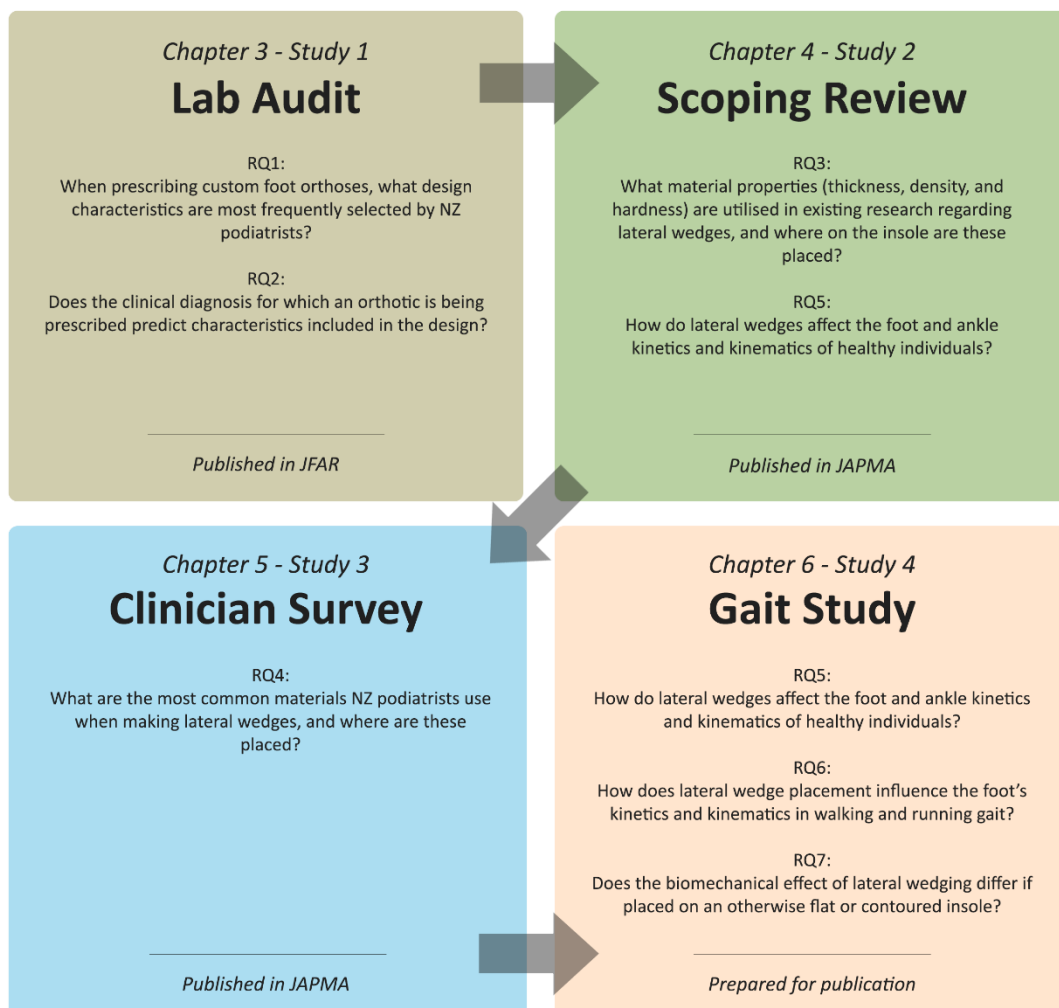


Figure 1.2: Graphical overview of studies included in the thesis

1.4.1 Chapter 1: Thesis Overview

Chapter 1 provides context for the research and outlines its aims, objectives, and proposed benefits.

1.4.2 Chapter 2: Introduction

Chapter 2 introduces the key concepts that will be considered and discussed throughout the thesis. These include foot anatomy, biomechanics, and podiatric models of foot function. It also provides an overview of human gait and the fundamental differences between walking and running gait. Finally, an introduction to foot orthoses will include how these devices are typically applied in a clinical setting and some of the challenges associated with research in the field.

1.4.3 Chapter 3: Custom Foot Orthoses: A Retrospective Analysis of 1000 Prescriptions from New Zealand Podiatrists

This chapter details an audit of NZ's two largest commercial orthotic laboratories. This study demonstrates what characteristics NZ podiatrists most frequently use when designing custom foot orthoses (CFO) and answers research questions 1: When prescribing custom foot orthoses, what design characteristics are most frequently selected by NZ podiatrists? and 2: When prescribing custom foot orthoses, what design characteristics are most frequently selected by NZ podiatrists?

1.4.4 Chapter 4: Lateral Wedging of the Foot: A Scoping Review

Chapter 4 is a scoping review that maps the existing literature regarding the design and influence of lateral foot wedging on healthy individuals. This addresses research questions 3: What material properties (thickness, density, and hardness) are utilised in existing research regarding lateral wedges, and where on the insole are these placed? and 5: How do lateral wedges affect the foot and ankle kinetics and kinematics of healthy individuals?

1.4.5 Chapter 5: Beliefs About and Use of Forefoot Lateral Wedging in Podiatric Medical Practice: A Survey of Podiatric Physicians in New Zealand

Chapter 5 presents a survey of the NZ podiatry profession undertaken in 2022 to gain a deeper understanding of their beliefs regarding the function of lateral wedging and their key objectives and design decisions when applying this modification clinically. This study addresses research question 4: What are the most common materials NZ podiatrists use when making lateral wedges, and where are these placed?

1.4.6 Chapter 6: The Immediate Effect of Lateral Wedging on First Metatarsophalangeal Joint Kinematics and Centre of Pressure

Chapter 6 presents a 3-dimensional gait analysis study designed to investigate the kinematic and centre of pressure (COP) effects of lateral wedging during walking and running gait. This study addresses research question 5: How do lateral wedges affect the foot and ankle kinetics and kinematics of healthy individuals? 6: How does lateral wedging placement influence the foot's kinetics and kinematics in walking and running gait? and 7: Does the biomechanical effect of lateral wedging differ if placed on an otherwise flat or contoured insole?

1.4.7 Chapter 7: Thesis Discussion

Chapter 7 presents and synthesises the key findings of this thesis, the implications of the research, the strengths and weaknesses, and future research directions.

Chapter 2: Introduction

2.1 Anatomy of the Foot

The human foot is a complex structure that is anatomically adapted to provide the strength and stability required for bipedal locomotion (23). Typically, an adult human foot is made up of 26 bones, excluding accessory bones and sesamoids, 33 joints, and numerous soft tissue structures, blood vessels, and nerves (23). Pedal joints have varying articular configurations thought to assist in the biomechanical/locomotive functions of the foot (24). Anatomically, a unique characteristic of human feet is the three arches: the medial longitudinal arch (MLA), lateral longitudinal arch, and transverse arch (Figure 2.1). Both the medial and lateral longitudinal arches are well defined, with general agreement on their anatomical location and structure (25). By contrast, the location of the transverse arch is inconsistently described, with some authors placing it at the level of the metatarsal heads, while others suggest a more proximal location at the midtarsal level (25).

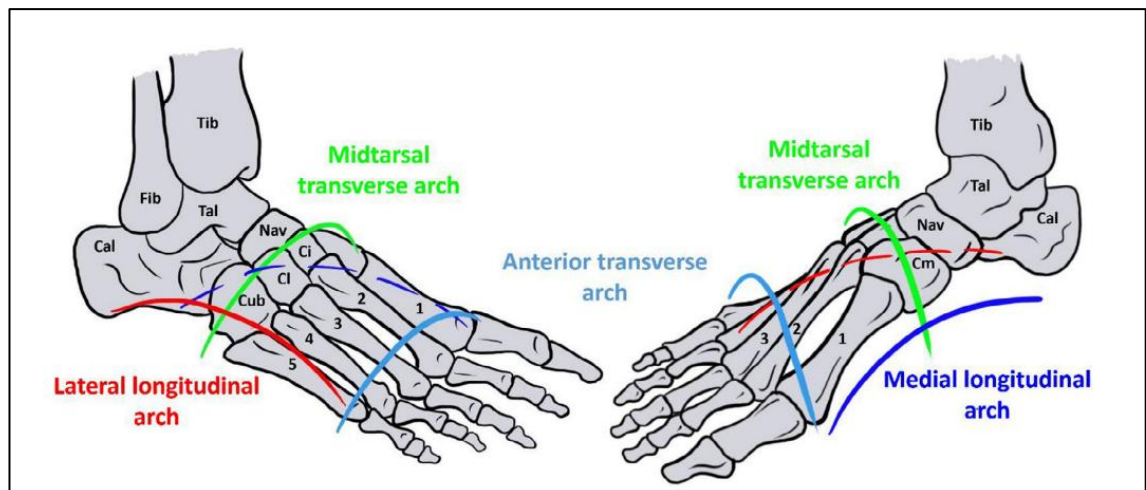


Figure 2.1 Arches illustrated, in this case of the right foot from the lateral view [left image] and medial view [right image]. Adapted from Behling et al. (25).

The role and purpose of the arches, particularly the MLA, remain contentious. While some studies report deleterious effects of low arches (26-29), others do not (25, 30-32). Early work from the beginning of the 20th century frequently focused on 'flat feet', and the detrimental effect that this foot posture could have on a person (33). It was thought that feet with a flat arch

profile were weak and unduly flexible, and they would cause problems that would persist into adulthood if not addressed surgically at a young age (34). The notion that a flatter foot was less functional remained the dominant thought for over a century and is closely associated with many of the podiatric theories discussed below. It was not until relatively recent times that evidence began to suggest this fundamental concept was misguided (25).

2.2 Podiatric Models of Foot Function

Dating back to the early 1900s, several authors have proposed theories or models regarding the 'ideal' foot function (25). The earliest concepts often related to arch function, stiffening of the foot, intrinsic stabilisation, and effective propulsion, and were typically based on clinical observation and theoretical extrapolation. Building on these principles, in 1971, Merton Root and colleagues produced the seminal text 'Biomechanical Examination of the Foot: Volume 1' (7), and subsequent publication 'Normal and Abnormal Function of the Foot', in 1977 (6). Frequently referenced for his significant impact on the profession, Merton Root is considered by many as the 'Father of Podiatric Biomechanics', and his ideas are termed Root theory. Sagittal Plane Facilitation theory, Subtalar Joint (STJ) Axis Location and Rotational Equilibrium theory, and Tissue Stress theory are also well-established models frequently applied to explain how the foot functions (35). As scientific methods have become more advanced, many of the fundamental ideas upon which these theories are based have been rigorously challenged, if not disproven altogether. Root theory assessment for example, is based on static assessments and STJ neutral, yet these static assessments have been shown to demonstrate limited correlation with dynamic function (8). Despite this, it remains common for clinicians to apply aspects of these theories in the assessment and management of lower limb conditions.

Whilst models can be useful in simplifying complex concepts, the profession must apply them as approximations and not as unquestionable truths. Sacks (36, p.23) famously said, "Theory ... can be a great enemy of honest observation and thought ... especially when it forgets it is theory or model and hardens into unstated, perhaps unconscious, dogma or assumption". The ongoing prevalence of these theories in podiatric clinical practice may indicate that the theories have hardened to dogma for some.

2.2.1 Root Theory

The two foundational texts penned by Merton Root and colleagues were by no means the first textbooks on foot biomechanics. However, they provided a clear framework for foot assessment that was widely adopted and later referred to as the Root theory. This theory categorises the foot as an 'abnormal' or 'normal' foot based on five central assessments, suggesting that an abnormal foot will compensate, and these compensations contribute to pain and injury (6). Root, Orien and Weed (6) state that an imbalance or 'abnormality' in any of the body's three movement planes will lead to compensation in the other two planes. Central to the classification of normal or abnormal is the definition of neutral. Root defines STJ neutral as "that position of the joint in which the foot is neither pronated nor supinated" (6, p.26). Root theory implies that the STJ can compensate for many deformities; however, single-plane issues can be identified and addressed by placing the STJ in its neutral position (6). An example of a potential deformity is the position of the forefoot in relation to the rearfoot (6). If the alignment between these two segments is not neutral (therefore referred to as forefoot varus or forefoot valgus, depending on the direction), the foot will compensate by pronating or supinating at the rearfoot (6).

For over 30 years, questions have been raised about the validity of assumptions proposed by the Root theory (8, 9, 37-40). One of the most comprehensive challenges came from Jarvis et al. (8), who studied 100 asymptomatic individuals to understand the relationship between feet defined as abnormal by Root theory and their kinematics during gait. These authors identified at least two 'deformities' in all feet assessed and, despite this, reported no distinct association between these deformities and foot kinematics during gait. The high incidence of 'abnormalities' within an asymptomatic population has also raised questions about the validity of these classifications (8, 41). Despite these challenges, Root theory is still widely used to guide foot assessment and the prescription of foot orthoses (42).

2.2.1.1 Lateral Wedging & the Root Theory

Lateral wedging was originally derived from the Root theory to address 'abnormal' forefoot alignment. Under this theory, the forefoot deformity is measured (Figure 2.2), and subsequently, a wedge of equal size is fabricated and placed under the appropriate part of the foot using a firm or rigid material (1, 6). The concept of balancing the foot was proposed to hold the foot in a position as close to neutral as possible, with the thought that this would facilitate optimal function (6, 35). Root stated that the foot compensates at the STJ or mid-tarsal joint

without maintaining a neutral position. In the case of forefoot valgus, the foot is thought to compensate at the STJ; however, if a lateral forefoot wedge is applied, the foot is balanced, and pathological compensations are avoided (6).

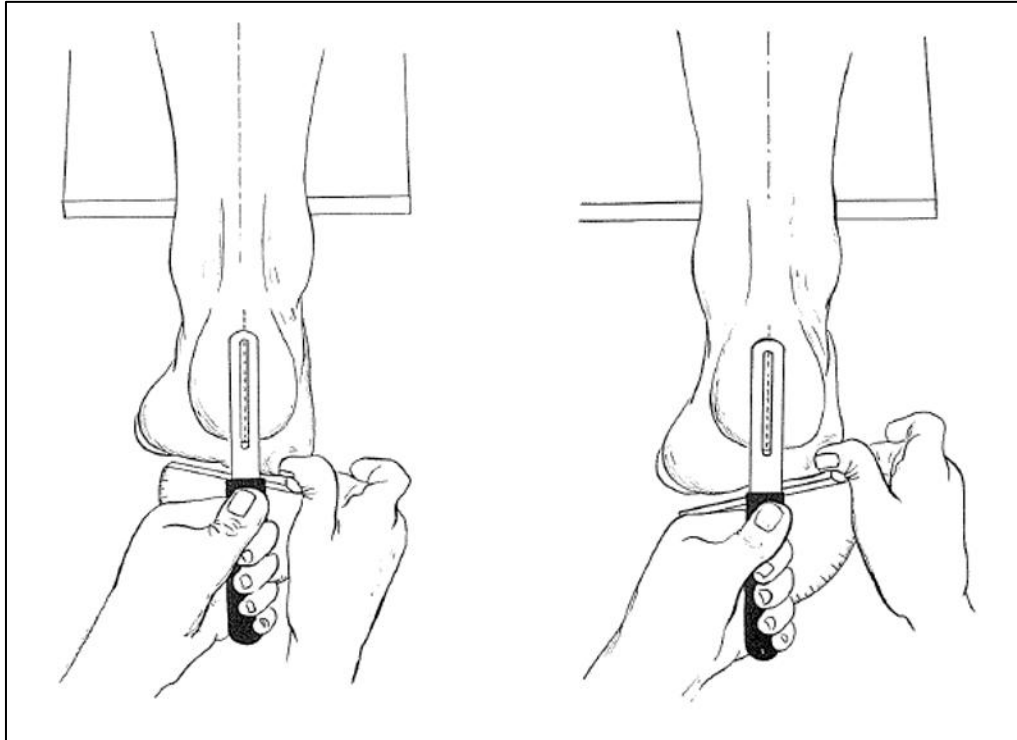


Figure 2.2 Clinical assessment developed by Root et al. (7), identifying forefoot varus (left) and forefoot valgus (right), Both images depict the right foot. Adapted from Root et al. (7).

2.2.2 Sagittal Plane Facilitation Theory

The Sagittal Plane Facilitation theory relates function and dysfunction to blockages in body movements in the sagittal plane (43). This theory focuses on the importance of efficient and unrestricted movement from heel to toe, allowing adequate hip extension and an upright, relaxed gait (43). A key tenet of this work is the idea that “the more perpendicular the longitudinal axis is to the support surface, the more effectively it can transfer weight” (43, p.649). This perpendicular position is thought to be facilitated by adequate ankle joint range of motion (ROM), first metatarsophalangeal joint (MPJ) ROM, and activation of the windlass mechanism (43, 44). Combined with calcaneocuboid joint ‘locking’, this is said to improve the stability of the foot through phases where rapid transference of weight occurs in the sagittal plane (43). Dananberg (43) posits that ‘sagittal plane blockades’ are pathologies that restrict foot movement in the sagittal plane. One example of a sagittal plane blockade is functional hallux limitus, a pathology defined as “the functional inability of the proximal phalanx of the

hallux to extend on the first metatarsal head” (43, p.650). Functional hallux limitus is suggested to be the result of poor timing of movement at the MLA, the midfoot and the first ray (43). A consequence of functional hallux limitus is an ineffective engagement of the windlass mechanism, which reduces sagittal plane movement efficiency (43, 44). However, although the windlass mechanism remains a frequently discussed concept within practice, its accuracy has been questioned (25). Behling et al. (25) highlighted that the original descriptions of the windlass mechanism assumed the plantar aponeurosis to be an inflexible, cable-like tissue, which appears to be oversimplified. Contemporary evidence indicates that the raising and lowering of the MLA is influenced by a complex interaction of soft tissues and muscles in the plantar aspect of the foot (25).

2.2.2.1 *Sagittal Plane Facilitation Theory & Lateral Wedging*

An in vitro study by Kogler et al. (4) suggested that when a wedge is placed under the lateral aspect of the forefoot, the calcaneocuboid joint moves into a closed pack, or locked, position. This position occurs when the joint space is temporarily minimised and stability is increased. Kogler et al. (4) also observed that strain in the plantar fascia was reduced when a wedge was placed under the lateral aspect of the forefoot (4). These authors suggested that this effect is due to a change in the loading pattern in which the locking of the calcaneocuboid joint reduces the use of support mechanisms on the medial aspect of the foot, leading to decreased strain in the plantar fascia (4). At the time of this research, Kogler et al. (4) noted, “It is surprising that, as far as we know, the association between the placement of a wedge under the lateral aspect of the forefoot and the midfoot locking mechanism has not been described in the literature” (4, p.1408). Over twenty-five years later, this gap in the evidence has not been addressed.

2.2.3 *Subtalar Joint Axis Location and Rotational Equilibrium Theory*

Subtalar joint axis location and rotational equilibrium theory (or ‘rotational equilibrium theory’) is based on work by Kirby (45). This work postulates that the movement/function of the foot can be predicted by the net balance of forces acting about the STJ axis. When weight-bearing, a ground reaction force is applied to the plantar surface of the foot. In this theoretical model, where a force is applied laterally to the STJ axis, a pronatory torque is created. Conversely, a ground reaction force acting medially to the STJ axis will create a supinatory torque (Figure 2.3). Therefore, the net result or balance of these forces will dictate the resultant moment and, ultimately, the action of the foot. According to Kirby (45) modification to the line of action of the ground reaction force through options such as footwear or orthoses would change the

function around the STJ axis. Based on this theory, if an orthosis were to apply a force under the foot lateral to the STJ axis, this would increase pronatory torque. On the contrary, if force is applied under the foot in a position that is medial to the axis, the supinatory torque would be increased.

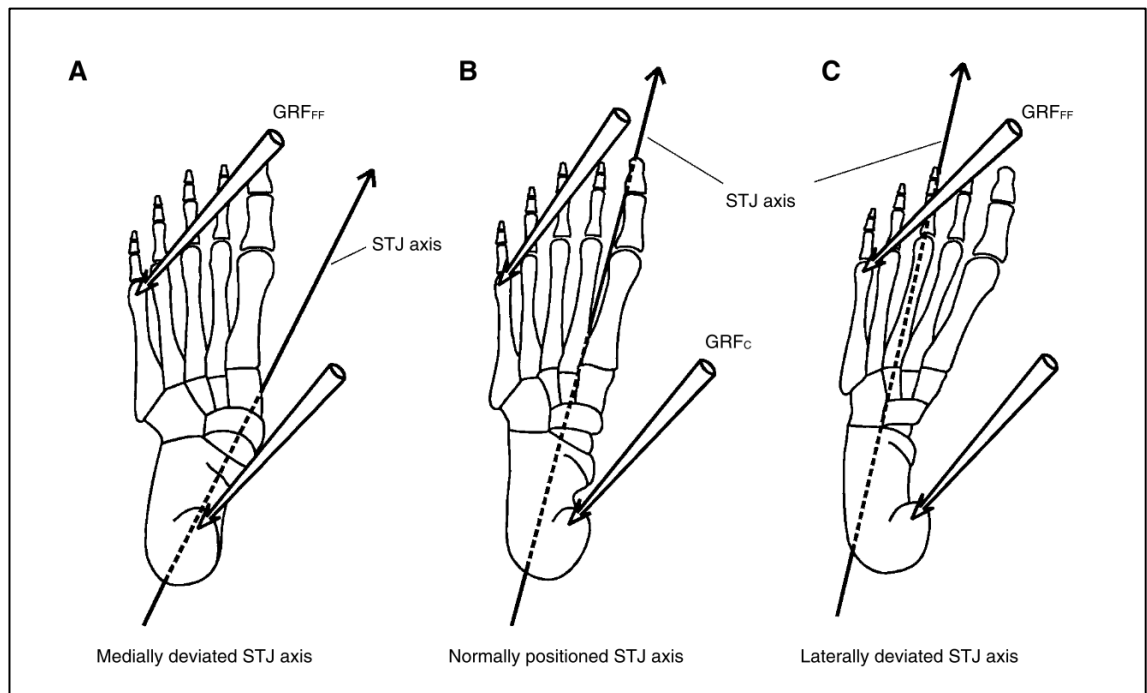


Figure 2.3 Theoretical depiction of how ground reaction force is applied to a foot with a medially deviated STJ axis [A], a neutral axis location [B], or a laterally deviated STJ axis [C]. Adapted from Kirby (46).

2.2.3.1 Lateral Wedges & the Subtalar Joint Axis Location and Rotational Equilibrium Theory

Based on this work, the rationale for using lateral forefoot wedging in the case of rotational equilibrium is clear and direct. A lateral forefoot wedge is said to move the line of the ground reaction force lateral to the STJ axis, which will have a pronatory effect on the foot and shift the COP medially (47). For example, anecdotally, it is thought that tension in the plantar fascia creates a supinatory torque about the STJ; lateral forefoot wedging has been shown to decrease tension in the plantar fascia. Therefore, lateral forefoot wedging likely has some influence over the balance of forces acting around the STJ (4, 47).

2.2.4 Tissue Stress Theory

Early questions and critiques of Root theory were apparent by the late 1980s (38-40, 48). This spurred several researchers to look for alternative ways to explain the anecdotal improvements associated with mechanical interventions such as foot orthoses. The tissue stress theory discussed by McPoil and Hunt (49), was one of these suggestions. Whilst the concept of a threshold for tissue tolerance had been previously discussed by Cornwall (50), it was McPoil and Hunt (49) who proposed this as an alternative lens for podiatrists to view foot and ankle pathology.

The tissue stress theory is more conceptual than those introduced previously and relies upon the clinician identifying inflamed or injured tissues. It is assumed that the tissue pathology is secondary to excessive mechanical load, and if this load is reduced to a tolerable level, the tissue will heal (49). Unlike those theories discussed previously, tissue stress theory does not offer a direct link to what might be considered a suitable intervention. It does, however, note that palpation, tests to stress tissue, range of motion assessment and strength testing would help to determine the underlying pathology. This should then be treated through a holistic management plan, of which footwear and orthoses may form a small part (49).

2.3 Walking and Running Gait

2.3.1 Overview of the Gait Cycle

Human gait is an automatic function for most people and is a common form of locomotion. The principal objective of gait is to move economically from one point to another (51). This occurs through a series of repetitive gait cycles. One cycle is generally considered from foot strike on one side to foot strike again on the same side (Figure 2.4). The cycle begins with a stance phase in which the foot is in contact with the ground, followed by a swing phase when the foot is not in contact with the ground. This complete cycle is also referred to as a stride.

Key points during the gait cycle are identified to allow for the analysis of position, symmetry, and movement. The most frequently discussed timings in the gait cycle include foot strike, midstance and toe-off. Foot strike is the point at which the foot first contacts the ground. This is the completion of the swing phase and the beginning of the stance phase; it also indicates the end of one gait cycle and the beginning of a new cycle (on the reference leg). Midstance is the point at which the body's centre of mass (COM) passes over the top of the foot. Finally, toe-off

is when the foot leaves the ground, signalling the transition from the stance phase to the swing phase of gait.

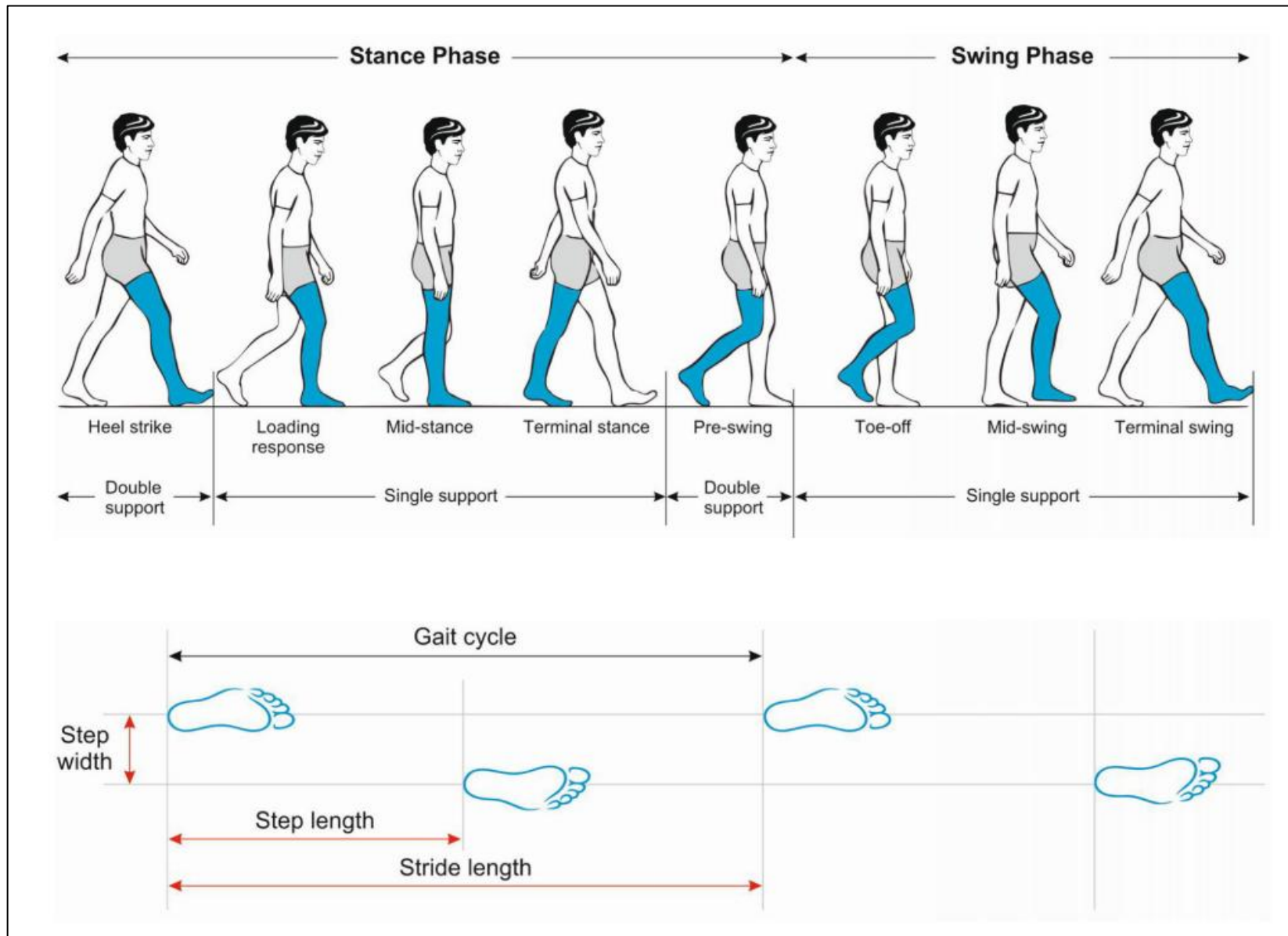


Figure 2.4 Overview of human walking gait cycle. Adapted from Pirker and Katzenschlager (52).

2.3.2 Differences Between Walking and Running Gait

The mechanics and energetics of walking and running gait are distinctly different (22). At slower speeds, it is more economical to walk than run. However, as a person's speed increases, they will reach a point where running becomes more economical. This transition point is different for each person, but on average it is approximately 7 km/h (22).

Walking gait is often likened to an 'inverted pendulum' where the body vaults over a stiff leg. Conversely, running gait could be related to compressing a spring (22, 53). This difference can be seen in the relative height of the COM at midstance; when walking, midstance represents the highest point of the COM, whereas during running, the COM is at its lowest point at midstance (Figure 2.5). The vertical ground reaction force applied to the body is much higher when running compared to walking, typically peaking at midstance. As a result of this, in running gait, the eccentric workload is higher, with lower limb joints exhibiting greater excursion, and intrinsic muscle activity in the foot is also increased (22, 54).

Running gait consists of a 'flight phase' that occurs twice per stride, when no feet are in contact with the ground. By contrast, at least one foot is always in contact with the ground during walking gait, and for short periods, both feet are in contact with the ground.

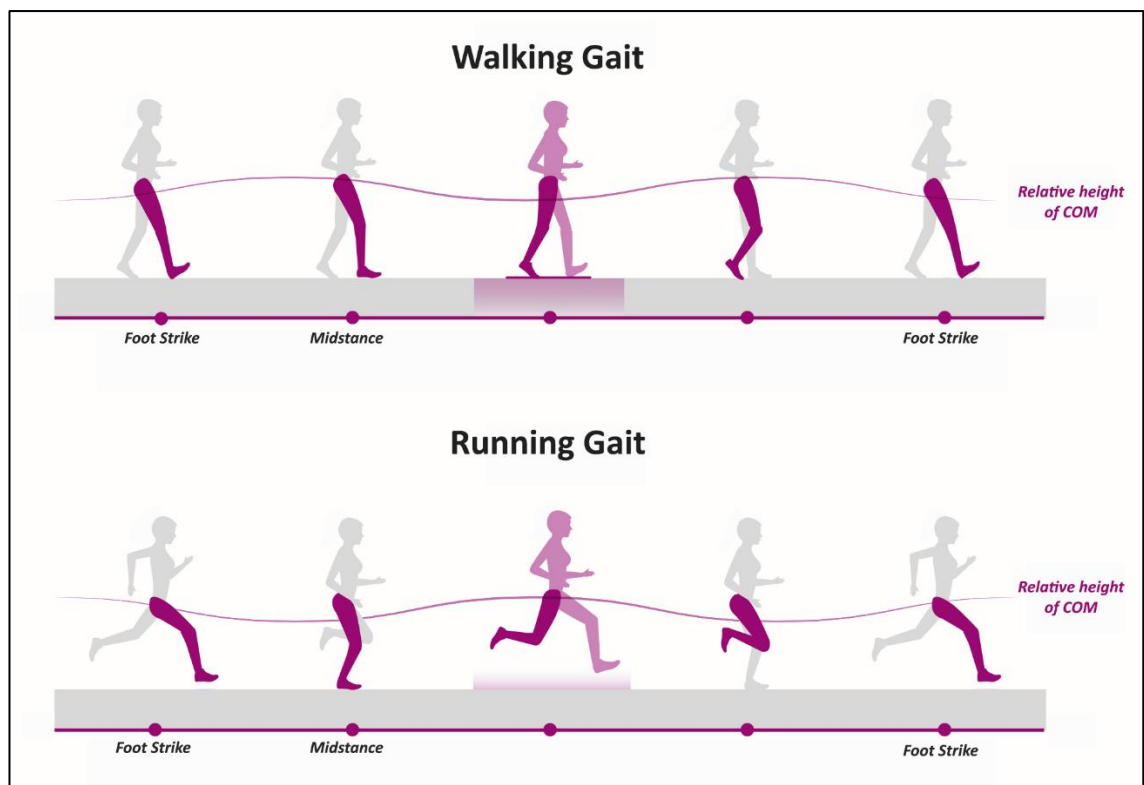


Figure 2.5 Comparison of COM relative height between walking and running gait.

2.3.3 Three-dimensional Gait Analysis

Kinematics describe the movement of the body without considering the internal and external forces that lead to the movement occurring (55, 56). Kinematic variables, often of interest to clinicians and researchers, encompass a spectrum of joints. These range from visually apparent actions, such as knee flexion and extension, to more subtle movements in smaller joints, particularly those in the foot (57). The limitations of clinical practice, including budget, space and time, often necessitate the use of simple two-dimensional gait analysis (58). However, in research, where accuracy is paramount and subtle movements are often the focus, three-dimensional (3D) motion capture is considered the gold standard (59, 60).

Traditionally, motion capture systems have relied upon numerous infrared cameras placed or mounted around a room (53). These cameras emit infrared light, reflecting off markers attached to a participant. Utilising the data collected from each camera and taking into account their relative positions, the system maps the location of each marker in three dimensions (53). Specific software packages model marker coordinate data to create a representation of the individual's form, allowing for the calculation of the kinematic variables of interest.

A key strength of motion capture is that it's highly accurate and reproducible, particularly for the frontal and sagittal plane kinematics at the ankle, knee, and hip (61, 62). Additionally, marker placement is non-invasive and allows for comparison between multiple conditions. However, it is important to note that a range of intrinsic and extrinsic limitations exist, which, if not carefully managed, can reduce the reliability and validity of motion capture data. Notably, variations in marker placement between trials can reduce the accuracy and reliability. Additionally, motion artifacts caused by skin, clothing, or footwear movement can result in markers not accurately representing the intended landmarks (53, 61).

2.3.4 Plantar Pressure and Centre of Pressure

Plantar pressure considers the interaction between the foot and its supporting surface and can provide useful information about loading patterns (63). Plantar pressure has been widely utilised as a means to assess foot posture (64-67); gait (68-71); footwear (72-74); foot orthoses (3, 75-84); and a range of other interventions and pathologies (85-88). There are several ways in which clinicians and researchers may assess plantar pressure. Most commonly, these include assessment of peak pressure areas, total contact area under the foot, and COP (89, 90).

When considering all contact between the foot and its supporting surface, the centroid point may be referred to as the COP (91). This can also be understood as the point where all applied

forces produce no moment (86). Researchers generally capture these data using an in-shoe plantar pressure system or force plates. A comparison of these methods has demonstrated similar outcomes (92). Centre of pressure is generally measured with one of two outcomes in mind, either its posterior-anterior velocity, or its medial-lateral position relative to the bounds of the foot (90). The medial-lateral position of the COP is commonly of interest to podiatrists due to its association with pronation/supination, and its theorised links to tissue strain and foot function (86).

Conceptually, the medial-lateral COP position is particularly relevant to the rotation equilibrium theory. Fuller (86) theorised an association by which the ever-changing location of COP relative to key joint centres (such as STJ) influenced foot function. For example, if a person strikes a raised piece of ground under their medial foot whilst walking, this will create a sudden increase in the supinatory moment about the STJ, potentially leading to a lateral ankle sprain. This influence may be used to explain the function of foot orthoses and specifically lateral wedges, which shift the COP laterally and alter joint moments. Jones et al. (11) examined 15 healthy subjects walking with lateral wedged insoles and reported a lateral shift in COP during early and midstance with the inclusion of the wedges. This lateral COP shift appears to be a common finding within existing research (12, 15, 16, 93, 94).

2.4 Foot Orthoses

Foot orthoses are extrinsic devices that aim to provide external support to the body (95). Specifically, a foot orthosis refers to a device that is placed under the foot, inside the shoe, typically intending to alleviate symptoms, prevent deformity, or enhance performance (96, 97). Foot orthoses are extremely common worldwide. Menz et al. (42) reported in 2017 that by 2021, the global revenue generated from foot orthoses was expected to be US\$ 3.8 billion.

Primitive forms of foot orthoses have been discussed for over two centuries (98). In the mid to late 18th century, authors such as Petrus Camper and Nicolas Andry wrote that modifications to shoes could positively change the position of the foot (99). Designs were becoming more sophisticated by the late 19th century and early 20th century. Whitman and Roberts pioneered rigid metal in-shoe devices aimed at supporting the arch for those diagnosed with 'weak foot' (98, 100). As materials and concepts have continued to develop, arguably one of the most significant advances came when Merton Root began creating functional foot orthoses from thermoplastic moulded to the foot (101). As discussed in 2.2.1, orthoses produced under the guidance of Root theory focus on STJ neutral, a concept that has been questioned recently.

Whilst influenced by past pioneers, modern-day orthoses have benefited from ongoing technological development, particularly regarding material and computer science. Today, foot orthoses come in many forms, ranging from 'over the counter' versions that are frequently sold in retail settings, to bespoke insoles individually designed by a clinician. Most frequently, orthoses utilised by podiatrists can be broadly classified as either prefabricated foot orthoses (PFO) or CFO (102-104). Podiatrists working in NZ have been reported to prescribe an average of 11.9 orthoses per week (102). However, differences have been documented between the prescription habits of podiatrists in NZ and other parts of the world, particularly Australia and the United Kingdom (UK). Chapman et al. (102) revealed that podiatrists working in NZ prescribe more orthoses than both their British (11.1 per week) and Australian (7.1 per week) counterparts. Of note, however, is the imbalance in the number of CFOs vs PFOs prescribed, which sees NZ podiatrists utilising PFO options almost three times as often as CFOs, despite the opposite being true of Australian podiatrists (102, 104).

2.4.1 Aims and Uses of Foot Orthoses

Although foot orthoses are a popular form of intervention, their exact mechanism of action continues to be disputed (105). Suggested mechanisms have included kinematic, kinetic, impact force modification, proprioceptive changes, and placebo (95, 98, 101, 105, 106). For much of the 20th century, foot orthoses were used under the guise of a kinematic model. That being with the intention to change the alignment of the body or restrict pathological motion (95, 96, 101, 106). In 2003 Williams, McClay Davis and Baitch (107) offered some of the first published data that challenged the kinematic approach, suggesting that orthoses confer predominantly kinetic changes. Albeit small, this study published data for each of the 11 participants, which demonstrated significant variation in individual kinematic responses to orthoses, despite standardised orthosis design for all participants (107).

Regarding specific pathology, foot orthoses are frequently used to manage long-term conditions such as diabetes, arthropathies, connective tissue disorders and neurological conditions. They are also widely used in the management of short-term musculoskeletal complaints such as plantar heel, forefoot and ankle pain (102, 108). In some cases, orthoses have been suggested for preventative management, such as reducing the likelihood of falls in older adults (109), or ulceration in individuals who may be at risk of tissue breakdown (102).

2.4.2 Wedging in Orthoses

Often, when designing foot orthoses, a clinician may choose to include a frontal plane wedge, frequently referred to as either a medial or lateral wedge (1, 3, 4, 106, 110). Sometimes termed varus (medial) or valgus (lateral) wedges, these modifications are thicker on either the medial or lateral side (1). Although various justifications have been proposed for their use, typically, research regarding frontal plane wedges has focused on their surmised influence on joint moments (of the foot and lower limb), joint motion, or COP (3, 14, 111). Lateral wedges have been shown to reduce the external knee adduction moment (KAM) (14), increase the external eversion moment about the ankle (11, 112), increase ankle eversion during gait (10, 18), and shift the COP laterally (3). Conversely, rearfoot medial wedges have been reported to reduce first MPJ extension (113) and ankle eversion (114-116), and shift the COP medially (3).

Frontal plane wedges are typically created by either adding sloped material to the orthosis, or in some cases, manipulating the shell shape so that the lateral or medial side is elevated compared to the other (1). Alterations to the frontal plane alignment of orthoses are extremely common and has become a mainstay of podiatric management strategies (42, 117). Aside from their influence on kinematics, kinetics, and COP, medial and lateral wedges have been shown to influence variables such as plantar fascial strain, plantar pressure distribution, lower limb muscle activity and patient-reported symptoms (4, 113, 118, 119). Reeves et al. (119) demonstrated a 19% reduction in peak tibialis posterior muscle activity during early stance when comparing a medial wedge to a flat insole. Medial rearfoot wedges have been shown to improve patient-reported pain and reduce tissue hypoechogenicity associated with plantar fasciopathy (113). In contrast, Kogler et al. (4) reported that medial (full-length) wedges significantly increased in-vitro plantar fascial strain, while lateral (full-length) wedges significantly reduced it.

2.4.3 Lateral Wedging and Medial Knee Osteoarthritis

Lateral wedging has garnered a great deal of attention from both researchers and clinicians owing to its proposed benefits for individuals with medial knee OA. This is perhaps unsurprising considering that approximately 12% of the population aged over 60 are estimated to have knee OA, meaning that a successful conservative intervention would benefit many people (120).

Conceptually, lateral wedges are thought to reduce load across the medial compartment of the knee, which is assessed by proxy as KAM (121, 122). Whilst evidence suggests that foot orthoses containing a lateral wedge reduce KAM by up to 6%, these changes do not correlate with symptoms experienced by patients (121). Previously, Bennell et al. (13) reported that for participants with medial knee OA, neither overall pain nor medial tibial cartilage volume differed

over 12 months when comparing individuals using a lateral wedged insole to those using a flat insole.

2.4.4 Materials Used in the Fabrication of Foot Orthoses

Before the development of modern plastic polyamides, thermoplastics and foam, orthoses were made from metal, wood, leather, and fabric (123). Material properties (hardness and density) have been shown to influence the effect of orthoses, particularly measures of plantar pressure and comfort (123-127). As foot orthoses are designed and fabricated for an individual's specific needs, it is important that the clinician has a robust, evidence-based understanding of the mechanical properties and characteristics of the materials being used (123, 124, 128). However, material properties are often poorly reported, and scales of measurement used vary, resulting in difficulties in applying or comparing these findings and leading clinicians to select based on their own experiences, cost, and availability (129).

Hardness defines the capacity of a material to resist indentation or deformation (129, 130). Materials rated high for hardness may be referred to as stiff or hard, whilst those at the other end of the scale are described as soft (123). Several scales measure a material's hardness; however, these scales are not comparable due to their differences (130). The most common assessment of hardness is using the durometer scale (130). In the case of orthosis materials, Shore A is the specific scale most frequently referenced, and materials tend to be between 35 and 75 Shore A (129). Like many challenges in orthosis research, Gerrard et al. (124) reported that most studies included in their systematic review of the effect of different orthosis materials on plantar pressure failed to provide standardised measures of hardness.

Density refers to the quantity of substance required to occupy a specified volume, or more precisely, the mass per unit volume of a material, denoted as kilograms per cubic centimetre (kg/m^3) (129). Considering materials utilised to construct foot orthoses, it is common to see a broad range from $100\text{kg}/\text{m}^3$ to $400\text{kg}/\text{m}^3$. The density of a material influences its elasticity and resilience, which clinicians may manipulate to influence a particular outcome of clinical interest (131). For example, shock attenuation is more effectively achieved by lower-density materials that can compress and conform to the foot (131).

One of the most common materials used for foot orthoses is ethylene vinyl acetate (EVA) (123, 124, 128, 129, 131). Ethylene vinyl acetate can be used to form the shell of the orthosis or may be applied to create additions and modifications. Utilised within CFOs and PFOs, EVA is easily modified and available in various densities, hardnesses, and thicknesses (128). Aside from EVA,

clinicians frequently use polyurethane foams (particularly Poron), rubber foams (such as Neoprene and Spenco®), and polyethylene foams (for example, Plastazote®) (131). When designing CFOs, stiffer materials may be selected, particularly if the device intends to elicit a mechanical change (1). For a long time, these materials have been polymer-based composites such as polypropylene; however, since the rise of 3D printing, PA11 (a polyamide manufactured from castor oil) has gained popularity (132).

There is currently no evidence relating to the influence of material density or hardness on outcomes associated specifically with lateral wedging. Van Alsenoy et al. (133) showed that orthoses made from a harder material (EVA, 70 Shore A) reduced ankle eversion more than those made from a softer material (thermoplastic polyurethane, 35 Shore A), despite both devices containing the same surface geometry. Softer materials are known to more effectively conform to the foot and increase the plantar contact area, thus assisting with offloading high-pressure regions and improving comfort (124, 126).

Chapter 3: Custom Foot Orthoses: A Retrospective Analysis of 1000 Prescriptions from New Zealand Podiatrists

The article reproduced in this chapter has been published in the Journal of Foot and Ankle Research (JFAR). Made available under [CC BY-NC-ND 4.0](#).

Jackson A, Sheerin K, Reid D, Ganley T, Lamb B, Carroll M. Custom foot orthoses: a retrospective analysis of 1000 prescriptions from New Zealand podiatrists. J Foot Ankle Res. 2025;18(2). doi:10.1002/jfa2.70044

3.1 Preface

The following chapter presents data regarding the prescription patterns of foot orthoses by NZ podiatrists. As outlined in section 2.4.1, there are significant international variations in foot orthoses prescribing habits. However, these behaviours and prescription choices have not been sufficiently explored within NZ podiatrists.

The study presented in this chapter prioritises the association between clinical diagnoses and prescription characteristics and the symmetry between left and right prescriptions. This chapter presents NZ-specific data detailing common modifications and characteristics in orthotic prescriptions, the degree of symmetrical application, and the associated clinical diagnoses.

The findings from this chapter are integral to the thesis, as they provide an understanding of current prescribing habits. Given the thesis's focus, which is to inform and enhance clinical practice, this is the initial step in developing an understanding of current practice.

3.2 Abstract

Background

Podiatrists frequently prescribe foot orthoses to manage a range of musculoskeletal complaints. This study aimed to understand what characteristics were included in the design of custom foot orthoses, how symmetrically these were applied, and whether there was an association between these features and the clinical diagnosis.

Methods

One thousand orthotic prescriptions were obtained from two commercial orthotic labs in New Zealand. Twenty-six prescription characteristics were analysed. Descriptive data detailed the frequency of included characteristics. The symmetry feature was derived according to the characteristics of both feet and analysed considering the number of times the left foot differed from the right foot. Clinical diagnoses were grouped, and for the most common five (plantar heel pain, pes planus, osteoarthritis, posterior tibial tendon, and ankle sprain), associations between the prescription characteristics selected and diagnosis were analysed using cross tabulations and chi-square tests.

Results

The most common prescription characteristics were a Polyamide 11 shell (80%), a shell thickness of 3 mm (54%), Modified Root shell style (61%), and varus cast correction (64%). Additionally, deep heel cups (36%), medial rearfoot (Kirby) skives (36%), and lateral forefoot wedges (22%) were the most prescribed modifications. Fifty-eight percent of prescriptions were identical between the left and right sides. The most common diagnosis was plantar heel pain (11%). Plantar heel pain was associated with the characteristics: plantar fascia groove ($p < 0.001$), forefoot lateral wedge ($p < 0.001$), and heel cushion ($p < 0.001$).

Conclusion

Strong associations between orthotic design characteristics and diagnoses indicate consistency in prescription variables amongst New Zealand podiatrists when prescribing custom foot orthoses. Plantar heel pain and pes planus are the two clinical diagnoses for which podiatrists prescribe the most custom foot orthoses. The high degree of similarity and symmetry in the

prescription of orthoses raises questions regarding the specificity of prescriptions and opens a potential for future research on the topic.

3.3 Background

Foot orthoses are frequently prescribed for the management of various lower limb pathologies. The term 'orthotic' relates to any extrinsic device applied to the body to support, assist or improve movement (134). Foot orthoses specifically relate to insoles placed in a person's shoe. These can be broadly categorised into two groups: custom foot orthoses (CFO) and prefabricated foot orthoses (PFO) (103). Custom foot orthoses are differentiated from PFOs in that they are most often created from an impression, cast or scan of a patient's foot. Generally, these CFOs are constructed by a commercial orthotics laboratory following an orthotic prescription, typically from a podiatrist.

Clinically, a distinguishing feature of CFOs, in contrast with PFOs, is the degree of specificity available in the construction process (42). Clinicians can utilise an extensive range of modifications and design features according to what they deem most beneficial for their patients. Research regarding the influence of foot orthoses has explored the impact of individual orthotic characteristics on a vast range of biomechanical outcomes, such as kinematics and kinetics of the foot and lower limb, plantar pressure distribution and foot centre of pressure movement (115, 135-139). However, only a small number of studies have investigated how clinicians develop their overall orthotic design, and none of these have been in the context of Aotearoa/New Zealand (NZ) (42, 108, 140).

Previous data has shown that NZ podiatrists prescribe significantly fewer CFOs than PFOs, at a rate of nearly three to one (102, 104). Chapman et al. (102) reported that NZ podiatrists prescribe 2.8 CFOs per week, unlike their Australian counterparts, who prescribe an average of 4.4 CFOs per week. In addition, several studies have examined these prescription habits in more detail (2, 42, 102, 108). Menz et al. (42) analysed prescription variables submitted to an Australian CFO lab, categorising CFO prescriptions into three clusters. The authors identified significant differences between clusters concerning design features (orthosis type, cast correction, arch fill, and rearfoot skives). Correlations were identified between the clusters and factors such as practice location, patient gender, and age. Jackson et al. (2) surveyed podiatrists in NZ regarding their orthotic prescription habits, finding that respondents predominantly aimed to reduce tissue stress and frequently prescribed lateral forefoot wedges or metatarsal domes. Podiatrists responding to this survey suggested that Root theory was the least influential

podiatric paradigm when prescribing foot orthoses. However, many also indicated that they primarily utilise lateral wedging to 'balance the foot' (2).

This study aimed to investigate the CFO prescription habits of NZ podiatrists. Specifically, the study examined the following questions. First, what characteristics are frequently included in the orthotic prescription? Second, what is the left-right symmetry of orthoses within a prescription, and which modifications are most commonly applied symmetrically? Finally, what is the relationship between the clinical diagnosis and characteristics included in the orthotic prescription?

3.4 Methods

3.4.1 Selection of Custom Foot Orthoses Prescriptions

One thousand orthotic prescriptions were sourced from two commercial orthotic labs (GO Orthotics Ltd. and FootMed Ltd.) based in NZ (500 from each lab). Each prescription represented one patient, with possible multiple prescriptions in a small number of patients. Both labs supplied 500 consecutive prescriptions from their databases, working backwards from December 2021. The prescriptions supplied for analysis were submitted to the labs between August and December 2021 by approximately 70 different podiatrists. All data supplied was anonymised, and all patient and podiatrist identifiers were removed. Labs provided data using Microsoft Excel (Microsoft Corp, Redmond, Washington) on a templated spreadsheet developed by the first author (AJ).



Characteristic/Variable

Patient bodyweight	Shell material type Shell thickness Shell style Cast correction (shape) Cast correction (degree)	Medial (kirby) skive Heel raise 1st ray cutout Lateral side high Medial side high Heel cup depth Plantar fascia groove	Lateral forefoot wedge Medial forefoot wedge Reverse mortons extension Kinetic wedge Metatarsal dome Plantar metatarsal pad (PMP) Plantar cover Plantar cover with U cutout Heel cushion Arch pad Mortons extension	Topcover material Topcover length
--------------------	--	--	---	--------------------------------------

Figure 3.1 Prescription characteristics extracted from data

3.4.2 Custom Foot Orthoses Characteristics

Figure 3.1 displays the 26 prescription characteristics extracted from orthotic prescriptions for analysis. Data from the 26 prescription characteristics were pooled and analysed as a number (n) and percentage (%) out of 1000 prescriptions. Characteristics were recorded as included if they were present in the prescription for at least one foot (left, right, or both).

3.4.3 Symmetry of Orthosis Prescriptions

The symmetry of prescriptions was analysed through two processes. First, the frequency of each orthotic characteristic being prescribed bilaterally (for both left and right sides) was compared to unilateral prescriptions (for only one side). Second, each prescription was evaluated as a whole to identify any differences between the left and right orthoses across all characteristics. These differences were then quantified, expressing the number and percentage of devices exhibiting varying degrees of asymmetry, from complete symmetry (no differences) to the highest degree of asymmetry observed in the dataset.

3.4.4 Grouping and Analysis of Diagnoses

Clinical diagnoses were classified into five categories: (i) plantar heel pain (PHP), (ii) pes planus, (iii) posterior tibial tendon pain/pathology, (iv) osteoarthritis (OA), (v) ankle sprain. Any diagnosis that referred to plantar fasciitis (including synonymous terms) or heel pain was classified as PHP. Pes planus included references to 'planus feet' or 'flatfeet'. Prescriptions grouped under OA all referenced OA in the foot or ankle. The posterior tibial tendon grouping included any diagnosis describing posterior tibial tendon pain, insufficiency, or dysfunction. Finally, if the diagnosis referred to lateral ankle ligaments or lateral ankle instability, it was grouped under the ankle sprain diagnosis.

3.4.5 Data Analysis

Frequencies and proportions were used to describe the selected characteristics and diagnoses. An exploratory mixed effect model (SAS 9.4 proc glimmix procedure) was employed to analyse the most frequent diagnosis of PHP. This model accounted for potential correlations between the left and right foot by including each characteristic and participant as a random effect. The analysis revealed a high prevalence of symmetrical features among participants. Based on this

finding, a symmetrical feature was derived and incorporated into the subsequent association analysis.

Associations between the five most common clinical diagnoses and CFO characteristics were assessed through cross-tabulations and analysed in SPSS Statistics (version 29, IBM Corp., USA). The associations were evaluated using a chi-square test. To account for the large number of tests (and elevated risk of Type 1 and Type 2 errors), the significance threshold was adjusted using the Holm-Bonferroni method (141).

3.5 Results

3.5.1 Prescription Characteristics

Table 3.1 displays the frequency of prescription characteristics. The most commonly prescribed shell material and shell thickness was Polyamide 11 (PA11) (n=801, 80%) and 3 mm (n=542, 54%), respectively. The majority of prescriptions included a Modified Root shell style (n=614, 61%). Common shell modifications included a deep heel cup (36%) (defined here as greater than 15 mm), 'lateral side high' (20%) and 'medial side high' (17%). Sixty-four percent of prescriptions used a varus cast correction, with approximately one-third of prescriptions (n=356, 36%) included a medial rearfoot Kirby skive, the most common skive depth being 4 mm (n=192, 19%). A Spenco/Neolon top cover was the most frequently prescribed top cover material (n=716, 72%), with 87% (n=870) of orthoses designed with full-length top covers.

Table 3.1: Foot orthoses prescription characteristics

Characteristic	Included, N (%)	Symmetrical, N (%)
Shell Style		
Modified Root	614 (61)	*
Sagittal Plane	134 (13)	*
Medial STJ axis control (GO Orthotics only)	109 (11)	*
Other	142 (14)	*
Cast Correction		
Varus	640 (64)	551 (86)
Valgus	56 (1)	34 (61)
Neutral	286 (29)	203 (71)
Shell Material		
PA11	801 (80)	*
Polypropylene	128 (13)	*
EVA	69 (7)	*
Other	2 (0)	*
Shell Thickness (n=918)		
2.5 mm	60 (7)	*
3.0 mm	542 (59)	*
3.5 mm	150 (16)	*
4.0 mm	85 (9)	*
Other (2.0 mm, 4.5 mm or 5.0 mm)	81 (9)	*
Additions		
Lateral forefoot wedge	218 (22)	175 (80)
Arch pad	122 (12)	94 (77)
Medial forefoot wedge	118 (12)	4 (3)
Heel cushion	116 (12)	105 (91)
Reverse Morton's extension	90 (9)	67 (74)
Metatarsal dome	67 (7)	48 (72)
Plantar cover	59 (6)	48 (81)
Plantar metatarsal pad (PMP)	58 (6)	52 (90)
Modifications		
Lateral side high	196 (20)	149 (76)
1 st Ray cutout	176 (18)	141 (80)
Medial side high	167 (17)	146 (87)
Plantar fascia groove	63 (6)	52 (83)
Heel cup depth		
Deep (> 14 mm)	360 (36)	330 (92)
Shallow (< 11 mm)	68 (7)	63 (93)
Kirby skive		
All depths	356 (36)	257 (72)
2 mm	169 (17)	102 (60)
4 mm	192 (19)	137 (71)
> 4 mm	21 (2)	18 (86)
Topcover material		
Neolon/Spenco	716 (72)	*
Lunasoft	77 (8)	*
Leather	70 (7)	*
Other	129 (13)	*
Topcover length		
Full length	870 (87)	*
Sulcus (3/4)	80 (8)	*
Shell only	38 (4)	*

* indicates 100% symmetry between left and right orthoses

3.5.2 Symmetry of Custom Foot Orthoses Prescriptions

Table 3.1 displays the prescription symmetry characteristics. The most symmetrically applied addition was heel cushions (poron applied on top of the shell, at the heel), which, when included on one side, were also applied to the contralateral side in 91% of cases. The majority of modifications were highly symmetrical with one distinct exception being medial forefoot wedges which were applied unilaterally in 97% of the prescriptions in which they appeared. Table 3.2 presents analysis of the symmetry characteristics. Fifty-eight percent (n=575, 58%) of prescriptions contained no difference between the left and the right side. By comparison, 313 prescriptions (31%) requested one or two differences between the left and right sides, and a further 112 (11%) prescriptions included between 3 and 7 asymmetries.

Table 3.2: Prescription symmetry

Prescription differences between left and right orthoses	Prescriptions, n (%)
No differences	575 (58)
1 difference	202 (20)
2 differences	111 (11)
3 differences	54 (5)
4 differences	31 (3)
5 differences	15 (2)
6 differences	10 (1)
7 differences	2 (0)

Table 3.3: Significant associations between clinical diagnosis and prescription characteristics

Diagnosis	Characteristic	Qualifier	Distribution when the diagnosis is selected (%)	Distribution when not the diagnosis (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction	
Plantar heel pain	Shell style	Mod Root	74 (67.3)	54 (60.7)	14.701	0.002	0.002	Yes	
		Sagittal Plane	23 (20.9)	111 (12.5)					
	Varus cast correction	No	29 (26.4)	331 (37.2)	4.981	0.026	0.002	No	
		Yes	81 (73.6)	559 (62.8)					
	Plantar fascia groove	No	87 (79.1)	850 (95.5)	44.686	< 0.001	0.002	Yes	
		Yes	23 (20.9)	40 (4.5)					
	Forefoot lateral wedge	No	72 (65.5)	710 (79.8)	11.777	< 0.001	0.002	Yes	
		Yes	38 (34.5)	180 (20.2)					
	Heel cushion	No	65 (59.1)	819 (92)	103.537	< 0.001	0.002	Yes	
		Yes	45 (40.9)	71 (8)					
Pes planus	Shell style	Medial STJ axis	27 (33.3)	82 (8.9)	47.183	< 0.001	0.002	Yes	
		No	44 (54.3)	600 (65.3)					
	Kirby skive	Yes	37 (45.7)	319 (34.7)	3.905	0.048	0.003	No	
		No	78 (96.3)	909 (98.9)					
	Kinetic wedge	Yes	3 (3.7)	10 (1.1)	3.969	0.046	0.003	No	
		No	55 (67.9)	823 (89.6)					
	Arch pad	Yes	26 (32.1)	96 (10.4)	32.581	< 0.001	0.002	Yes	
		No	63 (77.8)	819 (89.1)					
	Medial forefoot wedge	Yes	18 (22.2)	100 (10.9)	9.199	0.002	0.002	Yes	
		No	57 (70.4)	776 (84.4)					
	Medial side high	Yes	24 (29.6)	143 (15.6)	10.592	0.001	0.002	Yes	
		No	40 (49.4)	600 (65.3)					
	Deep heel cup	Yes	41 (50.6)	319 (34.7)	8.174	0.004	0.003	No	
		No	44 (54.3)	600 (65.3)					
Posterior tibial	Shell Style	Sagittal plane	10 (16.4)	124 (13.2)	51.127	< 0.001	0.002	Yes	
		Medial STJ axis	23 (37.7)	86 (9.2)					
	Varus cast correction	No	8 (13.1)	352 (37.5)	14.767	< 0.001	0.002	Yes	
		Yes	53 (86.9)	587 (62.5)					
	Arch pad	No	42 (68.9)	836 (89)	21.773	< 0.001	0.002	Yes	
		Yes	19 (31.1)	103 (11)					
	Kirby skive	No	21 (34.4)	623 (66.3)	25.457	< 0.001	0.002	Yes	
		Yes	40 (65.6)	316 (33.7)					
	Medial forefoot wedge	No	45 (73.8)	837 (89.1)	12.996	< 0.001	0.002	Yes	
		Yes	16 (26.2)	102 (10.9)					
	Ankle sprain	Valgus cast correction	No	38 (76)	906 (95.4)	33.707	< 0.001	0.002	Yes
			Yes	12 (24)	44 (4.6)				
Forefoot lateral wedge		No	26 (52)	756 (79.6)	21.193	< 0.001	0.002	Yes	
		Yes	24 (48)	194 (20.4)					
Lateral side high		No	20 (40)	784 (82.5)	54.513	< 0.001	0.002	Yes	
		Yes	30 (60)	166 (17.5)					

Note: if a characteristic was included in the prescription on AT LEAST one foot it is recorded here as 'yes'. If the characteristic was not applied to either left or right foot, it was recorded as a 'no'.

3.5.3 Relationship Between the Clinical Diagnosis and Orthotic Characteristics

Most prescriptions (n=937, 94%) included a clinical diagnosis. A complete list of diagnostic groups and the clinical diagnoses included is available in [Appendix 1](#). The five most common clinical diagnoses that CFOs were prescribed for were PHP (n=110, 11%), pes planus (n=81, 8%), foot/ankle OA (n=61, 6%), posterior tibial tendon pain or dysfunction (n=61, 6%), and ankle sprains (n=50, 5%). Table 3.3 presents the results of the significant associations between diagnosis and orthotic inclusions as part of the association analysis ([Appendix 2](#)). Table 3.3 presents only the significant associations where the prescription characteristic is more often included in the diagnosis. Those which were significant but less often included are not presented in this table. Of the five most common diagnoses, PHP, pes planus, posterior tibial tendon pain, and ankle sprains had several significant associations; however, in this data, OA was not significantly associated with any orthotic design decisions. Prescriptions related to posterior tibial tendon pain were less often (34%) symmetrical. No significant association was observed regarding symmetry for the other four common diagnoses.

3.6 Discussion

This study explored the CFO prescription habits of NZ podiatrists. Custom foot orthoses were frequently prescribed using a 'Modified Root' shell style, 3 mm PA11 (a polyamide bioplastic produced from castor beans and frequently used in additive manufacturing) (142), and a varus cast correction. Lateral forefoot wedges were the most commonly prescribed addition and full-length top covers were prescribed in the majority of orthoses. Approximately 60% of orthoses had no difference in design characteristics between the left and right side. The diagnostic groups PHP, pes planus, posterior tibial tendon pain, and ankle sprains, demonstrated strong statistical associations with orthotic characteristics, indicating that there is some consistency between podiatrists when prescribing orthoses for these conditions.

The finding that lateral foot wedges are the most prescribed addition supports the findings of previous NZ-based foot orthoses research conducted by Jackson et al. (2). Data indicated that the most common shell style selection was the 'Modified Root', which is derived from the work of Merton Root and colleagues, now known as 'Root theory' (6, 7, 143). This finding conflicts with previous NZ research that indicated the Root theory was less likely to influence orthotic design decisions than the Sagittal Plane Facilitation theory. This may be explained firstly, by the longstanding and accepted use of this shell style (104, 144), secondly prescription habits based on the beliefs of podiatrists stemming from their education and clinical experiences, and thirdly

the options provided by the labs on their prescription forms. This phenomenon is unlikely to be exclusive to the labs included in this study, as each lab that offers CFO fabrication requires the submission of a prescription form.

Similar to previous Australian research, the current study found a high level of symmetry among CFO prescriptions (42). Almost 60% of the CFO prescriptions in the current study were designed identically between the left and right feet. Several previous studies, including Mills, Blanch and Vicenzino (145) and Mundermann, Stefanyshyn and Nigg (146) have identified a link between orthotic design and perceived comfort. Thus, we postulate that the high degree of prescription symmetry may be an attempt to optimise comfort for the wearer if it is speculated that highly asymmetrical CFO designs with multiple differences on one limb compared to the other may be uncomfortable. Comfort is known to be both protective and improves tolerance and adherence to foot orthoses (147, 148). While individual preferences exist, arch height, heel cup fit, and cushioning have been shown to improve comfort (148). The two characteristics most often applied symmetrically in the current study were a heel cushion and a plantar metatarsal pad, features frequently considered for improving cushioning and comfort.

The high degree of prescription symmetry raises questions about the specificity of customised devices. With the ability to alter components of a CFO, why are most prescriptions symmetrical and only a small percentage containing one or two differences between body sides? When considering the concept of limb dominance and that humans often do not function in a biomechanically symmetrical way (149). We must consider why we do not see a greater degree of prescription variation in a device designed to be individually customised. The current results may indicate that highly symmetrical CFO prescriptions mean lower limb foot function is not being optimised or that podiatrists rely on the bespoke plantar contour of these devices to elicit an effect. Subsequently, research is required to understand why podiatrists frequently use symmetrical prescriptions and the biomechanical and comfort effects of asymmetrical CFO designs.

The most common clinical diagnosis associated with orthotic prescriptions in the present study was PHP. This finding was not surprising as PHP is reported to affect between 4% to 7% of the adult population and is the most common musculoskeletal condition seen by podiatrists (150-156). Due to the relatively high prevalence of PHP, researchers have paid great attention to the influence of foot orthoses on this condition. Whittaker et al. (156) concluded that foot orthoses reduce patient symptoms in the medium term and should be included in the management of this condition when initial inexpensive options have failed (156, 157). A recent best practice

guide for PHP by Morrissey et al. (150), also included the provision of foot orthoses (either PFO or CFO). Notwithstanding this population's frequent use of foot orthoses, guidance on optimal prescription and design decisions is unavailable. Based on the current study data, plantar fascia groove, forefoot lateral wedge, and heel cushioning are key design features when managing PHP through orthotic therapy.

Data also indicated that pes planus and posterior tibial tendon pathology commonly led to CFO prescription. Whilst pes planus has been the topic of recent controversy regarding its significance (25), this morphological term describes a foot which has reduced arch height, calcaneal eversion in stance, and lateral deviation of the forefoot (158, 159). Pes planus is often suggested to be a contributing factor to posterior tibial tendon pathology, or in fact developed due to insufficiency of the posterior tibial tendon (160). For this reason, it is not surprising that both diagnoses were associated with similar CFO design inclusions. Arch pad and medial forefoot wedge are consistent across both diagnoses. Interestingly, a varus cast correction and Kirby skive were associated with posterior tibial tendon pathology; however, this was not the case for pes planus despite the rearfoot position being previously linked to pes planus (140, 158, 161-163). A Delphi study by Banwell et al. (161), exploring the prescription of orthoses for pes planus also indicated that the Kirby skive is an important consideration, postulating that if the intention of the orthotic is to gain increased control, then a Kirby skive should be included. Medial forefoot wedges have been shown to shift the centre of pressure laterally in individuals with pronated feet, which could be expected to reduce the workload of the posterior tibial tendon (75).

Data indicated that a diagnosis of ankle sprain was significantly associated with a valgus cast correction, forefoot lateral wedges, and 'lateral side high' shell modification. These characteristics are all associated with minimising excessive inversion of the foot and reducing the workload of muscles in the lateral lower leg and ankle region. For patients with a recent ankle sprain or chronic ankle instability, the benefit of an orthotic has been suggested to lie in the impact it may have on neuromuscular function and postural control (164). Lateral wedges encourage rearfoot eversion as well as increasing the external eversion moment, which are both protective for lateral ankle instability and the risk of lateral ankle sprains (136).

The study findings need to be interpreted whilst considering several limitations. Firstly, the data relates to prescriptions from 2021. Given the rapid and continuous advances in orthotic design and fabrication, particularly additive manufacturing, some content may already be outdated. Of note, 13% of prescriptions analysed used a Polypropylene shell, and yet, as of 2024, both labs who supplied this data have discontinued Polypropylene to focus solely on PA11 and EVA.

Secondly, we analysed the clinical diagnosis provided by the referring podiatrist, although it was not recorded if this pathology was unilateral (if so, which side) or bilateral. The diagnoses were also unconfirmed clinical diagnoses, and we do not know the outcomes of the CFOs prescribed. An interesting extension of this work would be to undertake a specific analysis of the common diagnoses, including confirmation of diagnosis and an outcome of the CFO. Finally, diagnoses were grouped manually using descriptions provided on the prescription form. Future work may benefit from more explicit diagnostic categories, which could be added as dropdown boxes to the laboratory's prescription form.

3.7 Conclusion

An analysis of 1000 CFO prescriptions demonstrated NZ podiatrists frequently prescribe orthoses manufactured from 3 mm PA11, using a Modified Root shell style with varus cast correction in the rearfoot. Plantar heel pain and pes planus are the two clinical diagnoses for which podiatrists prescribe the greatest number of CFOs. Strong associations between orthotic design characteristics and diagnoses indicate consistency in prescription variables amongst podiatrists when managing these conditions. The high degree of prescription symmetry raises questions about the specificity of customised devices and opens an avenue for future research.

3.8 Novel Contributions of Chapter 3

This chapter represents the first study to present data detailing how NZ podiatrists prescribe CFO. This allowed for novel insights, including which modifications are most often included in prescriptions and how frequently these are used; how symmetrically certain characteristics are applied; and which modifications are associated with common clinical diagnoses. The findings demonstrated a high frequency of 'Modified Root' shell styles, lateral forefoot wedges, and rearfoot varus cast correction. Unsurprisingly, given its prevalence, PHP was the most common clinical diagnosis; however, the novel contribution within this finding was the association between diagnoses and prescription variables. This study analysed the four most common diagnoses (PHP, pes planus, posterior tibial tendon pain and ankle sprain), each demonstrating several associated prescription characteristics.

Chapter 4: Lateral Wedging of the Foot: A Scoping Review

The article reproduced in this chapter has been published in the Journal of the American Podiatric Medical Association. Made available under [CC BY-NC-ND 4.0](#).

Jackson A, Sheerin K, Reid D, Molyneux P, Carroll MR. Lateral wedging of the foot: a scoping review. *J Am Podiatr Med Assoc.* 2023;113(5). doi:10.7547/21-180

4.1 Preface

The previous chapter concluded that lateral wedges are the most common addition to CFO. Although there are numerous review articles describing the effect of laterally wedged insoles on people with medial knee OA (122, 165-170), the same systematic overview of evidence is not available for their effect on healthy individuals. In the case of medial knee OA, evidence currently appears to suggest that although lateral wedges cause a small reduction in biomechanical measures (165), they generally do not mitigate structural joint changes or reduce patient symptoms (169, 170). Whilst the primary measures of interest for research relating to medial knee OA are kinetic measures of the knee (such as KAM), some studies report additional findings related to foot and ankle biomechanics.

For podiatrists who frequently use lateral wedges in the design of foot orthoses, the lack of clarity concerning how this modification affects foot and ankle kinematics, and kinetics represents a significant gap in the literature. The review presented in this chapter provides a comprehensive overview of the impact of lateral wedges on foot and ankle biomechanics. Additionally, the review identifies gaps in the current evidence based on methodology, biomechanics, or wedge design, and will accordingly inform the design of subsequent chapters in this thesis.

4.2 Abstract

Lateral wedges are a common intervention used to alter biomechanical function of the lower limb. Although there is evidence investigating the use and impact of lateral wedges in individuals with medial knee osteoarthritis, knowledge of how these wedges affect foot function in healthy adults is limited. Therefore, this study intends to investigate how lateral wedging affects foot function in healthy adults and, furthermore, how wedge design influences the outcome. The framework outlined by Arksey and O'Malley was used for this scoping review. To ensure methodological quality and transparent reporting, the study adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews preferred reporting guidelines. A systematic search was conducted using MEDLINE by means of EBSCO; SPORT Discuss; CINAHL; AMED by means of OVID; and Scopus. The initial search yielded 252 articles in total; 21 studies were included in the final analysis. Significant incongruence exists in descriptions of wedge length among the 21 included studies. Thirteen studies (61%) reported using full-length wedges, five studies did not report wedge length, and only one study analyzed more than one wedge length. Ethylene vinyl acetate was the most common material, and reporting of hardness was inconsistent. A broad range of inclination angles were used, with limited explanation for why these values were selected. All but one study that analyzed ankle/subtalar joint frontal plane moments reported an increase in the external eversion moment. The review identified significant variation in the design of wedges used within this body of work and a lack of investigation into the influence of wedge design. Wedge design appears to be a secondary consideration, with very few studies examining multiple material types or wedge placements. All but one of the included studies reported a significant change in ankle/subtalar joint moments with lateral wedging. Unfortunately, further generalization was not possible because of the inconsistency and variation.

4.3 Background

Lateral wedging, also known as valgus wedging, is a common conservative intervention health professionals use as part of a management plan to alter biomechanical function in the lower limb. Lateral wedges are created by sloping material so that the lateral side is thicker than the medial side, and the gradient between is a uniform incline. These are typically added to an orthotic, an otherwise flat insole, or on occasion to the midsole of a shoe (1), the goal being to change foot function. The biomechanical effect of lateral wedges has been most frequently

examined by research investigating medial knee osteoarthritis (OA) (171, 172) and lateral ankle instability (16, 173).

The seminal work from Merton Root and his colleagues, now known as Root theory, appears to have been the first theoretical explanation for lateral wedging (6). According to Root, Orien and Weed (6) abnormal alignment of the foot, such as forefoot valgus, leads to compensatory movement, which may increase an individual's risk of injury. In this example, Root theory would recommend clinicians build a wedge of equal size to the structural imbalance, and place this under the lateral aspect of the forefoot, thus 'balancing' the rearfoot and forefoot and preventing compensation. Recently, however, the concept of subtalar joint (STJ) neutral, a central theme discussed in Root theory, has been challenged (8, 9). Many of the assessments within Root theory, including forefoot position, are static and non-weightbearing. Concerns have been raised over the value of these assessments when it comes to designing orthoses to be used dynamically (8, 9). Given the paucity of other theoretical explanations, this leads us to question the conceptual reasons behind lateral wedge prescription in practice.

When designing and fabricating underfoot interventions such as orthoses or insole modifications, the materials used may impact kinematic and kinetic outcomes (124, 174-176). In healthy populations, material selection has been shown to affect plantar pressure, modify contact areas, and elicit mechanical change (124, 174, 176). Therefore, the appropriate choice of materials appears to be important for clinical interventions to be effective. In a recent systematic review on the effect of different orthotic materials on plantar pressures, Gerrard et al. (124) suggested that it is essential that all clinicians who prescribe orthoses have access to robust evidence examining the effects of material selection.

Despite evidence reporting the effects of lateral wedging in individuals with medial knee OA, a systematic understanding of how lateral wedging affects foot function in healthy adults is lacking. Therefore, this study aimed to investigate how lateral wedging affects foot function in healthy adults and how wedge design influences the outcome. Based on a precursory assessment of the evidence, a scoping review has been deemed the most suitable way to answer this question.

4.4 Methods

The framework outlined by Arksey and O'Malley (177) was used for this scoping review: step 1, identify the research question; step 2, identify relevant studies; step 3, study selection; step 4, charting the data; and step 5, collating, summarising and reporting the results. To ensure

methodological quality and transparent reporting, the PRISMA-ScR preferred reporting guidelines were adhered to (see [Appendix 3](#)) (178). A comprehensive search was formulated and conducted by the first author (AJ) in April 2021 using Medline via EBSCO; SPORT Discuss; CINAHL; AMED via OVID; and Scopus. Search strategy terms displayed in Table 4.1 were truncated using wildcard symbols to broaden the search and modified for each database. No limitation was placed on the date of publication.

*Table 4.1: Search strategy used for Medline via EBSCO**

#	Search
1	(MH "foot orthoses")
2	(MH "orthotic devices+") AND (foot OR feet OR ankle)
3	"lateral wedge" OR "valgus forefoot" OR "lateral forefoot" OR "valgus rearfoot" OR "valgus hindfoot" OR "lateral rearfoot post"
4	(orthotic* OR orthoses OR insole) n8 (foot OR feet OR ankle)
5	(MH "shoes")
6	#3 AND #5
7	#1 OR #2 OR #4
8	#3 AND #7
9	#6 OR #8

*Strategy was modified for other databases

At the outset of this review process, inclusion and exclusion criteria were developed to ensure that only relevant studies were included for analysis. As the search was developing and familiarity with the literature increased, these criteria were reviewed and refined. Studies were included if they measured kinetic or kinematic variables in the foot when a lateral wedge is placed under the foot, assessed the effect of lateral wedging during walking or running gait, used live human participants, and were published in English. Studies were excluded if they had no extractable data for 'healthy' participants, involved participants under 18 years of age, measured the effect of lateral wedging during a sporting activity other than walking or running, or measured the effect of lateral wedging following a surgical intervention.

Reference management software EndNote version X9.3.1 (Clarivate Analytics, PA, USA) was used for the screening and analysis phase of this review. Before screening, all duplicates were removed by EndNote, checked, and manually completed by the principal investigator (AJ). Two reviewers (AJ and PM) independently screened all titles and abstracts against eligibility criteria. In cases of non-consensus, a third author's opinion was planned for consultation (MC); however, this was not required. Reference lists of retrieved articles were searched for further potentially relevant studies. Following title and abstract screening, two reviewers (AJ and PM) screened the full text of all remaining studies to compile a final list of included articles.

Data were charted using Microsoft Excel (Microsoft Corporation, WA, USA) to extract key information from the selected studies. This information included author(s), year of publication, study location, study population, wedge specifications (material, length, placement, and inclination), footwear conditions, gait type, outcome measures and relevant findings. In some cases, studies compared a pathological group to a healthy population. Only the relevant findings relating to the healthy group were extracted and charted in these instances.

4.5 Results

4.5.1 Selection and Characteristics of Studies

A total of 252 articles were retrieved for abstract review, with 21 studies satisfying the inclusion criteria included for final analysis (Figure 4.1). Characteristics of these 21 included studies are presented in Table 4.2. Participant numbers ranged from eight to fifty, with a mean age of 30.2 years old. The date range of publications spanned from 2003 to 2021, with 12 (57%) of the included studies published since 2013. Four of the included studies used a comparator group with two comparing healthy individuals to a pathological cohort (medial knee OA and lateral ankle instability) (15, 16), while the other two compared groups with differing foot postures (10, 179).

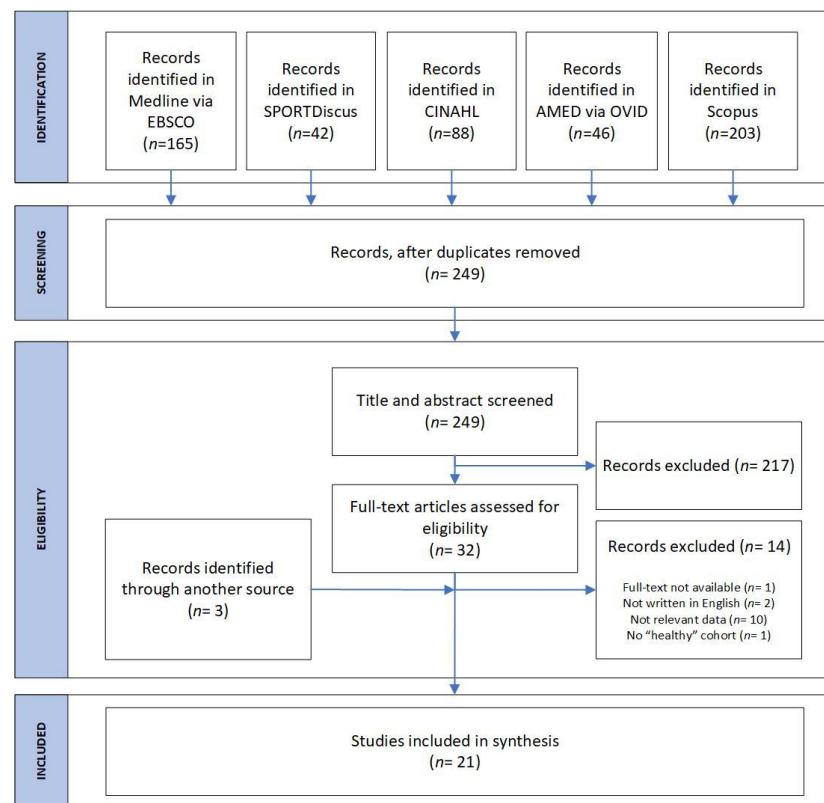


Figure 4.1: Flowchart diagram of literature search, screening, and selection

Table 4.2: Demographic and study design details of the included studies

Reference	Number of participants	Comparison group	Mean age \pm SD	Female percent	Gait type	Gait speed	Overground or treadmill
Kakahana et al. (16)	50	25 with lateral ankle instability 25 healthy controls	20.8 \pm 1.3 20.7 \pm 1.2	0 0	Walking	Self-selected	Overground
Kakahana et al. (15)	26	13 with OA 13 healthy controls	63.3 \pm 5.6 64.6 \pm 2.3	100 100	Walking	Prescribed cadence (95 steps/min)	Overground
Telfer et al. (179)	24	12 with a pronated foot type, 12 controls with neutral feet	29.9 \pm 8.7	50	Walking	Self-selected	Overground
Tse, Ryan and Hunt (10)	40	FPI = Pronated FPI = Neutral FPI = Supinated	26.0 \pm 2.2 26.7 \pm 2.8 27.3 \pm 4.1	56.3 60 55.6	Walking	Self-selected	Overground
Fukuchi et al. (12)	21	No	25 \pm 3.4	0	Walking	Prescribed 1.4ms ⁻¹	Overground
Kluge et al. (18)	22	No	22.3 \pm 2.2	86.3	Walking	Prescribed, 0.9ms ⁻¹ , 1.1ms ⁻¹ , 1.3ms ⁻¹ and 1.5ms ⁻¹	Treadmill
Lewinson et al. (93)	9	No	25.2 \pm 2.9	0	Running	Prescribed, 4.0ms ⁻¹	Overground
Lilley, Stiles and Dixon (180)	20	No	50.7 \pm 5.6	100	Running	Prescribed, 3.5ms ⁻¹	Overground
Møller Mølgaard and Kersting (181)	13	No	37.4 \pm NR	30.8	Walking	Self-selected	Overground
Kakahana et al. (182)	10	No	25.2 \pm NR	50	Walking	Self-selected	Overground
Forghany et al. (183)	8	No	33.5 \pm 4.5	0	Walking	Self-selected	Overground
Sawada et al. (94)	15	No	22.5 \pm 1.5	NR	Walking	Self-selected	Overground
Nester, van der Linden and Bowker (19)	15	No	NR	46.6	Walking	Prescribed 108 steps/min	Overground
Weinhandl et al. (20)	10	No	21.8 \pm 0.6	100	Walking	Self-selected (mean 1.37ms ⁻¹)	Overground
Pascual Huerta et al. (17)	12	No	24.6 \pm 5.6	50	Walking	Self-selected	Overground
Van Gheluwe and Dananberg (3)	23	No	22.2 \pm 7.6	NR	Walking	Prescribed, 1.1ms ⁻¹	Treadmill
Erhart et al. (112)	15	No	28.6 \pm 4	60	Walking	Self-selected and prescribed slow, normal and fast speeds (speeds not reported)	Overground
Jin, Xu and Wang (184)	30	No	21 \pm 1	0	Walking	Self-selected	Overground
Jones et al. (11)	15	No	30.5 \pm 8.6	33.3	Walking	Self-selected	Overground
Rabiei, Eslami and Movaghar (21)	50	No	21 \pm 2.2	100	Running	Not specified	Overground
Schmalz et al. (185)	10	No	34 \pm 9	40	Walking	Self-selected	Overground

SD, standard deviation; OA, Osteoarthritis; ms⁻¹, metres per second; FPI, Foot posture index; NR, not reported

Table 4.3: Wedge design specifications as reported in the included studies

Reference	Wedge placement	Wedge length	Wedge material (hardness or density)	Wedge inclination (angle°)	Footwear
Kakahana et al. (16)	Insole	Full length	EVA (elasticity of 100 to 300kg/mm ²)	Lateral (6°)	No footwear - Insoles taped to the foot
Kakahana et al. (15)	Insole	Full length	EVA (elasticity of 100 to 300kg/mm ²)	Lateral (6°)	No footwear - Insoles taped to the foot
Telfer et al. (179)	Insole	To the sulcus	Poly lactide (NR)	Lateral (6°, 4°, 2°) Medial (10°, 8°, 6°, 4°, 2°)	Standardised – Details NR
Tse, Ryan and Hunt (10)	Insole	To the sulcus	EVA (55, shore A)	Lateral (5°)	Standardised sandal. Brand and model NR
Fukuchi et al. (12)	Insole	Full length	EVA (NR)	Lateral (6°, 9°) Medial (6°, 9°)	Standardised - Adidas, Aegis 2.0
Kluge et al. (18)	Insole	Full length	Cork (NR)	Lateral (4mm approx. 4-5°)	Standardised - Brooks, Green Silence
Lewinson et al. (93)	Insole	Full length	EVA (NR)	Lateral (3°, 6°, 9°) Medial (3°, 6°, 9°)	Standardised - Adidas, Aegis 2.0
Lilley, Stiles and Dixon (180)	Insole	Full length	NR (NR)	Lateral (4°, 5°) Medial (4°)	Standardised - Somnio, Pacemaker 2.0
Møller Mølgaard and Kersting (181)	Insole	Full length	NR (NR)	Lateral (10°)	Standardised - Three models. Klaveness new rehab; Klaveness Thor; Nike, Air Pegasus
Kakahana et al. (182)	Insole	Full length	EVA (elasticity of 100 to 300kg/mm ²)	Lateral (6°)	No footwear - Insoles taped to the foot
Forghany et al. (183)	Insole	To the sulcus	Vinyl acetate ("high density")	Lateral (5°, 8.5°)	Standardised - New Balance, model NR
Sawada et al. (94)	Insole	To the sulcus	High intensity silicon (40, shore A)	Lateral (7mm approx. 5.3°)	No footwear - Insoles strapped to the foot
Nester, van der Linden and Bowker (19)	Insole	To the sulcus	EVA ("high density")	Lateral 10° Medial 10°	Participants own footwear
Weinhandl et al. (20)	Insole	Rearfoot	EVA (55, shore A)	Lateral (9°)	Participants own footwear
Pascual Huerta et al. (17)	Insole	Rearfoot	EVA (65, Shore)	Lateral 7° Medial 7°	NR
Van Gheluwe and Dananberg (3)	Insole	Forefoot and/or rearfoot	EVA (70, shore A)	RF Lateral (4°) RF Medial (4°, 8°) FF Lateral (3°) FF Medial (3°, 6°)	Standardised. Asics, Stratus
Erhart et al. (112)	Midsole	NR	NR (Asker C, Durometer 55)	Lateral (4°, 8°)	Standardised - Nike, model NR
Jin, Xu and Wang (184)	Insole	NR	Polyvinyl acetate (NR)	Lateral (6°)	No footwear - Insoles placed in socks
Jones et al. (11)	Insole	NR	NR (70, shore A)	Lateral (5°)	Standardised - ECCO, Zen
Rabiei, Eslami and Movaghar (21)	Insole	NR	Wood (NR)	Lateral (6°)	Standardised - Nike, model NR
Schmalz et al. (185)	Midsole	NR	NR (NR)	Lateral (14°)	Standardised – Details NR

EVA, Ethylene vinyl acetate; °, degrees; kg/mm², kilogram per square millimetre; RF, rearfoot; FF, forefoot; NR, not reported

4.5.2 Wedge Length

Specifications of the wedges used in the included studies are detailed in Table 4.3. Eight studies reported using full-length wedges (12, 15, 16, 18, 93, 180-182). Of these, two included pictures which show the wedge extending to the end of the insole (18, 180). Also included in the eight studies to report full-length wedging were the Fukuchi et al. (12) and Lewinson et al. (93) studies, both of whom included a picture showing wedges that extend just beyond the metatarsal heads to the sulcus of the foot. The remaining four studies in this group did not include a picture of their wedge length, and as such, it was not possible to determine the accuracy of the description 'full length' (15, 16, 181, 182).

Five studies added wedges extending to the sulcus of the foot (10, 19, 94, 179, 183). Only the Sawada et al. (94) article included a picture to provide visual clarification. The language used to describe length in this group was varied, with descriptions including: "3/4 length" (179), "graded to zero at the base of the 5th metatarsal" (183), "the lateral wedge insoles had base heights equal to that of the fifth metatarsal" (94), "just distal to the fifth metatarsal" (19), and "sulcus length" (10).

Studies by Weinhandl et al. (20) and Pascual Huerta et al. (17) were the only two to report looking solely at rearfoot wedges; however, neither included a picture to confirm placement. The Pascual Huerta et al. (17) study stated that the wedges used in their study were 14 cm long and 4 cm wide. The Van Gheluwe and Dananberg (3) study was the only one to examine differences in wedge length. This was also the only study to use a forefoot wedge, which in this case was compared to a rearfoot wedge. This study utilised six different insole conditions with a range of rearfoot (4° valgus to 8° varus) and forefoot (3° valgus to 6° varus) wedges, all compared to a neutral, flat insole. No details regarding wedge length were reported by five studies (11, 21, 112, 184, 185). Despite not reporting length in the manuscript, three of these five provided pictures which showed wedges running the complete length of the insole or midsole (11, 112, 185).

4.5.3 Wedge Material Type and Hardness

There was a range of materials used, with the most common being ethylene vinyl acetate (EVA), used in ten studies (47%) (3, 10, 12, 15-17, 19, 20, 93, 182). Other materials used included vinyl acetate (183), polyvinyl acetate (184), high-intensity silicon (94), polylactide (179), cork (18) and wood (21).

The reporting of the material used and the hardness of the material was inconsistent. Five studies did not define the type of wedge material used (11, 112, 180, 181, 185) and nine studies provided no detail relating to material hardness of the wedge (12, 18, 21, 93, 179-181, 184, 185). Within those studies that did report durometer (measure of hardness), there was variation in terminology. Scales used included Shore A (15, 16, 182), which ranged from 40-70, Asker C (112) and kilogram per square millimeter (kg/mm^2) (15, 16, 182). Two studies recorded the wedges simply as “high density” (19, 183). Three studies provided no detail of both the material type and hardness or density (180, 181, 185).

4.5.4 Inclination Angle

A broad range of wedge inclination angles were used, ranging from 3° to 14° laterally wedged ($6.21 \pm 2.51^\circ$). The highest inclination angle of 14° , was in the study by Schmalz et al. (185), where the wedge was placed in the midsole of a shoe. Considering only insole-based wedges, the range of inclinations was 3° to 10° laterally wedged ($5.94 \pm 2.10^\circ$). All studies in this review included an unwedged control condition as a comparison. Six studies compared more than one lateral wedge inclination (12, 93, 112, 179, 180, 183). Telfer et al. (179) included the most comprehensive range of inclinations, extending from 6° laterally wedged through to 10° medially wedged, in 2° increments. Although laterally wedged conditions were of interest to the current review, it was noted that seven studies additionally examined medial wedges (3, 12, 17, 19, 93, 179, 180).

Nineteen studies (90%) reported inclination in degrees, while two studies reported the lateral border's millimeter thickness. Kluge et al. (18) reported that using a 4 mm wedge is approximately equivalent to a $4\text{-}5^\circ$ angle. Sawada et al. (94) used a 7 mm wedge and noted that this was comparable to a 5.3° inclination angle. Neither study provided any further details about wedge dimensions such as foot or insole width.

4.5.5 Kinematic, Centre of Pressure and Kinetic Effect

Kinematic and kinetic outcomes of the included studies are displayed in [Appendix 4](#). Interpretation of kinematic and kinetic variables was difficult due to the varied terminology used across all studies.

4.5.6 Subtalar Joint Moments

Eleven studies reported on ankle/STJ inversion, eversion, or valgus moments (10-12, 15-17, 93, 112, 182, 184, 185). A mix of internal and external joint moments was measured, which, when not clearly outlined, can make results appear contradictory. The external moment includes the impact of ground reaction force and inertial forces, and therefore is equal and opposite to the internal joint moment (186). There are consistent findings amongst all but one study in this review that lateral wedging affects the ankle/STJ by increasing the external eversion moment (10, 11, 112), increasing the internal inversion moment (12, 93), increasing the external valgus moment (15, 16, 182, 185) or decreasing the internal valgus moment (184). These findings were all statistically significant ($p < 0.05$). The only study included that did not reach statistical significance was the work of Pascual Huerta et al. (17). In this study, the authors compared a 7° lateral rearfoot wedge to a flat condition and found no significant change in net ankle inversion moments.

4.5.7 Ankle Abduction Moment

The Møller Mølgaard and Kersting (181) study was the only study to report ankle abduction moment. It examined the effect of lateral wedging when used within three different types of footwear; the authors found a reduction in ankle abduction moment, across all conditions. Schmalz et al. (185) used the steepest wedge included in this review (14°) and did not find statistically significant results. The insignificant findings are supported by Nester, van der Linden and Bowker (19) who analyzed a 10° insole based lateral wedge, and also found no change with respect to rearfoot plantarflexion moments.

4.5.8 Centre of Pressure

Eight studies investigated the centre of pressure (COP) (3, 11, 12, 15, 16, 18, 93, 94). Seven of these studies (87.5%) reported that COP was shifted laterally with the use of lateral wedges (3, 11, 12, 15, 16, 93, 94). Lewinson et al. (93) noted that this effect was more pronounced as wedge inclination increased from 3° to 6° and 9°. Of these eight studies, the Kluge et al. (18) study was the only one to report insignificant findings.

4.5.9 Kinematics

Kinematics were reported by twelve of the included studies (10, 11, 15, 16, 18-21, 94, 180, 182, 183). Nine studies discussed ankle/STJ eversion, and of these, five reported a significant increase (10, 11, 18, 94, 183). Of these 12 studies, only Forghany et al. (183) multiple inclinations, reporting a significantly larger effect from their steeper wedge (8.5°) when compared to their less steep (5°) condition. Kluge et al. (18) who assessed a range of walking speeds, reported that speed did influence the effect of lateral wedging on ankle eversion, with wedges making less of a difference at faster speeds. Three studies in this review showed insignificant effects of lateral wedging on ankle eversion. All three compared a single inclination to the control condition (15, 16, 20). Two studies reported rearfoot eversion, both finding that lateral wedging did not induce a significant change (94, 180). Rabiei, Eslami and Movaghar (21) analyzed foot pronation (measured as the combined movement in all three planes, frontal, sagittal, and transverse) in healthy female runners using a rearfoot lateral wedge. These findings indicated a significant increase in foot pronation, from 5% to 35% of stance phase ($p = 0.012$), compared to the control condition.

4.6 Discussion

Understanding of the effect exerted by lateral wedging on foot function is limited by inconsistency in reporting of lateral wedge length, minimal reporting of specific wedge properties, a wide variation in wedge inclination angles, and an array of kinematic and kinetic outcome variables used to assess their biomechanical effect. Interpretation of the kinematic and kinetic effects of wedging is also restricted by the use of inconsistent terminology.

This review found that full length or sulcus length wedges were used in the majority of included studies, rather than rearfoot or forefoot wedges. This finding may be explained by a dominance of literature that has investigated the relationship between lateral foot wedging and knee adduction moments (KAM) (14, 165-167, 171, 187, 188). Sixteen studies (80%) included in this review analyzed frontal plane knee kinetics such as KAM. With the preposition that full length wedges are considered optimal to reduce KAM, it is perhaps not surprising that this was the dominant design (189, 190). Hinman et al. (190) were the first authors to identify the impact of wedge length on KAM. Prior to this work, researchers interchangeably used rearfoot or full-length wedges. Initially Hinman et al. (190), and more recently Fischer et al. (189), have compared multiple lengths of lateral wedge, both studies concluding that longer wedges (full length or sulcus length) elicited a larger reduction in KAM than a rearfoot only wedge. Despite

some evidence surrounding alteration to KAM with full-length lateral wedges, there is currently very limited research indicating the optimal length and positioning of lateral wedging to elicit functional changes in foot biomechanics.

Kogler et al. (4) have shown that lateral wedging under the forefoot is the most effective way to reduce strain in the plantar aponeurosis. This in vitro study analyzed nine different test conditions, considering all possible combinations of rearfoot lateral, forefoot lateral, rearfoot medial, and forefoot medial wedging. Results of this work showed that all configurations with a forefoot lateral wedge induced a greater reduction in plantar aponeurosis strain than those without, including a lateral rearfoot wedge. As the only study included in the current review to compare different wedge placements, Van Gheluwe and Dananberg (3) found that whilst rearfoot wedging had no impact on forefoot plantar pressures, lateral forefoot wedging shifted the COP laterally at the forefoot.

There has been limited investigation into the impact of material properties on lateral wedge function. Many different materials were used in the included studies, the hardness of these were inconsistently reported. A recent systematic review has indicated that some orthotic materials can reduce peak plantar pressures during walking (124). Whilst Gerrard et al. (124) reported no clear consensus about the effects of EVA hardness on force modulation; they did note that softer EVA deforms to the shape of the foot, thus increasing the contact area with the foot and impacting plantar pressures. Soft materials are generally thought to be more suitable when cushioning or shock attenuation is the desired outcome, whereas firm materials are better suited to the redistribution of load (176). Gerrard et al. (124) suggested that the ability of a material to conform to the foot is a key factor in altering plantar pressures. Extrapolating Gerrard et al. (124) results to lateral wedging, it may be postulated that lateral wedges constructed from firmer material may induce a larger change in joint moments and kinematics due to their reduced compressibility. Conversely, wedges manufactured from softer materials may exert less kinetic and kinematic effect. Unfortunately, although a range of materials were used across all included studies, no studies analysed more than one material type or hardness, therefore limiting our ability to draw conclusions or make recommendations relating to optimal material selection.

Lateral wedge inclination angles applied in the included studies ranged from 3° to 14°, with no clear rationale provided as to why particular inclination angles were selected. Previous research has highlighted comfort as a factor that may determine the degree of wedge inclination to be investigated (191-193). Research has postulated that a threshold of between 5° and 7° exists, and beyond this level, comfort is adversely affected (191-193). Erhart et al. (112) and Lewinson et al. (93) were the only studies in the current review to discuss comfort, both reporting higher

discomfort levels with their largest inclination angles (8° and 9°, respectively). All studies in the current review that compared multiple inclination angles reported that an increase in angulation is associated with a larger biomechanical change (12, 93, 112, 179, 180, 183). Beyond the concept of comfort, the basis for using a particular material thickness or inclination angle appears to be guided by a limited evidence base. Considering this finding, we postulate that inclination angles used in lateral wedge research may relate to the properties of commercially available prefabricated materials (such as thickness), rather than what is known to be optimal. That is, the convenience of available material may be a significant factor determining inclination angle selection.

Despite significant variance in wedge design and the mix of internal and external joint moments reported, lateral wedges were reported to modify frontal plane moments of the ankle/STJ, in all but one included study. Although analysed by a smaller number of studies, several reported that lateral wedging shifts the COP laterally, thereby lengthening the ankle joint eversion moment arm. This lateralisation of COP and change in moment arm appear to explain the increase in external eversion (valgus) moment at the ankle/STJ. With respect to other outcome measures analysed by the included studies, there is insufficient consistency to make generalisations or draw conclusions.

This review found major problems with inconsistent terminology in describing lateral wedges. Based on definitions drawn from included studies, we propose the following standard definitions for lateral wedge length and placement that can be adopted in future work.

- **Full-length lateral wedge:** Beginning from the most proximal aspect of the insole, under the calcaneus. Extending to the distal end of the insole, past the apex of the digits.
- **Sulcus length (3/4 length) lateral wedge:** Beginning from the most proximal aspect of the insole, under the calcaneus. Extending to the sulcus of the foot, just distal to the metatarsal heads and tapering to nothing at this point.
- **Rearfoot lateral wedge:** Beginning from the most proximal aspect of the insole, under the calcaneus. Extending to the styloid process full thickness and tapering to nothing prior to the midshaft of the 5th metatarsal.
- **Forefoot lateral wedge:** Beginning from the calcaneo-cuboid joint and extending distally to the sulcus of the foot.

4.7 Conclusion

The review has identified significant variation in the design of wedges used within this body of work and a lack of investigation into the influence of wedge design. Wedge design appears to be a secondary consideration, with very few studies examining multiple material types or wedge placements. All but one of the included studies reported a significant change in ankle/STJ joint moments with lateral wedging. Unfortunately, further generalisation was not possible due to the inconsistency and variation. This dearth of evidence suggests that clinicians using lateral wedges in practice are most likely fabricating these without robust evidence-based guidance. We recommend that future work seek to provide clinicians with an understanding of how best to manufacture and prescribe lateral wedges to achieve their desired clinical and biomechanical outcomes.

4.8 Novel Contributions of Chapter 4

This study (Chapter 4) is the first review focused on how lateral wedges influence the kinematics and kinetics of the foot. The review synthesised the existing knowledge to highlight several key pieces of information used to inform the design of subsequent chapters and may influence clinical practice. Firstly, there appears to be very little evidence comparing the influence of design characteristics such as wedge geometry (inclination and position) on biomechanical outcomes. This is despite the research presenting a large array of inclination angles, the mean of which is approximately 6°. Methodological disparity between studies means it is impossible to compare findings and retrospectively consider the influence of wedge geometry. This study has proposed standardised terminology for wedge length and placement, which future researchers may adopt to improve the transparency of wedge design within this body of work.

4.9 Update Since Publication

As data collection for this scoping review was completed in April 2021, providing an updated literature review published since that date was considered pertinent.

4.9.1 Results (published between May 2021 and August 2024)

A search was conducted on the 12th of August 2024 using the same strategies outlined in the scoping review, with a date restriction to identify all relevant studies published since May 2021. After screening, an additional six studies (75, 77, 79, 194-196) were identified that met the inclusion/exclusion criteria (Figure 4.2). Demographic and methodological details of the studies are presented in Table 4.4.

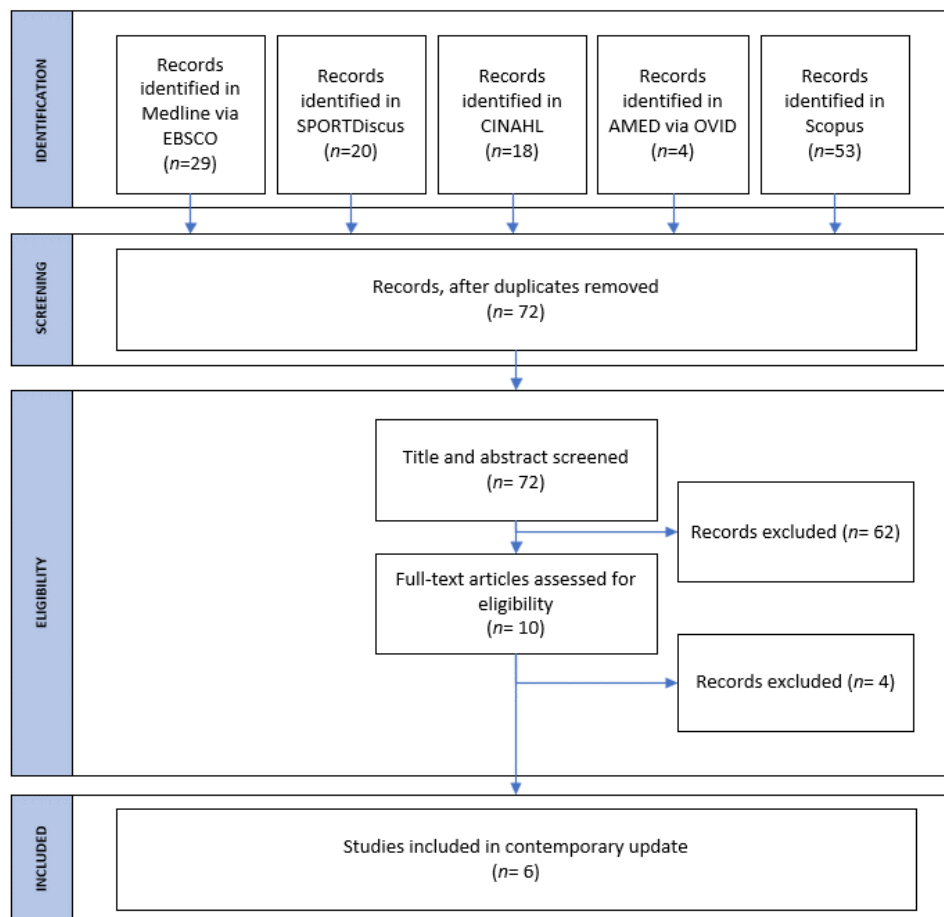


Figure 4.2 Flowchart diagram of search and screening of relevant literature published since May 2021

Table 4.4: Demographic and study design details of updated literature

Reference	Number of participants	Mean age \pm SD	Female percent	Gait type	Gait speed	Overground or treadmill
Du et al (196)	16	26.0 \pm 2.0	63	Walking	Self-selected	Overground
Cho et al (195)	35	23.4 \pm 2.0	0	Walking	Self-selected	Overground
Cai et al (194)	18	21.7 \pm 1.4	0	Running	Self-selected	Overground
Ma et al (79)	8	23.5 \pm 2.7	50	Running	Self-selected	Overground
Tse et al (77)	40	26.6 \pm 2.9	43	Walking	Self-selected	Overground
Zhang et al (75)	15	25.0 \pm 5.0	47	Running	Self-selected	Overground

SD, standard deviation

4.9.2 Wedge design

Wedge specifications applied within the recent six publications are presented in Table 4.5. Half of the studies identified did not effectively report material properties (75, 79, 194), and one did not report wedge inclination (79). These studies demonstrate increased attention to forefoot wedges, with half of the studies examining what they reported to be forefoot wedges (75, 79, 194). No studies compared various wedge design characteristics, aside from inclination which was examined by three out of six (75, 194, 196). Across the studies that reported inclination, the average was 5°, slightly lower than the 6° average reported in the scoping review.

Table 4.5: Wedge design specifications within updated research

Reference	Wedge placement	Wedge length	Wedge material (hardness or density)	Wedge inclination (angle[°])	Footwear
Du et al (196)	Insole	Rearfoot	EVA (30, Shore A)	Lateral (5 and 7)	Standardised - sandals
Cho et al (195)	Insole	Full-length	NR	Lateral (6)	Standardised
Cai et al (194)	Insole	Forefoot	NR	Lateral and medial (NR – 9mm and 6mm)	Standardised – neutral shoe
Ma et al (79)	Insole	Forefoot	EVA (35, Shore A)	Lateral (NR – individualised)	Standardised
Tse et al (77)	Insole	Sulcus length	Variable stiffness. EVA (55, Shore A), EVA (20, Shore A), and plastazote (70, Shore A)	Lateral (5)	Standardised - sandals
Zhang et al (75)	Insole	Forefoot	4mm PU (NR)	Lateral and medial (5 and 2.5)	Standardised – neutral shoe

NR, not reported; °, degrees; EVA, ethylene vinyl acetate; PU, polyurethane

4.9.3 Key findings

Plantar pressure and COP variables were reported by five (75, 77, 79, 195, 196) out of the six studies, making these the most common variables of interest in recent publications. Du et al.

(196) gathered and reported kinematic measures, including the first MPJ function in the sagittal plane. This appears to be the first available data regarding the influence of lateral wedging on first MPJ kinematics. Finally, Cai et al. (194) examined several kinematic and kinetic variables at the ankle, including range of motion, peak angular velocity, peak moment, maximum power and positive work.

Data presented by Zhang, Lam and Vanwanseele (75) and Du et al. (196) support the findings of the scoping review, concluding that laterally wedged insoles shift the COP laterally. Additionally, recent studies suggest that lateral wedging reduces the pressure time integral at the medial and central forefoot (79) and increases this variable at the lateral forefoot (75).

In the case of kinematics, Du et al. (196) reported a decrease in peak ankle dorsiflexion when comparing laterally wedged insoles to the control (barefoot) condition. This study compared barefoot to three experimental conditions: flat insoles, a 7 mm lateral wedge (suggested to be 5°), and a 10 mm lateral wedge (7°). Interestingly the reduction in peak ankle dorsiflexion was most pronounced for the flat insole (3.79° reduction) and whilst the wedged insoles reduced this variable (by 2.19° for 7 mm wedge and 1.66° for the 10 mm wedge) compared to the barefoot condition, the inclination of the wedge was inversely associated with the reduction in ankle dorsiflexion. Of relevance to this thesis was the data presented by Du et al. (196) concerning first MPJ range of motion with the use of lateral wedges. As the first study to explore this variable, the authors concluded that lateral wedging had no statistically significant influence on first MPJ sagittal plane kinematics during walking gait.

4.9.4 Impact of update

Research published since the original data were collected for the scoping review largely supports the findings presented in this chapter. Concerns raised by the scoping review regarding the limited evaluation of wedge design persist in recent work, particularly as material properties were often insufficiently reported. Centre of pressure was a focus of recent publications, with the findings supporting the notion that lateral wedging lateralises foot pressure, compared to a flat condition. In line with the scoping review, these additional studies did not present conclusive kinematic changes, including, for the first time, first MPJ kinematics.

4.9.5 Additional analysis of COP methodology

Considering studies identified by the scoping review, and the recent update, 10 examined COP (3, 11, 12, 15, 16, 18, 75, 93, 94, 196). Although not analysed earlier in the chapter, an important

consideration to contextualise these findings is the method of assessment used to gather the data. As discussed in Chapter 3, there are two fundamentally different ways that COP data can be acquired, which may influence interpretation.

Table 4.6: Method used to gather COP data in the existing literature

Reference	COP Assessment Methodology
Kakahana et al. (16)	Force plate
Sawada et al. (94)	Force plate
Van Gheluwe and Dananberg (3)	In-shoe plantar pressure
Zhang, Lam and Vanwanseele (75)	Plantar pressure plate
Kakahana et al. (15)	Force plate
Fukuchi et al. (12)	Force plate
Kluge et al. (18)	Force plate
Lewinson et al. (93)	Force plate
Jones et al. (11)	Force plate
Du et al. (196)	Force plate

Chapter 5: Beliefs About and Use of Forefoot Lateral Wedging in Podiatric Medical Practice: A Survey of Podiatric Physicians in New Zealand

The article reproduced in this chapter has been published in the Journal of the American Podiatric Medical Association. Made available under [CC BY-NC-ND 4.0](#).

Jackson A, Sheerin K, Reid D, Carroll M. Beliefs about and use of forefoot lateral wedging in podiatric medical practice: a survey of podiatric physicians in New Zealand. *J Am Podiatr Med Assoc.* 2025;115(1). doi:10.7547/22-022

5.1 Preface

The previous chapter highlighted gaps in the evidence regarding lateral wedge design. Notably, much of the existing research has focused solely on full-length lateral wedges, with no studies exploring the potential differences in outcomes when used for walking versus running. Despite these gaps, lateral wedging is a common modification to foot orthoses.

This chapter examines NZ podiatrists' beliefs about, and use of lateral wedging. Data derived from the chapter will answer research question 4: What are the most common materials NZ podiatrists use when making lateral wedges, and where are these placed? This knowledge is crucial as the clinical relevance of the evidence gaps identified in Chapter 4 depends on how lateral wedging is applied in practice. Currently, the clinical use of lateral wedging is not well understood. If forefoot lateral wedges are commonly used, and clinicians provide the same wedge for both running and walking, the significance of these gaps is heightened, necessitating further investigation. A key focus of this thesis is to inform clinical practice, which would not be possible without an understanding of current practice habits, as will be provided in this chapter. The methodological development of Chapter 6 will be strongly influenced by the findings of this chapter, particularly the wedge design utilised by NZ clinicians and their clinical intentions behind the use of lateral wedges.

5.2 Abstract

Background

There is currently limited evidence exploring the beliefs and application of forefoot lateral wedges in clinical practice by podiatrists. The study aimed to understand the rationale and beliefs that guided the use of forefoot lateral wedges amongst podiatrists.

Methods

A cross-sectional study of New Zealand podiatrists was conducted between 31 May 2021 and 26 July 2021. Data were collected anonymously using a web-based survey platform. The 30-item survey included questions to elicit participant characteristics, why and when podiatrists used orthotic modifications, what biomechanical assumptions influenced clinical decision making, and how podiatrists fabricated and placed forefoot lateral wedging.

Results

Sixty-five podiatrists completed the survey. Most respondents were trained in New Zealand (91%), had over 10 years' experience (70%), and worked with a mixed case load (60%). Seventy-seven percent (77%) prescribed 0 to 10 pairs of foot orthoses per week, with forefoot lateral wedges used in 44% of prescriptions. Forefoot lateral wedges were likely to be used in the treatment of peroneal tendon injuries (70%) and chronic ankle instability (64%). The most common belief being that forefoot lateral wedges increase first metatarsophalangeal joint range of motion (86%). Forefoot lateral wedges were regularly manufactured from 3 mm (74%), medium density ethylene vinyl acetate (91%) and positioned from the calcaneo-cuboid joint (53%) to the sulcus (77%).

Conclusion

NZ podiatrists frequently use forefoot lateral wedges. These were generally manufactured from 3 mm, medium density ethylene vinyl acetate and positioned from the calcaneo-cuboid joint to the sulcus. The most common rationales for use were to increase first metatarsophalangeal joint range of motion, shift the centre of pressure medially, and balance the foot. A discordance was found between the theories of foot function upon which clinicians placed the greatest importance, and the biomechanical outcomes that they thought were being achieved. Survey data also highlighted inconsistency in the nomenclature used to describe forefoot lateral wedge thickness and inclination.

5.3 Background

Lateral wedging can be defined as material sloped uniformly to be thicker on the lateral side than the medial side (136). These wedges are commonly added to foot orthoses or shoe insoles in the management of several lower limb pathologies (16, 165). Lateral wedging has most commonly been investigated in relation to the biomechanical effects on knee motion, particularly for their role in the management of medial knee osteoarthritis (OA) (171). In cohorts with medial knee OA, lateral wedging of the foot has been shown to reduce knee adduction moments (197); however, this effect is the subject of controversy (198). With respect to lower limb kinetics and kinematics, lateral wedges have been shown to shift the centre of pressure (COP) laterally (3, 11, 12) and increase the external eversion moment of the sub-talar joint (10, 112). However, current evidence investigating the effect is limited to a small number of observational studies (136). Beyond this, limited evidence exists to inform how lateral wedges impact other variables such as kinematics of the forefoot or how the wedge design may affect function.

There are numerous theories of foot function proposed, many of which provide a theoretical link which can be extrapolated to suggest how lateral wedging may function. Four of the most widely cited theories are Root theory (6, 7), Sagittal Plane Facilitation theory (43), Rotational Equilibrium theory (45), and Tissue Stress theory (49). Root theory has the most direct link to explain the functional effects of lateral forefoot wedging (6). Focusing on the concept of sub-talar joint neutral, and the importance of maintaining this position, Root theory highlights several abnormalities which are said to result in compensation, and movement away from the desired position. Under this theory, forefoot position is important. Any deviation forefoot position is measured and subsequently balanced by a wedge of equal size placed under the appropriate part of the foot using a firm or rigid material (1, 6). Sagittal Plane Facilitation theory also focuses on kinematics and proposes that lateral stability of the foot, along with two other key functions, are essential for efficient transfer of weight (43). Evidence linking the Sagittal Plane Facilitation theory and lateral wedging proposes that lateral wedging increases lateral stability of the foot (4). Rotational Equilibrium theory attempts to predict function of the foot according to the balance of forces around the sub-talar joint (45), something that lateral wedging is known to influence (136). Finally, the tissue stress theory is not proposed to be a model to understand foot function, but rather, how to manage it. According to this theory the focus is to reduce stress on injured tissues to allow healing (49). There is currently no evidence linking lateral wedging to alteration in tissue stress in the foot (136).

The extent to which lateral wedges affect foot function is linked to the steepness (gradient) of the slope (199), a variable which is interchangeably described in millimetres (thickness) or degrees (inclination angle) of the wedge. For example, Telfer et al. (179) demonstrated that for every two degrees increase in lateral wedge inclination, peak plantar pressure in the lateral forefoot decreased by 0.74%. Considering the impact of this variable on biomechanical outcomes, clear terminology is important to ensure suitable design decisions are made. Also of relevance to design is the length of wedge. There is limited evidence linking the length of a lateral wedge to a biomechanical influence upon foot function (3, 4). For the purposes of this study, the following terminology will be applied. A full-length wedge will be defined as a wedge beginning from the most proximal aspect of the insole, under the calcaneus, extending to the distal end of the insole, past the apex of the digits. A FLW will be defined as a wedge beginning from the calcaneo-cuboid joint and extending distally to the sulcus of the foot.

Previous research has highlighted a difference in prescription habits of New Zealand (NZ) podiatrists compared to those from Australia and the United Kingdom (102). Chapman et al. (102) reported that NZ podiatrists prescribe prefabricated orthoses more frequently than both their Australian and British colleagues and conversely prescribe fewer custom orthoses than both groups. However, this data did not explore the application of full-length lateral wedges or FLWs amongst NZ podiatrists.

There is currently limited evidence exploring the beliefs that guide the clinical application of FLWs amongst podiatrists practicing in NZ. Therefore, the current study aimed to understand the rationale of NZ podiatrists when they use FLWs, and to identify how lateral wedges are manufactured and applied in clinical practice. Data from this survey will be influential in the design of future lab-based work, analysing the kinetic and kinematic effects of FLWs, as they are used in practice by NZ podiatrists.

5.4 Methods

This study used a cross-sectional observational design. Data collection was completed anonymously using the web-based survey platform (Qualtrics XM, Provo, UT). The survey was implemented over an eight-week period between May 31st, 2021, and July 26th, 2021. Participants were recruited via an email invitation sent to all members of the national society (Podiatry New Zealand), and a research flyer distributed to delegates at the 2021 New Zealand Podiatry Conference. Incentivisation to participate was offered in the form of five prizes of \$100 shopping vouchers. Consent to participate was obtained through participants completing a yes

or no question on the landing page of the survey. If participants did not consent to participate, they were unable to proceed to the survey questions. Ethical approval was obtained from the Auckland University of Technology Ethics Committee (AUTEK, reference number 21/118) prior to commencing data collection.

The survey was piloted through a two-stage process. First, six NZ registered podiatrists with an average of 17 years' experience (SD 5.3) and expertise in biomechanical management and orthoses completed the survey online and provided written feedback. Following suggested amendments, a focus group with the same practitioners was held to finalise the survey questions. The focus group was facilitated by MC, who has previous experience in survey development. The final survey ([Appendix 5](#)) comprised 30 questions, divided into three sections. Participants were able to review responses to previous questions by using the back button at any stage until the survey was completed. The first section related to demographics and asked respondents about their experience, age, geographic region, qualification, type of work and frequency of orthotic prescription. Section two posed questions relating to when and why they used certain modifications, and what biomechanical hypotheses influenced their decisions. Section three contained questions about lateral wedge fabrication and placement. Twenty-three of the survey questions garnered categorical responses (3-10, 13, 14, 17-19, 22-27, 29-32). Questions 11, 12, 20 and 28 used percentage sliders, and questions 15 and 16 were Likert scales. Question 21 asked respondents to indicate what percentage of their FLWs were placed on the sock liner, an orthotic, or on the midsole of the shoe. Participants were required to assign a percentage of their total modifications to each category whilst the online platform created a sum which was required to equal 100.

The first question of section three screened respondents to identify those who made their own FLWs. To ensure that those responding to the questions had some experience in wedge fabrication, the final section of the survey was only shown to respondents who reported manufacturing their own FLWs. Any respondents who indicated using prefabricated FLWs bypassed the fabrication questions and were taken to the end of the survey. All survey data were reported in accordance with the Checklist for Reporting Results of Internet E-Surveys ([Appendix 6](#)) (200).

5.5 Data Analysis

All categorical data were described as number (n) and percent (%). Likert scale data from question 15 were combined for final analysis. 'Very unlikely' and 'unlikely' responses were

recorded as 'unlikely'. 'Likely' and 'very likely' responses were recorded as 'likely'. Percentage sliders were represented as a mean (out of 100) and standard deviation (SD).

5.6 Results

5.6.1 Participant Characteristics

In total, 88 survey responses were received, representing 25% of Podiatry New Zealand members and 18% of registered podiatrists within NZ (based on 481 podiatrists who hold annual practicing certificates). Twenty-three surveys were incomplete and therefore excluded (a 74% completion rate), leaving 65 which were included for final analysis. Characteristics of the respondents are detailed in

Table 5.1. Most respondents had greater than 10 years' experience (70%, $n = 46$), were trained in NZ (91%, $n = 59$), reported working with a variety of clinical presentations (60%, $n = 39$) and prescribed between 0 and 10 orthotics per week (77%, $n = 51$). Almost three quarters (70%, $n = 46$) of the respondents in the more populated North Island of NZ, and one quarter (25%, $n = 16$) held a post-graduate qualification.

Table 5.1: Demographic data of participants

	N (%)
Years of experience	
0 – 3 years	9 (13.9)
4 – 6 years	6 (9.2)
7 – 10 years	4 (6.2)
11 – 15 years	15 (23.1)
16+ years	31 (47.7)
Region of practice	
North Island, NZ	46 (70.7)
South Island, NZ	19 (29.3)
Highest qualification	
Diploma of Podiatry	9 (14.1)
Bachelors degree	39 (60.9)
Postgraduate diploma or certificate	12 (18.8)
Masters degree	3 (4.7)
Doctoral degree	1 (1.6)
Undergraduate training	
NZ tertiary institute	59 (90.8)
Australian tertiary institution	2 (3.1)
Other	4 (6.2)
Predominant type of clinical work	
General podiatric care	8 (12.3)
Mixed patient load	39 (60.0)
Biomechanical/Musculoskeletal	16 (24.6)
Other	2 (3.1)
Number of orthoses prescribed per week	
0 – 10	51 (77.3)
11 – 25	13 (19.7)
26+	2 (3.1)

5.6.2 The Use of Lateral Forefoot Wedges

In relation to the total number of orthotics prescribed, participants reported including a FLW in 44% (SD 26.76) of cases. When asked what modifications they routinely used, 79% (n=52) reported using FLWs. Only metatarsal domes (80%, n=53) were more widely used.

Respondents were asked about their likelihood of using a FLW in the management of various lower limb conditions (Figure 5.1). The four conditions for which FLWs were most frequently used included peroneal tendon issues, chronic ankle instability (CAI), plantar heel pain and medial knee OA. Conversely, of the list presented to participants, first MPJ joint sprain was the diagnosis which least often led to the use of FLWs.

Figure 5.2 presents data from the question, “How important do you think it is to consider the following, when using a lateral forefoot wedge”. The most important factors for consideration when prescribing FLWs were *forefoot alignment* and *rearfoot pronation/supination*. These were deemed ‘important’ by 88% (n = 58) and 73% (n = 48) of participants, respectively.

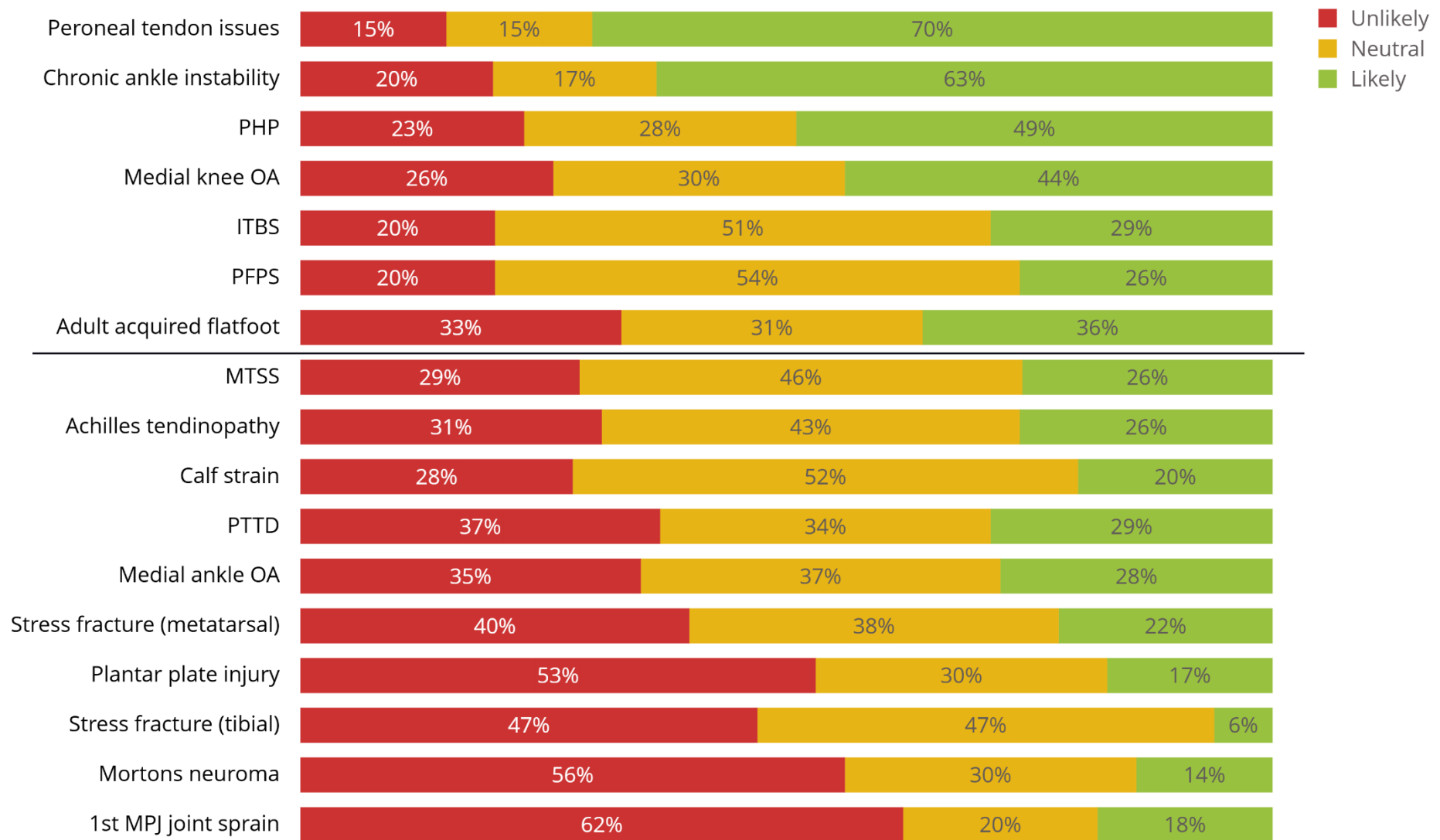


Figure 5.1: Likelihood of FLW prescription, based on common lower limb diagnoses. Data above the line indicating the conditions where FLWs were more likely to be used. Data below the line indicates conditions where FLWs were more unlikely to be used

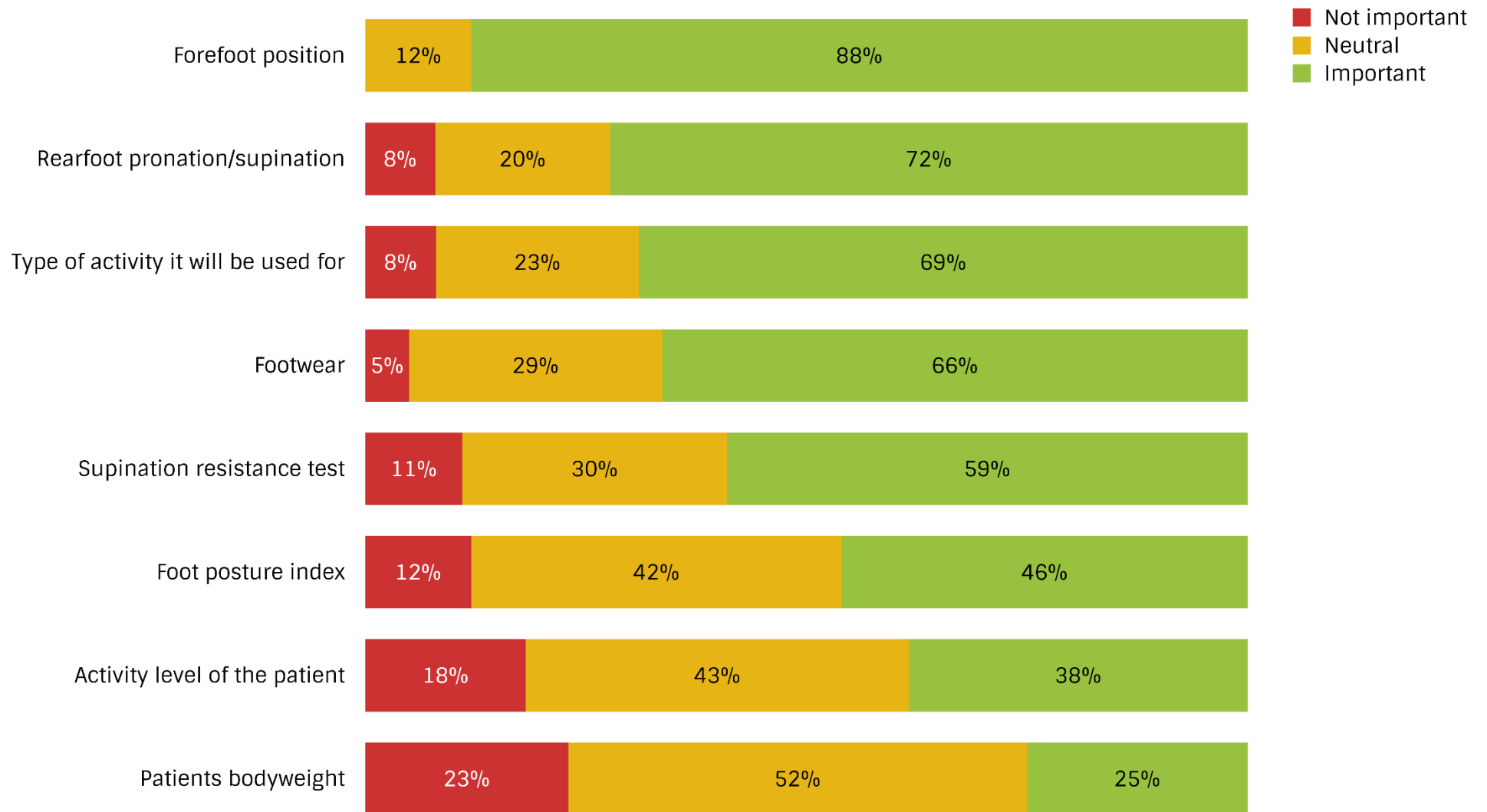


Figure 5.2: Importance of various considerations when prescribing forefoot lateral wedging

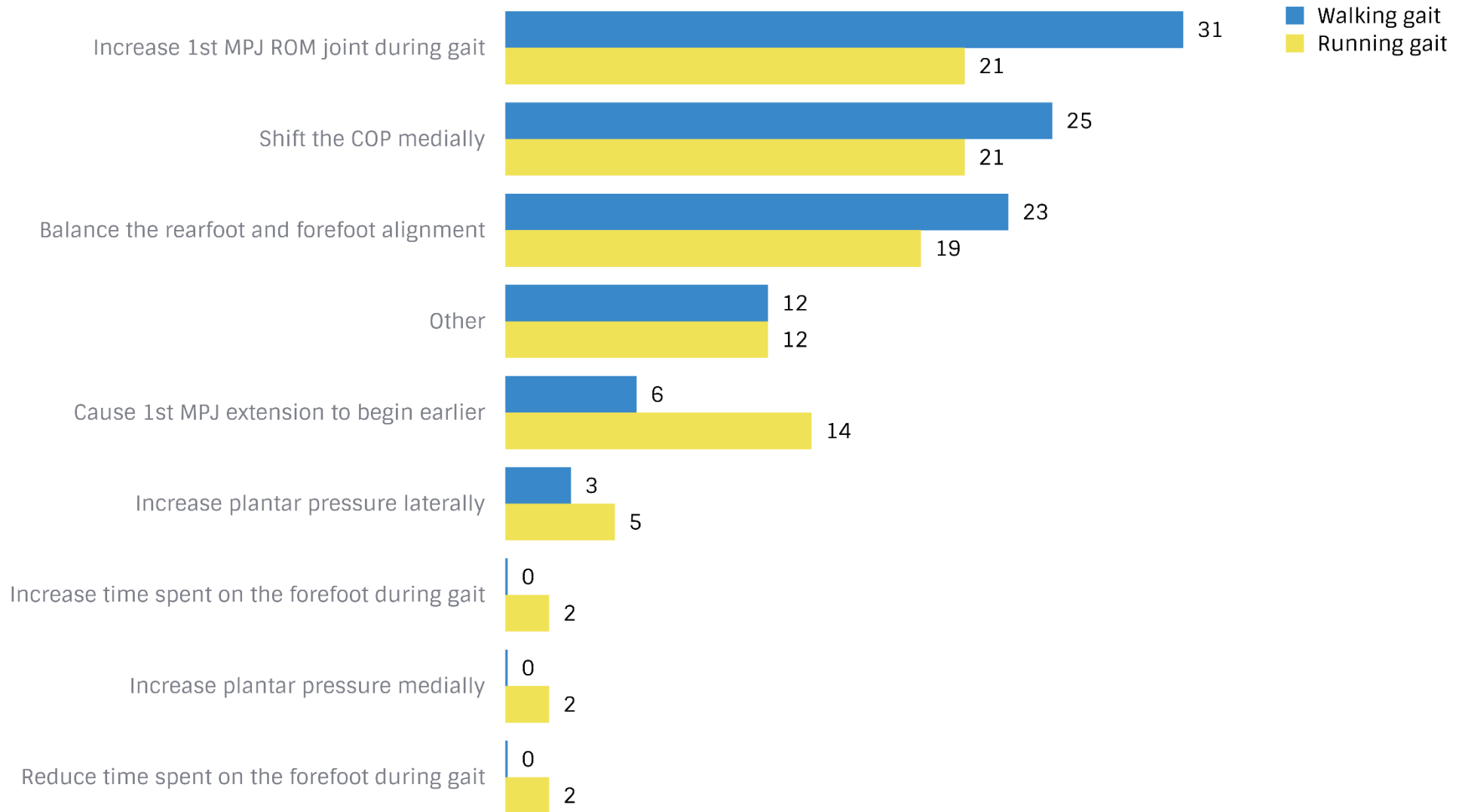


Figure 5.3: The most common reasons respondents would prescribe FLWs for both running and walking gait (%)

5.6.3 The Biomechanical Function of Lateral Forefoot Wedging

In answer to the question *'How influential do you think each of the following podiatric theories/paradigms are in your orthotic prescription?'*, the tissue stress theory (81.2/100, SD 20.4) was reported to be the paradigm which most significantly affects orthotic prescription. This was followed by Sagittal Plane Facilitation theory (69.0/100, SD 21.1), Rotational Equilibrium theory (55.4/100, SD 28.6) and lastly, Root theory (50.2/100, SD 28.4).

The primary reason that NZ podiatrists prescribed lateral forefoot wedging for both running and walking gait was to increase first MPJ ROM. Whether selected as their main reason for use or not, most participants (86%, $n=56$) agreed that this is an expected biomechanical function of lateral forefoot wedging. Figure 5.3 contrasts the reasons that FLW are prescribed, for both running and walking gait. The majority of respondents (68%, $n=45$) indicated that the biomechanical effect of lateral forefoot wedging is different in running gait, compared to walking gait. However, the three most common reasons for the use of FLWs were the same for both walking and running gait.

5.6.4 Fabrication of Lateral Forefoot Wedges

Sixty-three percent ($n=42$) of the respondents in this survey choose to construct their own FLWs. Respondents who reported using prefabricated FLWs most often used wedges manufactured by FootBionics (FootBionics®, Christchurch, NZ) (52%, $n=12$) and Formthotics (Foot Science International Ltd, Christchurch, NZ) (22%, $n=5$).

5.6.5 Wedge Placement

Placement of FLWs was considered to have a large impact (81/100, SD 15.9) on their outcome. Seventy-seven percent ($n = 33$) of respondents reported not always using the same design of FLWs, with patient symptoms highlighted as the most common reason for adjusting design. The most common FLW design reported began at the calcaneo-cuboid joint and finished at the sulcus of the foot (Figure 5.4). Beginning this modification at the calcaneo-cuboid joint was standard for 53% ($n=23$) of participants, whilst 40% ($n=17$) used the styloid process as their landmark. Less variation was reported regarding the distal border with 77% ($n=33$) agreeing on ending the FLW in the sulcus of the foot. A small number of respondents reported finishing the FLW proximal to the metatarsal heads (19%, $n=8$) or at the end of the insole (5%, $n=2$).

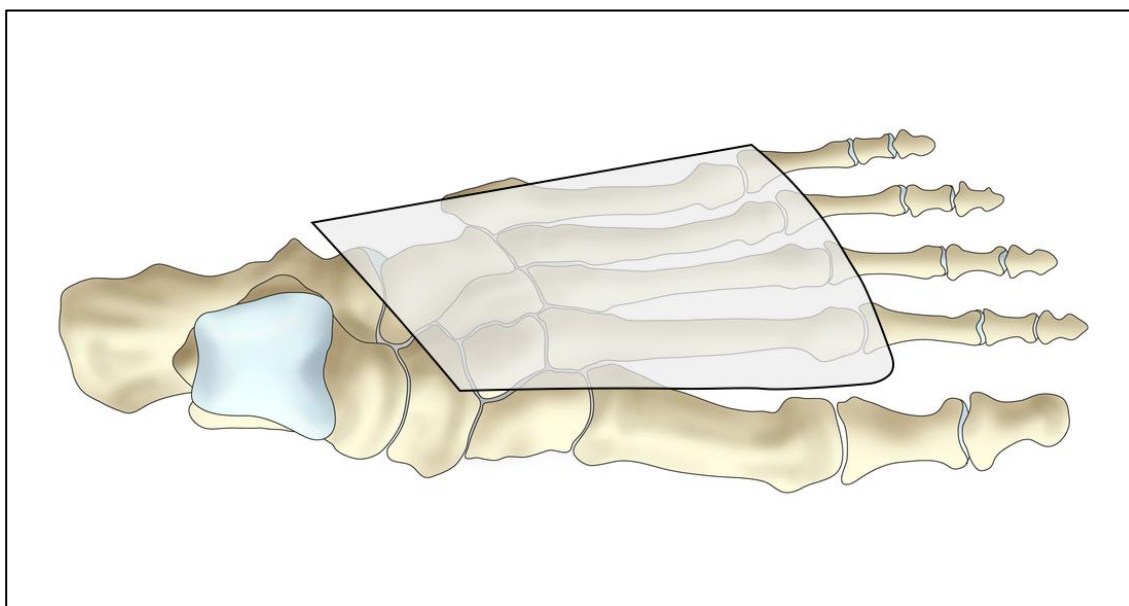


Figure 5.4: Approximate FLW shape when placed from the calcaneo-cuboid joint to the sulcus of the foot

5.6.6 Wedge Material

Respondents considered that material density (82/100, SD 12.4) and thickness (82/100, SD 13.7) were important when constructing FLWs. When asked what materials they have used in the past 12 months, 91% ($n=39$) reported using 'medium density' ethylene vinyl acetate (EVA), whilst 'low density' EVA (51%, $n=22$) and felt (51%, $n=22$) were also widely used. The most commonly used FLW material thickness was 3 mm EVA, 74% ($n=31$) of respondents reported having used this in the last 12-month period. Fifty-two percent (52%, $n=22$) used 4 mm EVA, 33% ($n=14$) used 5 mm EVA and 21% ($n=9$) used 6 mm EVA in this time period. Eight-millimetre EVA was used by four respondents (10%) and 10 mm EVA, by three (7%). However, no respondents reported using 6, 8 or 10 mm EVA as their primary choice of thickness.

5.7 Discussion

This is the first study to investigate the frequency of application for a range of forefoot orthotic modifications amongst NZ based podiatrists. These findings highlight the regular use of FLW within this cohort, with FLWs reportedly included in almost half of all orthotic prescriptions. This makes them the second most widely applied orthotic modification. This survey identified the majority of respondents prescribed between 0 and 10 orthotics or modified insoles per week. A

similar frequency of prescription was reported by Chapman et al. (102), who found that NZ podiatrists on average prescribed 12 orthoses, per week.

Peroneal tendinopathy and CAI were the diagnoses that most frequently led to FLW prescription. Both diagnoses have been linked to patients whose COP is laterally deviated (201, 202). Therefore, if the widely held assumption revealed in this survey is true, and FLWs do shift the COP medially, this is likely to have a positive impact on these clinical presentations. However, this assumption contrasts current research which suggests that lateral wedges shift the COP laterally (12, 136). There is currently limited evidence investigating this function of FLWs, or any positive outcome effect when managing peroneal tendinopathy. It has been postulated that orthoses have a positive impact on CAI due to heightened input to mechanoreceptors, although limited work has been completed exploring the role of FLWs in this scenario (164). Kakihana et al. (16) compared full length lateral wedges in people with and without ankle instability and concluded that in those with unstable ankles, the change in sub-talar joint moments is the same as age-matched controls. Plantar heel pain was the third most likely diagnosis to be managed with FLW. The in vitro study by Kogler et al. (4) provides the only evidence regarding lateral wedging configurations and their impact on the plantar fascia with data indicating that FLW reduced plantar fascial strain. The limitation of this work was the use of cadaveric limbs.

The tissue stress theory was found to be the most influential paradigm that guided orthotic modification and prescription. The tissue stress theory works on the premise that orthoses are used to reduce stress being placed on a tissue, to a tolerable level (49). Therefore, based on the study data, the assumption made when using FLWs under the guidance of the tissue stress theory is that FLW will positively impact tissue stresses.

This survey has revealed incongruity between the surmised function of FLW and the inferred explanations of podiatric theories of foot function. This is highlighted in two examples related to the application of the Root and Sagittal Plane Facilitation theories. Regarding the Root theory, almost a quarter of respondents primarily use FLW to 'balance the foot', and most respondents identified the patient's forefoot position and rearfoot pronation/supination as 'important' when prescribing FLWs. These concepts are key pillars of the Root theory (6, 7), despite the Root theory being rated as the least influential paradigm by respondents. Regarding the Sagittal Plane Facilitation theory, almost all respondents believed that FLW increased the ROM in the first MPJ, and this was reported as the most common reason for FLW use in both walking and running gait. A recent scoping review, however, found no evidence relating to the impact of lateral wedging on first MPJ kinematics (136). The Sagittal Plane Facilitation theory, ranked by participants as the second most influential paradigm, places a great deal of importance on first MPJ ROM (43). This theory suggests that first MPJ movement to engage the windlass mechanism is essential for

efficient forward transfer of weight. The Windlass mechanism was first discussed by Hicks (44) and relates to the association between MPJ position and the plantar fascia. This is said to cause the medial arch to rise and the forefoot to supinate. The contradiction in this case is that Hicks (44) described the irresistible supination of the forefoot as the windlass mechanics is engaged, yet over half of our respondents believe that FLWs both shift the COP medially and increase first MPJ ROM. Extrapolation of the original windlass mechanism description would suggest that first MPJ range of motion cannot increase at the same time as the COP shifts medially. However, recent data has shown the plantar fascia to be extensible (203), something that was not considered in the original explanations of the Windlass mechanism. What was previously thought to be a direct link between first MPJ kinematics and medial arch height appears to be an oversimplification of a complex interaction between the plantar fascia and intrinsic muscles of the foot (203, 204). If extensibility of the plantar fascia also impacts the associated forefoot supination, then this could create the possibility of a concurrent medial shift in COP alongside an increase in first MPJ ROM, as participants in the current survey believe is true. However, there is limited evidence to support this supposition and further investigation is required.

Data indicated the respondents believed FLW functioned differently in walking gait versus running gait. Respondents also indicated that the biomechanical objectives for FLW prescription were entirely different when managing runners and that running gait enhances the effect of a FLW. Whilst research has indicated biomechanical outcomes derived from orthoses differ between walking and running gait (205), there is limited data supporting functional differences from FLW use between walking and running gait (136). Given the differing use and the beliefs of clinicians that there are functional differences when using FLW in running versus walking gait, further investigation is warranted.

Full length lateral wedges have been the dominant design examined in research, notably for their biomechanical effect in the management of medial knee OA (136, 171). However, as indicated by the survey, full length wedges made up a small percentage of lateral wedges prescribed by respondents. Evidence contrasting the effect of varying wedge length (full length vs FLW) is limited (136). Van Gheluwe and Dananberg (3) compared the impact of lateral wedge length on plantar pressure and found FLW increased peak plantar pressure in the lateral forefoot, whereas rearfoot lateral wedges had no effect on forefoot plantar pressure. Further supporting the biomechanical impact of FLW, Kogler et al. (4) demonstrated that wedging under the lateral aspect of the forefoot provided the most significant reduction in strain in the plantar fascia.

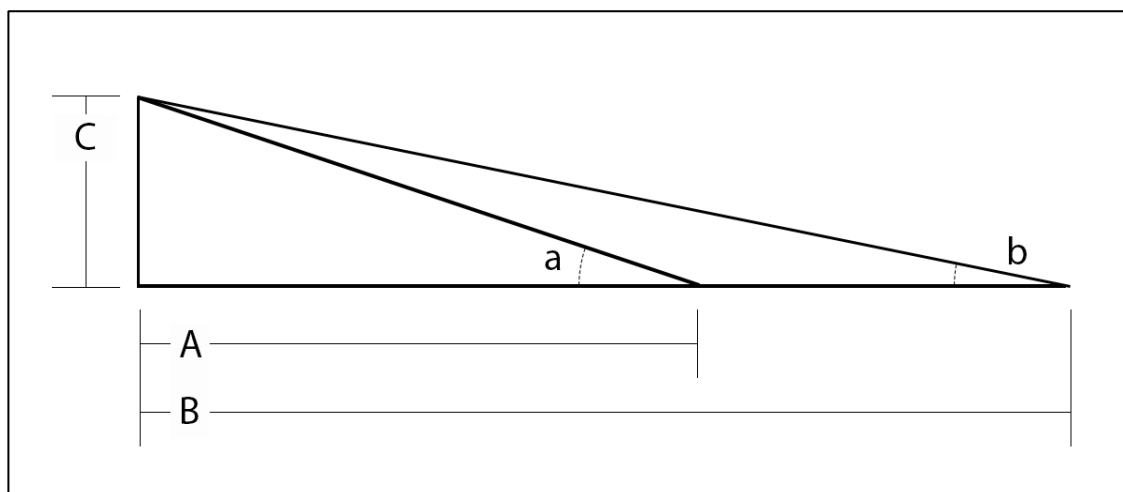


Figure 5.5: The relationship between material thickness and width means that at a consistent material thickness (C) the inclination angle (b) will be smaller than (a) due to the modification being wider ($B > A$)

The most common material thickness used to manufacture FLWs was 3 mm. However, it is important that the difference between inclination angle and material thickness (in the case of wedges, referring to the thickest part) is clearly understood. Three-millimetre (3 mm) material does not produce a consistent angle, as this depends on the width of the modification. Figure 5.5 displays the relationship between thickness and width, in which the width of a wedge entirely changes the inclination angle if the thickness remains constant. For example, 3 mm material bevelled to 0 mm over a width of 60 mm (a relatively small FLW) produces an inclination angle of 2.9° , whereas that same material bevelled over 100 mm (a large FLW) produces an angle of 1.7° . This difference means if the same material thickness is used regardless of modification width, patients with larger feet receive wedges with lower inclination angles. This is an important distinction as research has previously indicated that for a range of biomechanical outcomes, a larger inclination angle elicits a larger response (179).

The survey data must be considered in the context of its limitations. Firstly, despite efforts to maximise recruitment, the sample size was lower than anticipated, which may limit the generalisability of the data. Whilst the response rate was low, recent NZ podiatry workforce data indicated only 19% of NZ podiatrists worked in the area of sports medicine (206). Consequently, the survey may have only been of interest to a relatively small percentage of the NZ podiatry workforce. However, the study was the first to examine practice habits related to FLW. The responses allowed participants to select a range of common presentations, modifications and beliefs that underpin the prescription of FLW. This allowed space for reflection on their practice habits and established a benchmark for current clinical practice in NZ.

5.8 Conclusion

NZ podiatrists frequently use FLW. These were generally manufactured from 3 mm, medium density EVA and positioned from the calcaneo-cuboid joint to the sulcus. The most common rationales for use were to increase first MPJ ROM, shift the COP medially, and balance the foot. A discordance was found between the theories of foot function upon which clinicians placed the greatest importance, and the biomechanical outcomes that they thought were being achieved. Survey data also highlighted inconsistency in the nomenclature used to describe FLW thickness and inclination.

5.9 Novel Contributions of Chapter 5

This chapter provides a novel insight into how a group of NZ podiatrists apply lateral wedges in practice. While only two studies have previously explored prescription habits of podiatrists, most data have come from Australia and the UK (42, 102). This is the first study to exclusively consider NZ practitioners, which is important considering the different practice habits highlighted by previous work (102).

A notable finding from this chapter is the disparity between what clinicians' report to be prescribing in practice, and the wedge designs used in the research identified in Chapter 4. Respondents to this survey predominantly use 3 mm EVA to fabricate wedges which equates to approximately 1.7°-2.9°, less than half the inclination of what is commonly used in research (136). Podiatrists surveyed typically place lateral wedges under the forefoot, not full-length as is the case in most of the existing research. Finally, survey participants applied lateral wedges with the principal intention of increasing first MPJ joint ROM, although limited evidence exists to support this management strategy (196).

Chapter 6: The Immediate Effect of Lateral Wedging on First Metatarsophalangeal Joint Kinematics and Centre of Pressure

6.1 Preface

The most significant insights from earlier chapters in this thesis include the frequent use of lateral wedges with the intention of enhancing the first MPJ kinematics and shifting the COP medially. This is supported by limited evidence. New Zealand podiatrists use lateral wedges of a lower inclination (2° - 3°) than those reported in research (average 6°), and more often place these in the forefoot, despite full-length being the common placement examined by research. There is currently limited evidence contrasting the effect of lateral wedging between walking and running gait. Yet, Chapter 5 indicates that New Zealand podiatrists perceive a difference and report applying lateral wedges differently depending on whether the pathology is related to walking or running gait.

This chapter investigates the effects of lateral wedging on first MPJ extension and COP in both walking and running gait, considering various wedge lengths and inclinations. First MPJ extension and COP are chosen as key outcome variables due to the importance clinicians place on these variables. This investigation is particularly important for first MPJ extension due to the limited existing evidence.

6.2 Abstract

Background

Lateral wedges are one of the most common modifications added to foot orthoses. Podiatrists may prescribe lateral wedges to increase the first metatarsophalangeal joint range of motion or alter the centre of pressure. This study aimed to explore the effect of lateral wedging on first metatarsophalangeal joint extension and centre of pressure during walking and running gait.

Methods

This study utilised a randomised crossover design in which 24 healthy participants ran and walked in 10 different insole conditions. The ten conditions comprised differing lateral wedge inclinations (3° vs 6°), placement (full-length vs forefoot), and overall contour (contoured vs sham). First, metatarsophalangeal joint sagittal plane kinematics and foot centre of pressure were examined using 3D motion analysis and an instrumented treadmill. Data were analysed across the stance phase using statistical parametric mapping.

Results

Fifteen men and nine women, with a mean age of 37 years (SD8.1) participated in the study. Extension of the first metatarsophalangeal joint was significantly reduced by lateral wedging ($p=0.01$) throughout the entire stance phase (0-100%). The inclination or placement of lateral wedges only influenced first metatarsophalangeal joint extension in walking gait, with 6° wedges reducing extension much more than 3° wedges ($p=0.01$). Lateral wedging shifted the centre of pressure medial relative to the midline of the foot ($p=0.01$), but this effect was only observed with 6°, and full-length wedges. This medial shift in centre of pressure was detected earlier in the stance phase during walking (11-24%) compared to running gait (26-52%).

Conclusion

Lateral wedges reduce extension of the first metatarsophalangeal joint during walking and running, regardless of wedge inclination and placement. The centre of pressure is shifted medially by 6°, and full-length lateral wedges. If the clinicians' intention when using lateral wedging is to shift the centre of pressure medially, these data indicate that a wedge which is of higher inclination (6°), or full-length should be used. On the other hand, if the orthosis is

designed to reduce first metatarsophalangeal joint extension, there is no difference between the effects of 3° and 6° inclination. Study data indicates that contour of the insole increases the effect of lateral wedging on centre of pressure, eliciting a greater medial shift, compared to a sham insole.

6.3 Introduction

Lateral wedges are a common modification to foot orthoses (2, 117). These wedges taper from thick on the lateral side to thin on the medial side and are frequently used to increase first metatarsophalangeal joint (MPJ) extension or alter the centre of pressure (COP) (2). Most experimental studies on lateral wedges have concentrated on their application for populations with medial knee osteoarthritis (OA) (13, 121, 190, 191, 207, 208). Consequently, there is limited understanding of the biomechanical effects of these wedges on foot function.

Theoretically, adequate first MPJ extension is important for efficient propulsion during gait (43, 209). Extension of the first MPJ is often linked to the Windlass mechanism, whereby extension of the first MPJ results in elevation of the medial longitudinal arch and necessitates downward movement of the first metatarsal head (43, 44, 47). When first described by Hicks (44), the Windlass mechanism was highly theoretical and observed primarily in cadaveric specimens. Hicks (44) reported that when the first MPJ was extended, the first metatarsal head moved downward and was pulled closer to the calcaneus, meaning the arch was made 'shorter and higher'. For several decades, the Windlass mechanism has persisted as a fundamental concept utilised in podiatric clinical practice, often to measure or report sagittal plane efficiency (43, 47, 210). For example, clinicians may seek to improve the Windlass mechanism with the intention of reducing plantar fascial strain (47, 210-212), or enhancing the efficiency of the propulsion of the foot (209, 213). Recent research supports the positional association whereby dropping of the first metatarsal head in a plantar direction reduces the force required to extend the first MPJ (214). To illustrate this, Gomez-Carrion et al. (214) reported a 46% reduction in the force required to extend the first MPJ with an orthotic modification (kinetic wedge) designed to allow downward movement of the first metatarsal head.

Limited extension of the first MPJ has been associated with the development of foot pathologies such as plantar heel pain, overload of the lesser metatarsals, and compensatory changes to gait, including early toe off and increased transverse plane rotation of the foot during the propulsive phase of gait (47, 215-220). Fuller (47) posits that when increased force is applied to the first metatarsal head, the tension in the plantar fascia's medial slip is increased, often resulting in

pathological changes to the tissue. Hall and Nester (220) showed that when the extension of the first MPJ was artificially restricted, it resulted in increased ankle dorsiflexion and reduced knee and hip extension during the propulsive phase of gait. Furthermore, first MPJ extension is also thought to be important for optimal athletic performance (43, 209, 221).

Research exploring the influence of lateral wedges on first MPJ kinematics is limited (196). Du et al. (196) examined four conditions (1; barefoot, 2; standardised sandals only, 3; standardised sandals and a 7 mm lateral wedge, 4; standardised sandals and a 10 mm lateral wedge), and a range of kinematic and kinetic outcomes for walking gait in 16 healthy participants. In relation to first MPJ movement, this study reported no significant difference in peak dorsiflexion or peak plantarflexion between the standard sandal on its own, and the same sandal with either a 7 mm or 10 mm lateral wedge (196). Lateral wedges to increase first MPJ extension remain common in clinical practice, despite not being supported by current evidence (2, 136, 196). A recent survey of NZ podiatrists reported that 86% of respondents believed that first MPJ extension is increased when a lateral forefoot wedge is applied (2).

The centre of pressure, the centroid of force application to the foot from its supporting surface, is often extrapolated to explain foot function (64, 65, 69, 71, 86, 222-224). The medial-lateral position of COP, generally described in relation to the midline of the foot, is associated with frontal plane kinematics of the foot and lower limb (69). Mousavi et al. (69) reported that in feet where the rearfoot is everted, the COP is more medial than in those feet which are neutral or inverted. Where the COP falls in relation to joint axes is thought to directly influence joint moments, and subsequently the function of the foot (86). A concept often referred to as 'Rotational equilibrium theory', and first proposed by Fuller (86), suggested that the mechanical stress on tissues can be partly explained or predicted by examining the COP. Fuller (86) theorised that when the body's velocity is equal to zero and there is no net moment, as the forces acting on the body cancel each other out. Current evidence indicates that the foot COP is shifted laterally when a lateral wedge is placed on an insole under the foot (3, 11, 15, 16, 93, 94). In contrast, Erhart et al. (112) identified a medial shift in plantar pressure when lateral wedges were placed in the shoe's midsole.

Current evidence exploring the influence of lateral wedging on foot function predominantly relates to walking gait, and no previous studies have directly compared walking to running (136). Considering the differences between gait types, such as the increased vertical ground reaction force and reduced contact time during running, it is reasonable to assume that a lateral wedge, which aims to influence load and temporal parameters of gait, would act differently between walking and running (22, 105, 106, 225). It has also been shown that first MPJ kinematics and COP vary between walking and running gait (70, 226). This aligns with the clinical belief of NZ

podiatrists who report using lateral wedges differently for running compared to walking gait (2). Therefore, this study aimed to explore the effect of lateral wedge design on first MPJ extension and COP and contrast these outcomes between walking and running gait. This study addresses research questions 5, 6, and 7. RQ5: How do lateral wedges affect the foot and ankle kinetics and kinematics of healthy individuals? RQ6: How does lateral wedging placement influence the foot's kinetics and kinematics in walking and running gait? RQ7: And does the biomechanical effect of lateral wedging differ if placed on an otherwise flat or contoured insole?

6.4 Methods

6.4.1 Study Participants

Twenty-five healthy, uninjured runners were recruited to participate using convenience sampling. To be eligible for participation, individuals needed to regularly run a minimum of 10 km per week, be uninjured for the previous 6 months, be over 18 years of age, and be comfortable running on a treadmill at 10 km/h. As per the recommendation from Yamato, Saragiotto and Lopes (227), an injury was defined as a condition that restricted the runners ability to run for seven days, or required intervention from a health professional. Conversely, potential participants were excluded from participation if they reported any systemic arthropathies or recent (previous 12 months) lower limb surgery. Advertisements for the research were posted on social media and in local running shoe stores. Potential participants followed a link or QR code to an expression of interest survey, which once completed, alerted the researchers, who then made contact. Power calculations (conducted with RStudio version 3.6.3) were based on data from Turner et al. (228) who reported a SD of 6.9° (mean 29.2°) when measuring peak first MPJ dorsiflexion in walking gait from a cohort of 25 healthy adults. Therefore, 25 participants would provide a detectable effect size of 1.4° assuming 90% power and an alpha level of 0.05. All participants provided signed informed consent before participation. The study was approved by the Auckland University of Technology Ethics Committee (AUTECH# 22/121).

6.4.2 Protocol

Participants attended a single data collection session at Auckland University of Technology, Millennium Campus between 29 August and 25 November 2022. Clinical assessments were completed, including body mass, height, Foot Posture Index (FPI) (229), and first MPJ range of

motion (ROM) in both weight-bearing and non-weight-bearing using a handheld goniometer. An experienced podiatrist (AJ) then selected and checked the shoe size for suitability. Following this, a five-minute warm-up period was provided to familiarise the participant with the laboratory environment, the treadmill, and the footwear. The standard sock liner of the shoes remained in place for this phase. Following the initial warm-up, the sock liner of the shoe was exchanged for the first insole condition.

6.4.3 Lateral Wedges and Footwear

Participants wore standardised footwear (ASICS Gel Cumulus 23) for all walking and running trials. In total, 10 insole conditions were examined (Table 6.1). These included five contoured insoles (Formthotics™ Original Single Medium, Foot Science International, Christchurch, NZ) and five sham insoles (identical material to the contoured option, with no arch profile or other contour) (Figure 6.1), each with matched combinations of forefoot or full-length and 3° or 6° inclination lateral wedges. To ensure a uniform finish, trained technicians from GO Orthotics Limited applied all wedges to the insoles, using pre-wedged strips supplied by Formthotics™. The wedge strips were made from polyethylene foam with a density of 140 kg/m³ and hardness of approximately 61 Asker C. Full-length wedges ran from the most proximal aspect of the insole to the most distal aspect. In contrast, forefoot wedges extended from the calcaneo-cuboid joint to the sulcus. A randomised crossover developed by an independent statistician was used for the insole sequence.

Table 6.1: Insole conditions used in the study

Sham Insoles	Contoured Insoles
No wedge	No wedge
Full-length, 3° lateral wedge	Full-length, 3° lateral wedge
Full-length, 6° lateral wedge	Full-length, 6° lateral wedge
Forefoot, 3° lateral wedge	Forefoot, 3° lateral wedge
Forefoot, 6° lateral wedge	Forefoot, 6° lateral wedge



Figure 6.1 Comparison of insole contour. The sham insole is shown in the foreground and the contoured insole behind.

6.4.4 Three-Dimensional Gait Experimental Setup

Rigid clusters of four retro-reflective markers (12 mm diameter) were positioned on the right anterior shin and lateral thigh. Twenty-one individual reflective markers were also placed on specific anatomical landmarks. These were bilaterally applied to the anterior superior iliac spines and posterior superior iliac spines and unilaterally to the right greater trochanter, medial and lateral femoral epicondyles, and medial and lateral malleoli. An adapted version of the Leardini model (230) previously used by Weir et al. (231) was employed to model the foot. This model is comprised of markers placed on the posterior of the shoe at the superior aspect of the calcaneus as well as the medial and lateral aspect just above the midsole, the medial apex of the sustentaculum tali, the lateral apex of the peroneal tubercle, the base and head of each the first, second and fifth metatarsals and finally, the most dorsal and distal aspect of the first proximal phalanx (Figure 6.3). Kinematic data were gathered using an 8-camera motion capture system (Vicon, Oxford, UK) recording at 200 Hz, whilst kinetic data were simultaneously collected from a synchronised instrumented treadmill at 1000 Hz (Bertec, Columbus, OH, USA). Prior to gathering data for each condition, a static calibration was performed, and the knee and ankle markers were removed.

The participant was then asked to walk on the treadmill for two minutes at 1.4 m/s followed by a two-minute run at 2.8 m/s. Each of the walking and running trials began with a 90-second familiarisation period, before data were recorded continuously during the final 30 seconds.

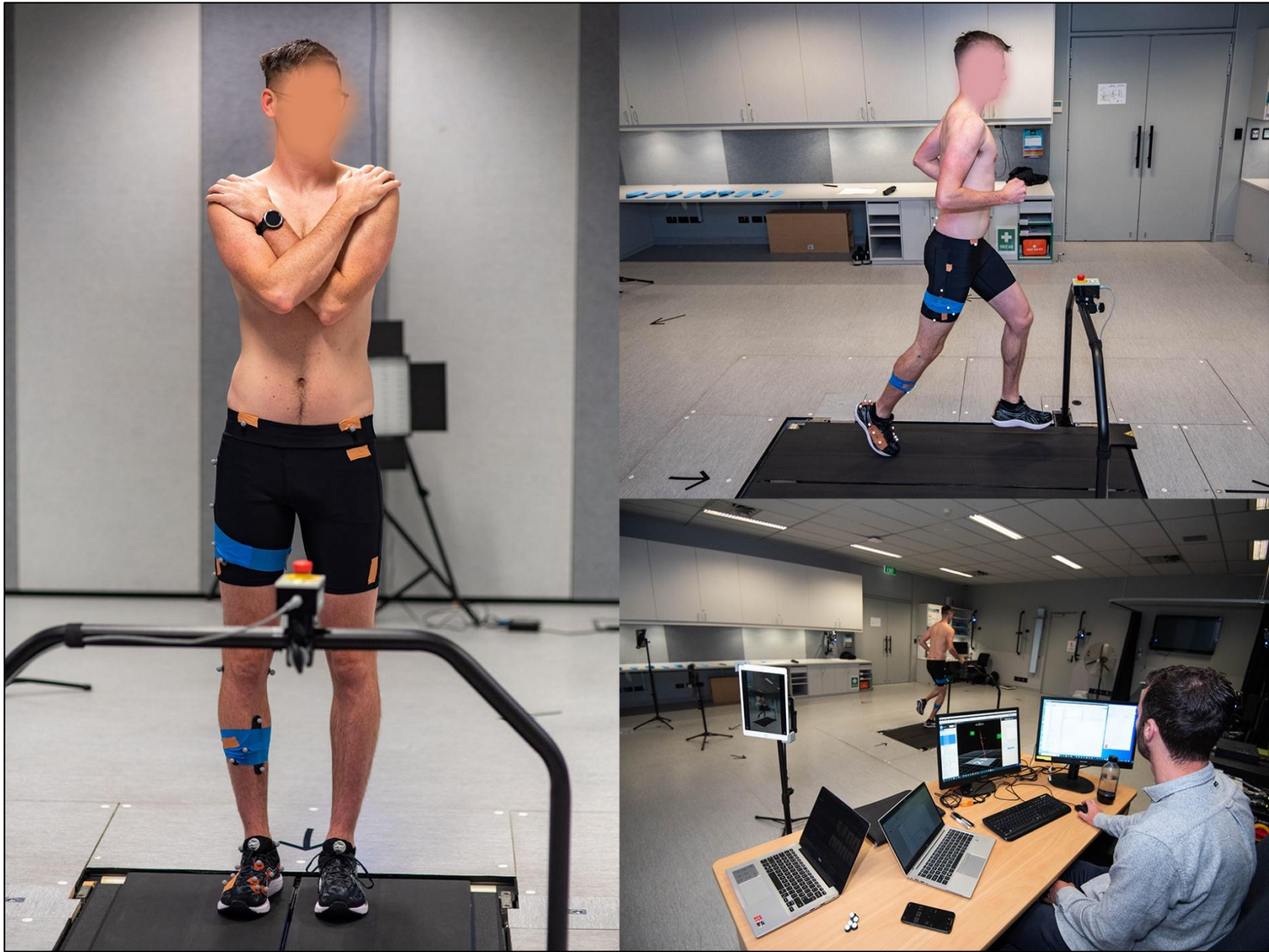


Figure 6.2 Experimental setup



Figure 6.3: Marker placement on the shoe as per the model detailed by Weir et al. (231).

6.4.5 Data processing

Data captured during the trial were initially processed in Nexus software (v2.12.1, Vicon, Oxford, UK) where markers were labelled using automated pipelines and checked for accuracy manually. The data were reviewed to ensure that all included steps resembled a typical stride pattern, with any irregularities systematically removed. Subsequently, the data were cropped to encompass 20 steps, and gap filling was executed using either spline or rigid body fill techniques. The processed data were then exported to Visual3D (C-Motion Inc., MD, United States).

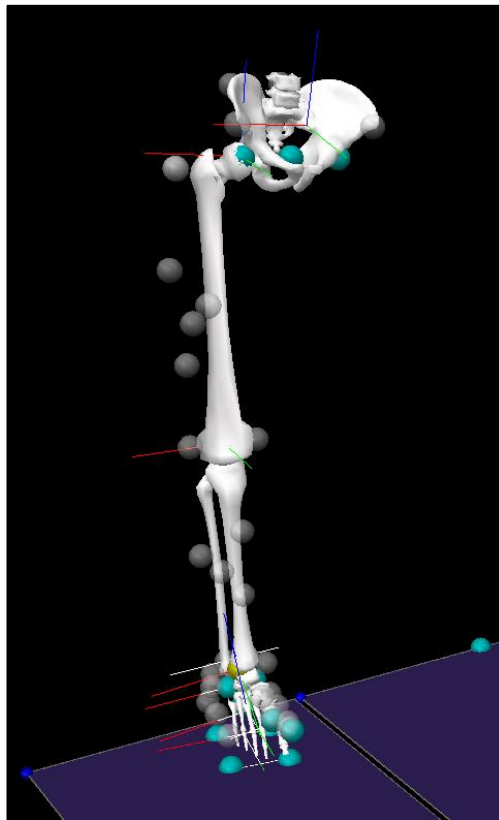


Figure 6.4 Model used in Visual3D for kinematics analysis

The seven-segment [pelvis, thigh, shank, virtual foot, foot, forefoot, rearfoot] (Figure 6.4) lower limb model was applied to all trials. First MPJ kinematics were calculated as a planar angle using vectors created by a virtual marker (150% offset axially from the first metatarsal shaft) and two physical markers on the first metatarsal head and hallux, then projected onto the YZ plane with the forefoot segment as a reference. Foot COP was calculated for the right foot segment with the resolution coordinate system set to a virtual foot segment. To calculate the virtual foot, markers were dropped from the medial and lateral malleoli, as well as fifth and first metatarsal head onto the lab floor to respectively represent the proximal and distal ends. The

anteroposterior axis then extended from the midpoint between the malleoli markers, to the midpoint between the metatarsal markers. Centre of pressure data represented the position from the anteroposterior axis, normalised to foot width (calculated as the distal radius of the foot segment), where a negative number represented a location medial to the axis, and a positive number indicated a lateral position. As COP was normalised to foot size, the value infers a location in relation to the midline of the foot and is not a discrete value. For example, a COP of -1 indicates 100% of the radius of the foot (half the distance between markers placed on the 1st and 5th metatarsal heads), medial to the longitudinal axis.

All data were interpolated to 101 points for subsequent statistical analysis. Filter cutoffs were determined using Winter's residual analysis (232), where data were filtered using a range of nine filter cut-offs (0-24Hz), then subtracted from the raw data, and plotted against the cutoff frequency. This method indicated an optimal threshold of 15 Hz for both the kinematic and kinetic output. Finally, processed data were exported as .txt files in preparation for statistical analysis.

6.4.6 Statistical Analysis

Continuous demographic data were analysed using mean and standard deviation, whilst categorical demographic data were presented as raw values and percentages. Biomechanical data, including first MPJ extension and COP position were tested across the entire time series of stance phase using statistical parametric mapping (SPM) and open-source code SPM1d (233). All statistical analyses were conducted in Matlab (Mathworks Inc., Natick, MA, USA). To select the appropriate statistical test, data were first tested for normal distribution and as a significant portion of the data violated the assumption of data normality, non-parametric tests were applied. The main effect (for wedge inclination, placement, and insole contour) was examined using a Friedman test, and additional pairwise comparisons were conducted using Wilcoxon signed rank test to determine within-group effect of inclination and placement. For the main effect, the alpha level was set at 0.05.

6.5 Results

6.5.1 Participants

Table 6.2 provides an overview of participant clinical and demographic data. Twenty-five participants were recruited for the study. Data from one participant was excluded due to data

corruption, therefore data from 24 participants, nine women (38%) and 15 men (62%) with a mean age of 37, were analysed. Participants reported running on average four times per week (mean weekly total of 41.9km).

Table 6.2: Participant demographic and clinical data

Characteristic	Mean (SD)
Sex	9 women, 15 men
Age (years)	36.6 (8.1)
Weekly running mileage (Km)	41.9 (22.6)
Typical weekly running frequency (days per week)	4.3 (1.7)
Body mass (Kg)	72.8 (8.9)
Height (m)	1.75 (0.08)
Body mass index (Kg/m ²)	23.8 (2.5)
Foot Posture Index	2.5 (3.1)
Maximum first MPJ extension (NWB) (°)	76.0 (12.1)
First MPJ range of motion (WB) (°)	46.3 (7.6)

Kg: Kilograms, Km: Kilometres, m: Meters, NWB: Non-weight bearing, WB: Weight-bearing, °: Degrees

6.5.2 First metatarsophalangeal joint kinematics

Table 6.3 shows significant effects were demonstrated for inclination ($p < 0.001$, $p=0.004$ and $p=0.017$) and wedge placement ($p < 0.001$, $p=0.003$ and $p=0.012$) for both walking and running gait. However, in relation to insole contour, the effect was only significant in walking gait ($p=0.008$).

6.5.2.1 Wedge inclination – Walking Gait

All pairwise comparisons (control vs. 3°, control vs. 6°, and 3° vs. 6°) were significant for the influence on first MPJ extension in walking gait.

Unlike the unwedged control condition, 3° wedges reduced first MPJ extension between 0-17% ($p=0.002$), 21-24% ($p=0.021$), 35-41% ($p=0.015$), 52-56% ($p=0.021$) and 58-87% ($p=0.003$) of the stance phase. The average difference in joint position over these periods ranged from 0.74° to 1.29°. When compared to a control condition, 6° wedges also demonstrated a significant effect on first MPJ extension ($p < 0.001$). In walking gait, an average 1.53° reduction in first MPJ extension (with wedges) was observed between 0 and 95% of stance. Pairwise comparisons between the two wedge inclinations (3° vs. 6°) were significant in walking gait ($p=0.001$ and $p <$

0.001), but not in running gait. During walking, the 6° wedge further reduced first MPJ extension, compared to the 3° condition, by 0.43° and 0.56°, respectively, during two periods (3-35% and 38-85%) of stance.

6.5.2.2 *Wedge Inclination – Running Gait*

Both wedged conditions (3° and 6°) demonstrated a significant effect compared to the control condition (both $p < 0.001$). However, in running gait, pairwise comparison revealed no significant difference between the two inclinations.

Compared to the control condition, 3° wedges demonstrated an average 1.89° reduction in first MPJ extension between 14 and 100% of the stance phase in running gait. Similarly, an average 1.80° reduction in first MPJ extension was observed between 0 and 100% when comparing the 6° wedge to the control.

6.5.2.3 *Wedge Placement – Walking Gait*

Wedge placement demonstrated significant effects ($p < 0.001$) on first MPJ extension, between 0 and 99% of the stance phase in walking gait. Pairwise comparisons indicated a significant difference between full-length and forefoot wedges in contrast with the control condition. However, when directly comparing the two wedge placements (full-length vs forefoot), a significant difference was observed in walking (1-26%, $p=0.003$), and not in running. Significant differences were found between the forefoot wedges and the control between 2-15% ($p=0.003$), 38-39% ($p=0.024$), 50-53% ($p=0.022$) and 55-84% ($p < 0.001$) of the stance phase. Over these periods of stance, the mean reduction in first MPJ extension ranged from 0.79° to 1.27°. Compared to the control condition, full-length wedges exerted a significant difference from 0-100% ($p < 0.001$) of the stance phase, with a mean reduction in first MPJ extension of 1.60°.

6.5.2.4 *Wedge Placement – Running Gait*

Wedge placement demonstrated significant effects on the first MPJ extension, from 13 to 69% ($p=0.003$), and from 78 to 100% ($p=0.012$), of the stance phase in running gait. Pairwise comparisons revealed a difference ($p < 0.001$ and $p=0.007$) when contrasting either wedge placement to the control; however, there was no significant difference when directly comparing placements.

Compared to the control condition, forefoot wedges were associated with reduced first MPJ extension between 77 and 94% of the stance phase (mean reduction 1.70°). Full-length wedges reduced the joint's extension for the entire stance phase (0-100%), with a mean change of 2.48° over this period.

6.5.2.5 Insole contour – Walking Gait

The contour of the insole onto which the wedge was placed demonstrated a significant effect during walking gait ($p=0.008$). Participants exhibited an average of 0.54° greater first MPJ extension when the wedge was placed on a contoured insole (49-73% of stance).

6.5.2.6 Insole Contour - Running Gait

There was no significant difference between wedges placed on a contoured versus sham insole in relation to the first MPJ extension during running gait.

6.5.3 Centre of Pressure

Inclination ($p=0.009$ and 0.013), wedge placement ($p=0.008$ and 0.005) and insole contour ($p < 0.001$ and $p=0.020$) all demonstrated significant effects for changes in COP in both walking and running gait (Table 6.3).

6.5.3.1 Wedge inclination

Six-degree wedges created a medial shift in the foot COP compared to the control condition for walking (12-22% of stance, $p=0.005$) and running gait (28-52%, $p=0.003$). No significant difference was observed between 3° wedges and the control condition, nor between 3° and 6° wedges.

6.5.3.2 Wedge placement

Compared to the control condition, full-length wedges elicited a medial shift in COP for walking (11-24%, $p=0.001$) and running (26-52%, $p=0.002$) gait. Contrasting full-length to forefoot wedges, a difference was observed for walking gait (23-27%, $p=0.022$), in that full-length wedges shifted the COP medially compared to forefoot wedges. No significant difference was found

when comparing the two wedge placements for running gait or when contrasting forefoot wedges to the control for either gait type.

6.5.3.3 Insole contour

A significant difference was detected when lateral wedges were applied to contoured insoles compared to those placed on sham insoles. Specifically, wedges applied to the sham insole shifted the COP more medially than those on contoured insoles for both walking (10-77%, $p < 0.001$) and running (13-19%, $p=0.009$) gait.

Table 6.3: Main effect and pairwise comparison of design factors on COP

Factor	Gait type	Significant effect	Region of significance (% of stance [P])	Pairwise comparison	Significant effect	Region of significance (% of stance [P])
Inclination	Walking	Yes	14 – 20 [0.009]	Control vs. 3°	No	-
				Control vs. 6°	Yes	12 – 22 [0.005]
				3° vs. 6°	No	-
	Running	Yes	29 – 50 [0.013]	Control vs. 3°	No	-
				Control vs. 6°	Yes	28 – 52 [0.003]
				3° vs. 6°	No	-
Placement	Walking	Yes	14 – 23 [0.008]	Control vs. full-length	Yes	11 – 24 [0.001]
				Control vs. forefoot	No	-
				Full-length vs. forefoot	Yes	23 – 27 [0.022]
	Running	Yes	25 – 70 [0.005]	Control vs. full-length	Yes	26 – 52 [0.002]
				Control vs. forefoot	No	-
				Full-length vs. forefoot	No	-
Contour	Walking	Yes	10 – 78 [< 0.001]	Sham vs. Contoured	Yes	10 – 77 [< 0.001]
	Running	Yes	13 – 18 [0.020]	Sham vs. Contoured	Yes	13 – 19 [0.009]

Table 6.4: Main effect and pairwise comparison of design factors on first MPJ extension

Factor	Gait type	Significant effect	Region of significance (% of stance [P])	Pairwise comparison	Significant effect	Region of significance (% of stance)	Mean difference		
Inclination	Walking	Yes	0 – 98 [< 0.001]	Control vs. 3°	Yes	0 – 17 [0.002]	0.86°		
						21 – 24 [0.021]	0.74°		
						35 – 41 [0.015]	0.80°		
				Control vs. 6°	Yes	52 – 56 [0.021]	0.91°		
						58 – 87 [0.003]	1.29°		
						0 – 95 [< 0.001]	1.53°		
	3° vs. 6°	Yes	3 – 35 [0.001]	0.43°					
			38 – 85 [< 0.001]	0.56°					
			Running	Yes	14 – 72 [0.004] 76 – 99 [0.017]	Control vs. 3°	Yes	14 – 100 [< 0.001]	1.89°
Control vs. 6°	Yes	0 – 100 [< 0.001]				1.80°			
3° vs. 6°	No	-				-			
Placement	Walking	Yes	0 – 99 [< 0.001]	Control vs. full-length	Yes	0 – 100 [< 0.001]	1.60°		
						Control vs. forefoot	Yes	2 – 15 [0.003]	0.79°
								38 – 39 [0.024]	0.79°
				50 – 53 [0.022]	0.92°				
				Full-length vs. forefoot	Yes	55 – 84 [< 0.001]	1.27°		
						1 – 26 [0.003]	0.59°		
	Running	Yes	13 – 69 [0.003] 78 – 100 [0.012]			Control vs. full-length	Yes	0 – 100 [< 0.001]	2.48°
				Control vs. forefoot	Yes	77 – 94 [0.007]	1.70°		
				Full-length vs. forefoot	No	-	-		
Contour	Walking	Yes	31 – 75 [0.008]	Sham vs. Contoured	Yes	49 – 73 [< 0.001]	-0.54°		
	Running	No	-	-	-	-	-		

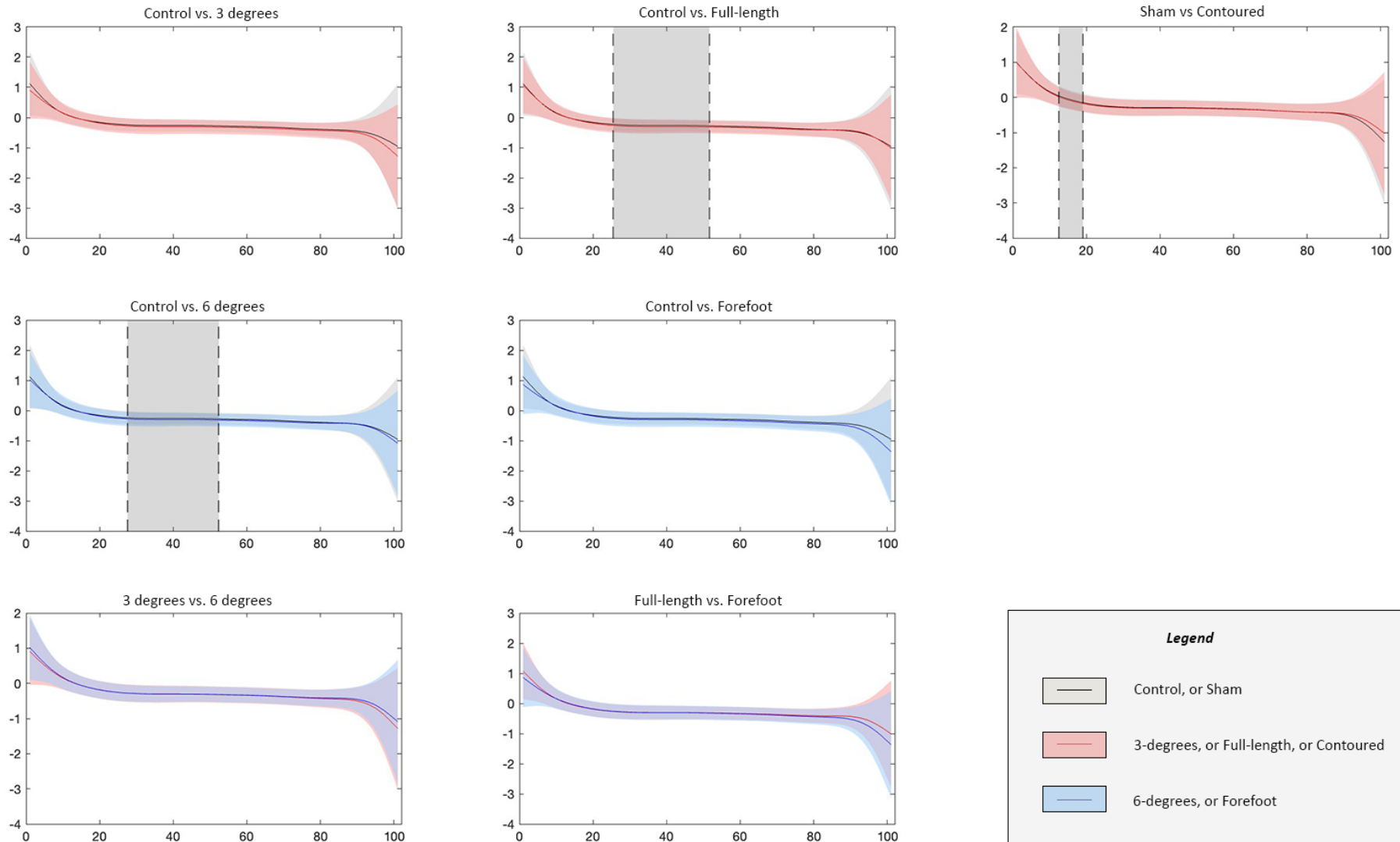


Figure 6.5: Centre of Pressure (COP) trace and Statistical Parametric Mapping (SPM) analysis of running gait. X axis represents 0-100% stance phase. Y axis represents COP normalised to foot width and presented the number of radii from the midline where a positive value indicates lateral deviation and negative values indicate medial deviations. Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue.

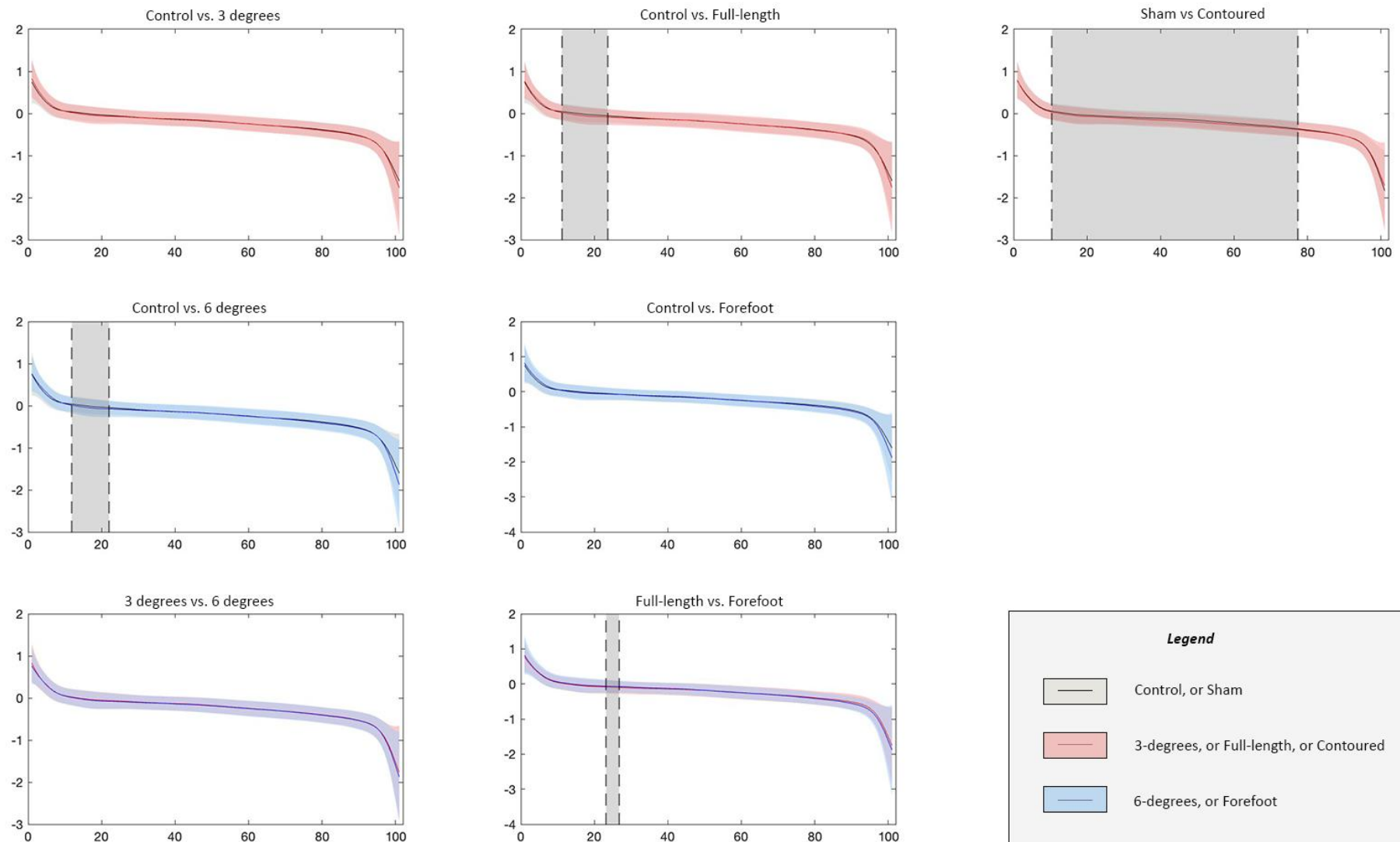


Figure 6.6: Centre of Pressure (COP) trace and Statistical Parametric Mapping (SPM) analysis of walking gait. X axis represents 0-100% stance phase. Y axis represents COP normalised to foot width and presented the number of radii from the midline where a positive value indicates lateral deviation and negative values indicate medial deviations. Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue.

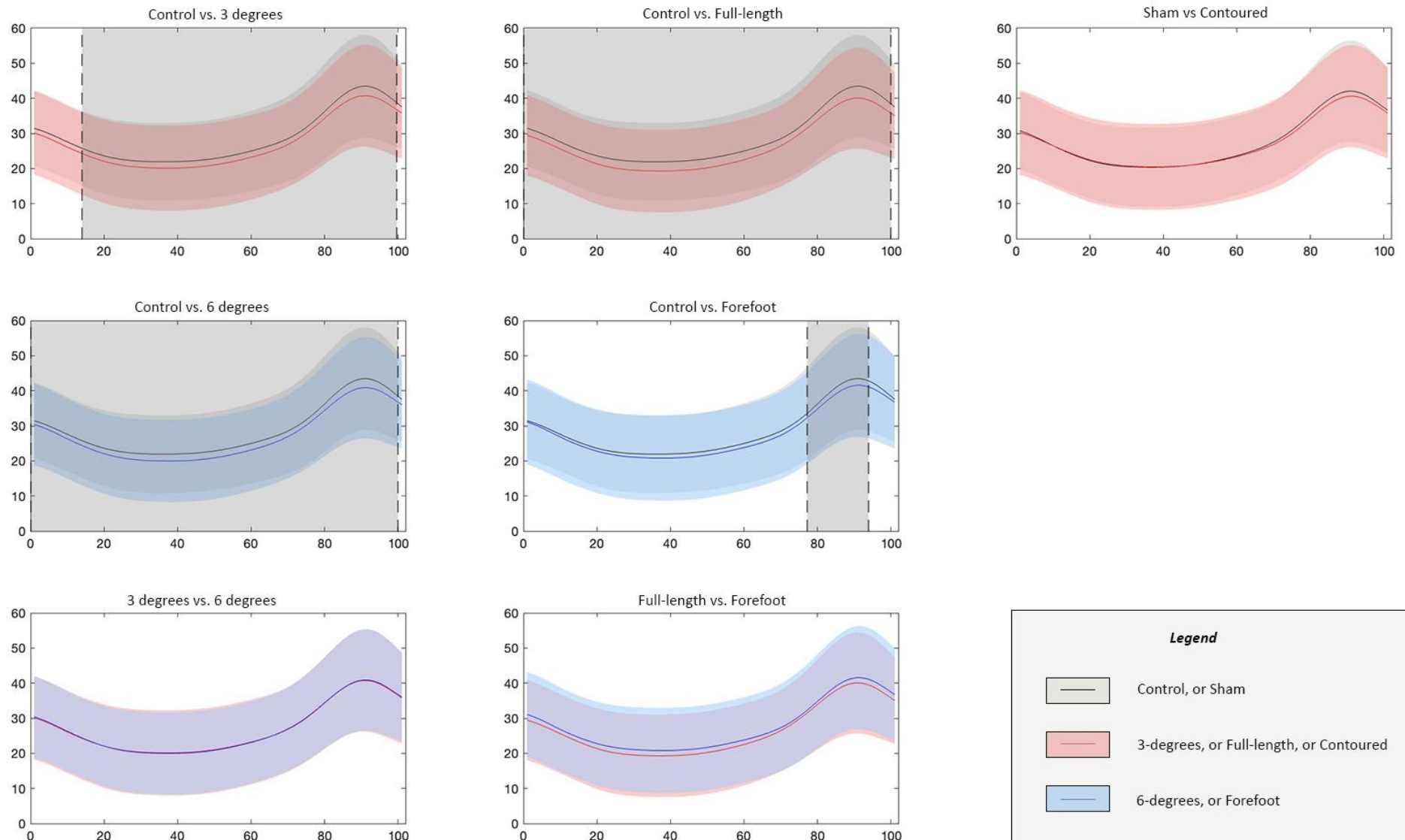


Figure 6.7: First metatarsophalangeal joint (MPJ) kinematics and Statistical Parametric Mapping (SPM) analysis for running gait. X axis represents 0-100% stance phase. Y axis is first MPJ position (degrees extended). Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue.

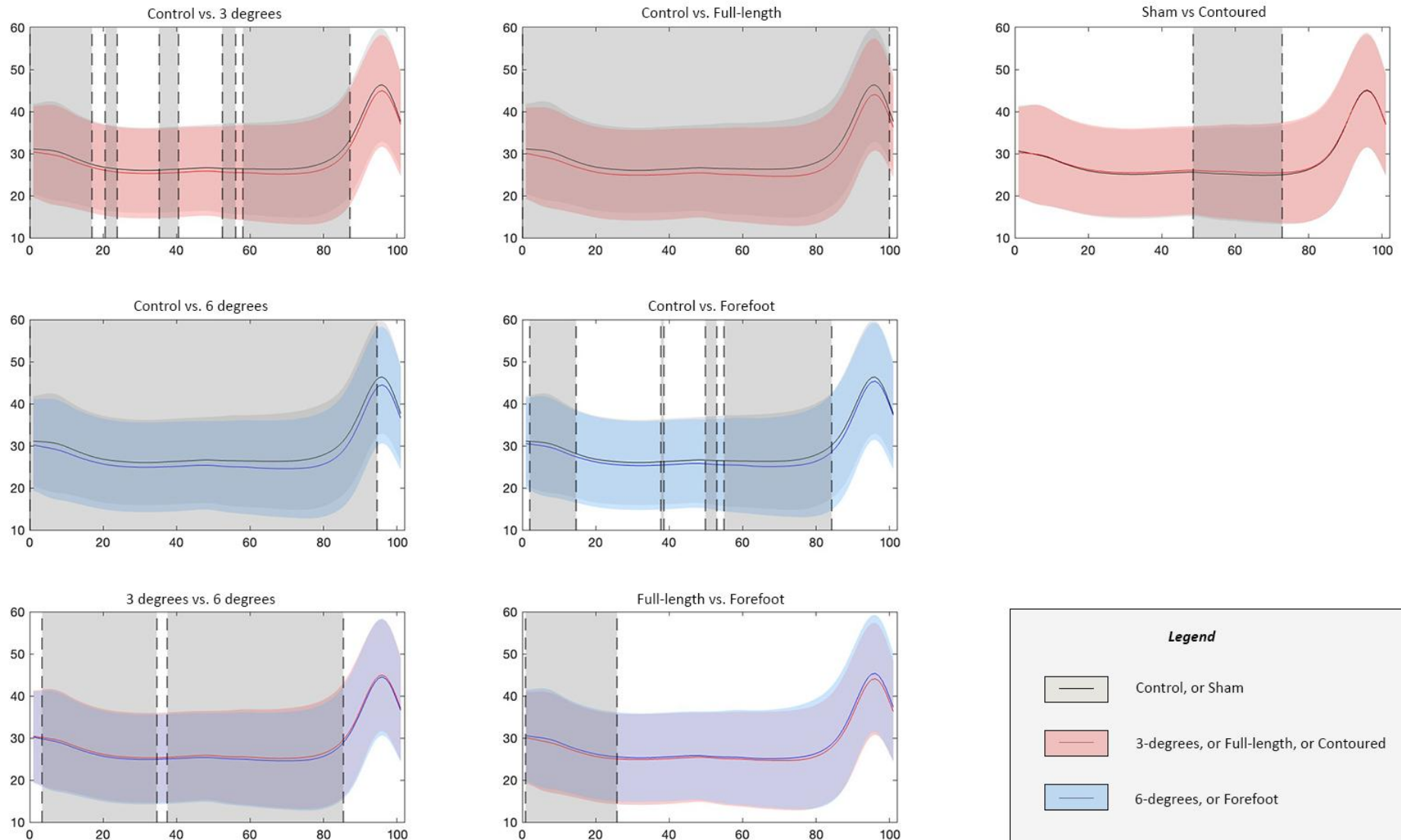


Figure 6.8 First metatarsophalangeal joint (MPJ) kinematics and Statistical Parametric Mapping (SPM) analysis for walking gait. X axis represents 0-100% stance phase. Y axis is first MPJ position (degrees extended). Vertical shading represents periods of (SPM) significance. Coloured shading represents standard deviation. Note, the purple shadowing is a result of red being overlaid on blue.

6.6 Discussion

This study explored the effect of varying lateral wedge inclination and placement on first MPJ extension and foot COP during walking and running gait. Data indicated a consistent reduction in first MPJ extension with the use of a lateral wedge, regardless of wedge inclination or placement. Data also demonstrated a statistically significant medial shift in COP when lateral wedging was applied.

6.6.1 Reduced first MPJ Extension

Data demonstrated that lateral wedges reduce first MPJ extension in both walking and running gait, compared to unwedged insoles. The reduction in first MPJ extension observed in this study contrasts with the findings of Du et al. (196) who reported no significant influence of lateral wedging on first MPJ function during walking gait. Several potentially important differences exist between the current study and Du et al. (196) which may, in part, explain the contrasting results. Firstly, Du et al. (196) utilised wedges that may have overestimated the inclination of the wedge. The authors used wedges 7 and 10 mm thick on the lateral side, equating them to 5° and 7° lateral wedges, respectively. This assumes that the wedges were 80-82 mm wide. The average width of the ball of the foot for men has previously been reported to be 98-105 mm (234, 235). Therefore, if the wedge were applied over a width of 120 mm for a participant with a wider foot, this would equate to 3.3° and 4.7° for the 7 and 10 mm wedges, respectively.

Differing wedge materials may contribute to the variation in findings between the current study and previous research. Du et al. (196) constructed wedges from EVA, and the current study used polyethylene foam. Both studies reported material hardness using different scales, limiting the comparability. The current study reported modification hardness of 61 Asker C, whilst Du et al. (196) used material which was 30 Shore A. The reported density was notably different, potentially indicating a reporting error. Du et al. (196) described using material with a density of 940kg/m³, which exceeds the typical maximum density of EVA. In contrast, the material density used in the current study was 140kg/m³. The material properties of foot orthoses have been shown to influence impact peak, vertical loading rate, peak propulsive force, plantar pressure distribution, and comfort (124, 133, 236).

The medial shift in COP observed in the current study may have also contributed to the reduction in first MPJ extension due to the increased plantar loading of the first metatarsal head and reduced capacity for downward movement. Theoretically, this could be associated with the Windlass mechanism, which proposes a direct and unavoidable relationship between extension

of the first MPJ and downward movement of the metatarsal head (44). It has been suggested that first MPJ extension is restricted if the metatarsal head is not allowed to drop (43). Although the Windlass mechanism is theoretical, the association between the position of the first metatarsal head and first MPJ kinematics has been supported by several previous studies (237-241). To illustrate this point, Roukis, Scherer and Anderson (241) demonstrated a 19% decrease in first MPJ extension when the first metatarsal head was elevated 4 mm using an orthosis.

The concept of kinematic coupling may also explain the reduced first MPJ extension found in the current study. This phenomenon describes how the movements of joints within the foot are significantly affected by the surrounding joints. Under this concept, the motion of the first MPJ both impacts and is impacted by the midtarsal joints (242). Williams, Arch and Bruening (242) demonstrated that a 19% restriction in first MPJ ROM reduced midtarsal motion by approximately 10%. Similarly, Manfredi-Marquez et al. (243) reported midfoot supination occurred as the first MPJ extended. Lateral wedges have been shown to cause abduction and plantarflexion of the navicular (244). Extrapolation may suggest that these movements in the midfoot could limit first MPJ extension due to kinematic coupling.

6.6.2 Medial COP Shift

The second main finding of this study was that, compared to the control condition, 6° or full-length wedges shifted the COP medially. This finding contradicts previous research, which suggests that a lateral wedge shifts the COP laterally (11, 12, 15, 16, 18, 75, 93, 94, 196). These existing studies employ diverse methodological approaches, including differences between treadmill and overground conditions, in-shoe pressure analysis versus force plate analysis, and various wedge designs. While these differences make it challenging to draw out potential explanations for the conflicting outcomes, some potentially important differences exist in the data analysis used in this research, specifically regarding normalisation and reference system, as well as the statistical approach. The current study normalised data to the width and length of the foot and referenced changes with respect to the midline of the foot. This approach is considered best practice; however, only three studies (18, 94, 196) referenced a similar process. Differences in how data were normalised or considered in relation to the lab coordinate system could have also influenced data. Giacomozzi et al. (245) noted the improved accuracy when motion capture is used alongside COP analysis, allowing researchers to identify and reference the long axis of the foot.

Regarding the statistical analysis, Zhang, Lam and Vanwanseele (75), were the only other study to apply SPM to the effect of lateral wedges on COP in healthy adults. Previous studies have

employed more simple statistical methods where COP position is taken as a mean position across a sub-phase of stance, for example, early-, mid- and late-stance (11, 12, 15, 16, 18, 93, 94, 196). Statistical parametric mapping increases the sensitivity of the analysis as differences in COP at every time point are incorporated into the analysis of variance.

Current research offers a limited explanation for how lateral wedges shift the COP laterally, particularly as this effect differs from what is observed when wedges are placed medially, or in the midsole. Medial forefoot wedges, for example, have also been shown to shift the COP laterally (75). Lateral wedges built into the midsole of the shoe shift COP medially (112). Zhang, Lam and Vanwanseele (75) proposed that the medial toe box being generally deeper than the lateral toe box could account for medial and lateral wedges both shifting COP laterally. These authors hypothesised that a lack of space in the lateral toe box increased pressure between the foot and the insole when a lateral wedge was in place. If this assumption is true, the deep lateral toe box of shoes used in the current study may have allowed the lateral wedges to function without the internal pressure produced by the shoe upper, and therefore function more naturally, shifting the COP medially.

Despite conflicting with the existing experimental research, data indicating that lateral wedges shift COP medially aligns with the clinical belief of podiatrists reported in Chapter 5, a survey of NZ podiatrists (2). Based on this survey, almost two-thirds of respondents stated that they would expect lateral wedges to shift the COP medially. Furthermore, a quarter of respondents reported this being the primary reason they use lateral wedging (2).

6.6.3 Wedge Design

Previous research has indicated that the magnitude of the biomechanical effect of lateral wedging is positively correlated with the degree of inclination (12, 75, 112, 179, 183). Contrary to this, the current study found no statistically significant difference between 3° and 6° wedges in relation to their influence on COP during walking or running gait, and no difference in first MPJ extension during running gait. The exception was the effect on first MPJ extension in walking gait; here, 6° wedges further reduced the extension of the first MPJ by approximately half a degree compared to 3° wedges.

Data from this study question the value of using higher inclinations to manipulate first MPJ kinematics or COP, particularly for running gait. A potential concern related to higher inclinations is patient comfort and tolerance, with evidence suggesting that wedges over 5° may lead to patient dissatisfaction and reduced adherence (93, 112, 191-193). Therefore, as the 3°

wedges used in this study do not significantly differ in effect from the 6° wedges, the lower inclination may be more appropriate clinically. This finding aligns with the practice habits of NZ podiatrists, who typically opt for 3 mm (approx. 2-3°) material to fabricate lateral wedges (2).

There is limited evidence investigating the biomechanical effect of lateral wedge length. Most studies only examined one length (commonly 'full-length'), and comparison is difficult due to methodological differences between studies. Consequently, scientific understanding of the influence of lateral wedges is clearer for full-length wedges compared to those placed in the forefoot, even though the latter are more commonly used in clinical practice (2, 136). Based on data from the current study, forefoot wedges do not appear to influence COP. It is perhaps unsurprising that forefoot wedges only influence joint extension in late stance, as this is the period where the forefoot is loaded. This finding aligns with Van Gheluwe and Dananberg (3) who previously reported that forefoot wedges did not influence the rearfoot.

Data showed a greater reduction in the first MPJ extension when wedges were placed on sham (rather than contoured) insoles in walking gait. The mechanism for this is speculative. However, contoured insoles appear to redistribute plantar pressure (76) and may change how lateral wedges affect pressure distribution and subsequently COP. The raised arch could also elevate the proximal base of the first metatarsal and lead to an associated plantar movement of the metatarsal head, evoking engagement of the Windlass mechanism and encouraging first MPJ extension. Data indicated a significant difference in COP when wedges were placed on contoured rather than sham insoles. Specifically, for both walking and running gait, wedges placed on contoured insoles shifted the COP medially, compared to when placed on a sham insole. This effect only occurred for a short period of stance, in the case of running gait (13-19% of stance). Research to understand the effects of sham versus contoured insoles is currently unclear and often demonstrates non-significant findings (11, 246, 247). A recent randomised controlled trial found that contoured insoles were no more effective than sham insoles at reducing pain or self-reported physical function and quality of life in patients with first MPJ OA (246). Although Paterson et al. (246) did not report biomechanical findings, their results question the clinical value of using contoured insoles as a default for underfoot interventions. Contrary to Paterson et al. (246), a randomised controlled trial by Yurt, Sener and Yakut (248) investigating sham versus contoured insoles for painful flexible flat foot, found a pronounced difference in which the contoured insoles more effectively reduced symptoms. Jones et al. (11) found no difference between lateral wedges placed on a contoured insole compared to those on a sham insole for a range of kinetic outcomes, including STJ moments and COP excursion. Zhang, Lam and Vanwanseele (75) reported non-significant results regarding how lateral wedges

with differing arch heights influenced COP. These authors, however, compared an insole with a 20 mm arch to one with a 24 mm arch; no sham insole condition was included as a comparator.

6.6.4 Running vs Walking Gait

Despite the biomechanical distinction between walking and running gait, there is limited evidence contrasting the effect of lateral wedges between gait types (22, 136). Data found that the effect of lateral wedging differed for walking compared to running gait. The effects of lateral wedging on COP occurred earlier in stance for walking (12-27%) compared to running (26-52%) gait. Forefoot wedges compared to the control condition, reduced first MPJ extension over a greater duration of stance phase for walking (2-84%) compared to running (77-94%) gait. These differences may relate to the foot spending longer on the ground in walking gait, or the broader range of strike patterns observed in running gait (22, 249). Clinically, the implications of these variances are unclear. These distinctions should influence decisions regarding wedge placement, particularly if the goal of the lateral wedge is to impact the early stance phase for runners.

Full-length wedges and both wedge inclinations (3° and 6°) influenced first MPJ kinematics over similar periods of stance for walking compared to running gait. However, the reduction in extension was greater in running gait. This supports previous evidence that orthoses exert a larger effect on running gait than on walking gait (139). The mean change in first MPJ extension when running on a lateral wedge ranged from 1.7° to 2.4° , compared to differences between 0.7° and 1.6° when walking. Mager et al. (250) identified less first MPJ joint stiffness in running compared to in walking gait despite participants displaying no significant differences in kinematics. It is possible that with less stiffness in the joint during running gait, there is greater capacity for the wedge to make a difference. Previous reports have also indicated that the influence of shoes on foot and lower limb kinematics may be greater for walking than for running gait (251).

6.6.5 Strengths and Limitations

This research must be considered in the context of its strengths and limitations. The current study used a randomised crossover design and examined a wide range of lateral wedge designs across both walking and running gait. The robust methodological approach allows a clear comparison of design considerations and gait type, enhancing clinical decision-making. The use of SPM for the statistical analysis ensured that the entire stance phase was considered, allowing the authors to present findings uninfluenced by clinical assumptions and biases. Centre of

pressure analysis has been shown to have some limitations during the initiation and termination of stance phase, when force is low and is more difficult to distinguish from background noise. This may have led to errors in the calculation and greater variation in data primarily at the beginning and end of stance phase. Another potential limitation is that reflective markers were placed on the shoe, and not directly on the foot, which may not accurately reflect the movement of the joints of the foot. To minimise this potential issue, shoe markers were not removed between conditions and were checked by an experienced biomechanical podiatrist for accuracy following each insole replacement prior to continuing data collection. A benefit of this method however, is that the shoe's integrity and function were not compromised (252). The intention of this research was to inform clinical practice. However, it is important to note that these findings are biomechanical and collected in a lab environment using healthy participants therefore may not have any bearing on patient perception or symptomatic change for populations with foot pain.

6.6.6 Future Directions

Further research should seek to establish if the reduction in first MPJ extension, and medial COP shift are seen in populations who are frequently prescribed lateral wedges, such as those with medial knee OA, chronic ankle instability, and plantar heel pain (2, 171). Additionally, there have been previous indications that the effect of lateral wedging may depend on the foot posture of the wearer (94). It would be clinically useful to know if this also applies to COP and the first MPJ extension. Given the common variation in strike patterns among runners, further research could explore the impact of a runner's strike position or running velocity on the outcome of lateral wedging.

6.7 Conclusion

The current study demonstrated that lateral wedges reduce extension of the first MPJ for both walking and running gait. First MPJ extension in running was largely unaffected by inclination and placement. On the contrary, during walking both the 6°, and full-length wedges elicited a greater reduction in first MPJ extension compared respectively to the 3°, and forefoot wedges. Lateral wedges caused a medial shift in COP, consistent for both 6° and full-length wedges. This study demonstrated that the influence of lateral wedges varies between walking and running gait. The outcomes were more pronounced for running gait but occurred over a shorter duration compared to walking gait. The data provide new insights into the biomechanical function of

lateral wedges, offering guidance for their clinical application. The results emphasise the importance of lateral wedge placement and design as insole contour, inclination, and length affect first MPJ extension and COP differently for each walking and running gait.

6.8 Novel Contributions of Chapter 6

Chapter 6 is significant regarding its implications for practice and contribution to scientific knowledge, as the results contrast with current clinical beliefs. Lateral wedges are commonly used in clinical practice (2, 117) to increase first MPJ extension and shift COP medially (2), but their design and implementation often do not align with existing research. Chapter 6 demonstrated that lateral wedges reduce first MPJ extension, the opposite of what is expected by clinicians. These data demonstrated that, as expected by NZ podiatrists, COP is shifted medially, however, only when using full-length or 6° wedges.

Further novel contributions provided in Chapter 6 include the examination of wedge length, gait type and reflection of clinical practice. As identified in Chapter 4, wedge design has been largely overlooked in previous research concerning the effect of lateral wedges on healthy adults. This chapter provided results for two wedge lengths and determined that the influence of length is different depending on the outcome measure of interest; wedge length does not appear to change the outcome regarding first MPJ extension, and only full-length wedges had a significant influence on COP. This study was also novel in comparing the effects of lateral wedging on walking and running gait, demonstrating that the influence of lateral wedging is observed over differing periods of stance phase for walking compared to running.

Chapter 7: Thesis Discussion

This thesis investigated the use and function of lateral wedging in podiatric practice and the biomechanical effects of varying wedge designs on walking and running gait. This chapter will provide an overview of the main findings of the thesis. The implications, strengths, limitations, and future directions related to this work will be presented.

7.1 Main Findings

7.1.1 Research question 1: When prescribing custom foot orthoses what design characteristics are most frequently selected by NZ podiatrists?

As presented in Chapter 3, when prescribing CFO, the design characteristics most frequently used by NZ podiatrists were rearfoot varus cast correction (64%), Modified Root shell style (61%), heel cup deeper than 14 mm (36%), medial rearfoot (Kirby) skive (36%), and lateral forefoot wedge (22%) (117). Survey data presented in Chapter 5 also indicated that NZ podiatrists frequently used lateral wedges when prescribing custom and prefabricated foot orthoses.

7.1.2 Research question 2: Does the clinical diagnosis for which an orthotic is being prescribed predict characteristics included in the design?

Each of the four most common diagnoses identified in Chapter 3 (plantar heel pain, pes planus, posterior tibial tendon pain, and ankle sprain) exhibited associations with specific CFO characteristics (Table 7.1). Three to five prescription characteristics were more likely to be included when designing an orthosis for each diagnosis.

Table 7.1: CFO design characteristics associated with common clinical diagnoses

Plantar heel pain	Pes Planus	Posterior tibial tendon	Ankle sprain
Modified Root or Sagittal plane style shell	Medial STJ axis shell style	Sagittal plane or Medial STJ axis shell style	Lateral forefoot wedge
Lateral forefoot wedge	Arch pad	Rearfoot varus cast correction	Rearfoot valgus cast correction
Heel cushion	Medial forefoot wedge	Arch pad	Lateral side high
Plantar fascia groove	Medial side high	Medial rearfoot (Kirby) skive	-
-	-	Medial forefoot wedge	-

The data presented in Chapter 3 explored 1000 CFO prescriptions submitted by NZ podiatrists. The most common diagnoses in this data set were PHP ($n=110$, 11%), pes planus ($n=81$, 8%), posterior tibial tendon pain or dysfunction ($n=61$, 6%), and ankle sprains ($n=50$, 5%).

Table 7.1 outlines the associations for each clinical diagnosis, where clinicians were more likely to include the characteristic in their orthotic design. Except for pes planus (140, 159, 161, 253), prior to the study outlined in Chapter 3, there were no available data detailing common design characteristics utilised by podiatrists when prescribing CFO. Although this is not an indication of 'best practice', the details of common practice habits serve as a starting point for future research on the optimal design of CFO for these common clinical conditions.

7.1.3 Research question 3: What material properties (thickness, density, and hardness) are utilised in existing research regarding lateral wedges, and where on the insole are these placed?

Existing research predominantly describes full-length or 'sulcus' length wedges, and an average inclination of approximately 6° . Whilst EVA was the most common material, the density and hardness were inconsistently reported, making comparisons between studies difficult.

The scoping review presented in Chapter 4 revealed that 56% ($n=15$) of the included studies utilised full-length or sulcus length wedges. Comparatively, forefoot wedges and rearfoot wedges were each utilised by 15% ($n=4$) of studies. A major gap in the research prior to this thesis was that only one study (3) had examined more than one length of lateral wedge. Chapter 4 also identified a wide range of wedge inclinations utilised within previous research. These ranged from 3° to 14° . Across 27 studies, the average wedge inclination was found to be 5.8° with an SD of 2.0° .

7.1.4 Research question 4: What are the most common materials NZ podiatrists use when making lateral wedges, and where are these placed?

New Zealand podiatrists most commonly constructed lateral wedges using 3 mm medium-density EVA, which they positioned from the calcaneo-cuboid joint to the sulcus of the foot (Figure 7.1).

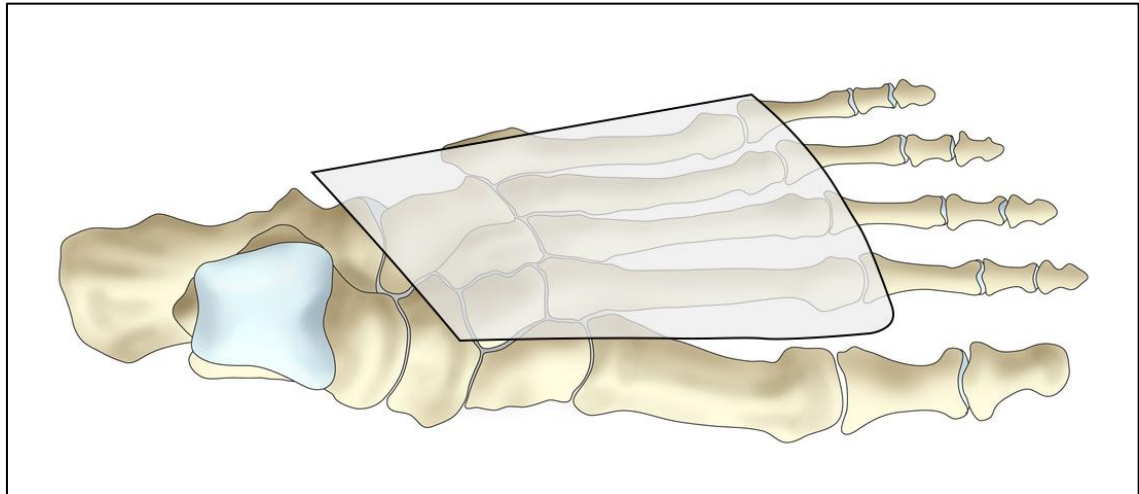


Figure 7.1 Typical placement of a lateral wedge by NZ podiatrists

The survey presented in Chapter 5 found that 53% of NZ podiatrists fabricated wedges that began at the calcaneo-cuboid joint, while 40% selected the styloid process as their proximal landmark. Comparatively, when anatomically placing the distal border, the majority (77%) of respondents opted for the sulcus of the foot. Ninety-one percent used medium-density EVA, making this the most common material selection. Additionally, 51% of respondents often chose to use either low-density EVA or felt to manufacture lateral wedges. The survey also found that 37% of podiatrists did not fabricate their own wedges; these clinicians relied upon prefabricated wedges and, therefore, had limited control over the material properties and length of the wedges.

7.1.5 Research question 5: How do lateral wedges affect foot and ankle kinetics and kinematics of healthy individuals?

Lateral wedges reduce first MPJ extension during the stance phase of walking and running gait. Some lateral wedge variations (6°, and full-length) also shift the COP medially during both walking and running gait.

7.1.6 Research question 6: How does lateral wedging placement influence the foot's kinetics and kinematics in walking and running gait?

In relation to COP, the decision to place a lateral wedge either under the forefoot or along the full length of the insole is important. Chapter 6 found that only full-length lateral wedges made a significant difference to the COP position, forefoot lateral wedges did not.

By contrast, wedge placement was less important in relation to first MPJ extension. A significant difference was identified only in walking, where full-length wedges reduced first MPJ extension to a greater extent than forefoot wedges. In running gait, no significant differences were detected when comparing full-length to forefoot wedges, and both were significantly different from the control condition.

7.1.7 Research question 7: Does the biomechanical effect of lateral wedging differ if placed on an otherwise flat or contoured insole?

In most cases, the biomechanical effect of lateral wedging is influenced by whether it is placed on a sham (flat) or contoured insole. This difference was observed in relation to COP during both walking and running, and the first MPJ extension during walking. The contour of the insole did not significantly affect first MPJ extension in running gait.

When lateral wedges are placed on a contoured insole, their influence on the COP increases, resulting in a more pronounced medial shift than when the same wedge is applied to a sham insole. The mean magnitude of this difference in Chapter 6 was 3 cm. In contrast, a contoured insole reduces the effect of lateral wedging on first MPJ extension. When a lateral wedge is placed on a sham insole, it reduces first MPJ extension in walking gait by approximately 0.5° more than when the same wedge is placed on a contoured orthosis.

7.2 Implications of the Thesis

7.2.1 Theoretical Implications

Podiatric theories provide clinicians and researchers with a conceptual framework that may be used to explain foot function and plan management strategies. Four theories, which are commonly discussed in a podiatric context, and in this thesis, are Root theory (6, 7), Sagittal Plane Facilitation theory (43), Subtalar Joint Axis Location and Rotational Equilibrium theory (45, 46), and Tissue Stress theory (49).

The Windlass mechanism, a key tenet of Sagittal Plane Facilitation theory became a significant point of discussion within this thesis. Many podiatrists believe lateral wedging increases first MPJ extension and report this intention as their primary objective when using lateral wedges (Chapter 5). This suggests a significant emphasis on the Windlass mechanism. The Sagittal Plane Facilitation theory also ranked second amongst the same group of podiatrists as the theories most likely to influence the prescription of orthoses. Despite these beliefs, the notion of

increasing first MPJ extension with lateral wedging was not supported with the data (Chapter 6). The findings of Chapter 6 appear to support elements of Hicks (44) original descriptions of the Windlass mechanism, in particular the idea that first MPJ extension requires downward movement of the first metatarsal head. An argument presented in Chapter 6 to explain the reduction in first MPJ extension caused by lateral wedges is that the concurrent increase in loading of the medial forefoot restricts the capacity of the first metatarsal head to move downwards. What remains unclear, however, is the influence that this restriction in the first MPJ extension has on tissue stress in the lower limb or an individual's symptoms.

Experimental elements of this thesis did not test the concepts that underpin Root theory, Subtalar Joint Axis Location and Rotational Equilibrium theory, or Tissue Stress theory and therefore cannot rebut nor substantiate the application of lateral wedging for these means. Interestingly NZ podiatrists do not consider Root theory to be influential in their prescription of orthoses (Chapter 5) and yet balancing the forefoot with the rearfoot was the third most common reason for prescribing a lateral wedge (Chapter 5) and Modified Root was the most common shell style when prescribing CFO (Chapter 3). Previous research has also disproven the association between forefoot valgus and compensatory changes in gait (peak rearfoot eversion during midstance) (8). The Tissue Stress theory is seen by podiatrists as the most influential paradigm when prescribing foot orthoses (Chapter 5). Podiatric application of the Tissue Stress theory relies on the assumption that an intervention (lateral wedging in this case) will reduce stress placed on a tissue to a tolerable level. Although this thesis did not measure tissue stress, podiatrists frequently use lateral wedging for peroneal tendon issues, CAI, and PHP. Peroneal tendinopathy and CAI have been previously linked to lateral COP deviation (201, 202). Therefore, the medial shift in COP observed in Chapter 6 may reduce tissue stress associated with these diagnoses and aid in reducing symptoms. Lateral wedging was linked to a reduction in plantar fascial strain by Kogler et al. (4), however, this study was completed in vitro, and therefore, caution should be applied when generalising these findings.

7.2.2 Clinical Implications

The findings from this thesis have the potential to influence practice and should be considered by clinicians who engage in the fabrication of foot orthoses. Each study was designed to be directly relatable to clinical practice, either by exploring the beliefs and habits of clinicians or examining the effect of lateral wedges designed similarly to those typically seen in practice. Four important clinical insights have emerged from this thesis:

1. Reevaluating lateral wedge function

The results of this thesis regarding first MPJ kinematics oppose commonly held clinical beliefs. This requires clinicians to critically review their understanding of lateral wedge function.

2. Impact of lateral wedge design

Lateral wedge design is often poorly described in research, making clinical implementation a challenge. However, results from this thesis show that design is an important consideration.

3. Ensuring effectiveness in lateral wedge prescription

It is standard practice for clinicians to place modifications on contoured insoles. However, this is not always the most effective solution. It is important to consider what is optimal rather than what is typical.

4. Aligning lateral wedge use with purpose and activity

The intended use of orthoses is crucial. Lateral wedges function differently during walking than running, and their design and implementation should reflect these variations.

7.2.2.1 *Reevaluating Lateral Wedge Function*

The primary clinical insight derived from this research is the discovery that the function of lateral wedges contradicts prevailing clinical assumptions of NZ podiatrists. Clinicians have traditionally posited that lateral wedges increase the extension of the first MPJ. However, the findings from this thesis indicate that lateral wedges reduce the first MPJ extension. Despite this inconsistency, lateral wedges remain one of the most commonly employed modifications in foot orthoses, featuring in approximately 22% to 44% of prescriptions by NZ podiatrists (2, 117). The sustained utilisation of these modifications implies that the outcomes, irrespective of the noted discrepancy, must generally be perceived as satisfactory. This raises questions about the underlying mechanisms of lateral wedges. If the clinical effect is positive, this would seem to

indicate that the patient benefited from a reduction in first MPJ extension. However, as the kinematics of this movement are small and impractical to assess clinically, the podiatrist may attribute any symptomatic improvement to successfully increasing the first MPJ extension as planned.

A critical gap not addressed in this thesis is the symptomatic effect of decreased first MPJ extension on individuals presenting with foot pain. Accordingly, it is unclear whether any positive outcomes derived from lateral wedges are created by the reduction in first MPJ extension, or another mechanism, such as kinetic changes or placebo (105). This finding should not discourage clinicians from using lateral wedges, as the thesis merely describes the influence these modifications have on the first MPJ extension and raises clinical questions. It should, however, prompt clinicians to critically review the desired biomechanical outcome when prescribing lateral wedges and consider how this relates to other patient-centric outcomes, in particular symptomatic change and comfort.

7.2.2.2 Impact of Lateral Wedge Design

Existing research seldom examines the impact of wedge design and often provides inadequate descriptions of wedge characteristics. To ensure that podiatrists remain current and provide their patients with the most appropriate and effective management, it is essential to engage in evidence-based practice. However, this can be particularly challenging when the body of research lacks transparency regarding the specifics of interventions used. This is a significant concern in the case of lateral wedges used for healthy individuals. There is almost no comparison of differing wedge lengths, poor descriptions of wedge placement, and minimal information regarding material properties. Differences in terminology regarding the placement of wedges, material density and hardness and in some cases, inclination or thickness make interpreting or reproducing the results challenging.

Based on the findings presented in Chapter 6, wedge design influences outcomes, particularly in relation to COP, and should receive greater attention from researchers. This thesis should encourage clinicians to carefully consider the placement and inclination of wedges. The findings indicate that wedge placement and inclination significantly affect the impact of lateral wedges on the COP. However, first MPJ extension is generally not influenced by these factors. Clinically, this suggests that podiatrists should meticulously assess their objectives when prescribing lateral wedges, as longer (full-length) and higher inclination (6°) wedges more significantly shift COP (medially). In contrast, wedge length and inclination matter less for reducing first MPJ extension. Given that previous evidence has suggested steeper wedge inclinations can be less

comfortable and thus reduce compliance, this needs to be balanced alongside the desired biomechanical objective (191-193).

Underfoot interventions, such as lateral wedging, appear to work in part by manipulating the location and magnitude of force as it is applied to the plantar surface of the foot. This force is applied differently depending on wedge placement and inclination, but also may vary based on foot type, footwear, and strike position. For instance, if the foot's COP naturally falls more laterally, the lateral wedge may function differently than it would in a foot where the COP is positioned more medially. In such cases, the more laterally positioned COP may exert greater force on the lateral wedge, resulting in a different reaction force from the modification compared to a foot with a more medially located COP. The same variation may also occur according to other factors, such as strike position, footwear fit and type. These interactions are theoretical and were not explored by the current thesis; however, this would be an interesting avenue for future research.

7.2.2.3 Ensuring Effectiveness in Lateral Wedge Prescription

A constant challenge for clinicians is regularly and robustly challenging assumptions, biases and practices formed out of habit. According to Potthoff et al. (254), there is a strong association between habit and the behaviour of healthcare workers. They observed that as new evidence and best practices emerge, these ingrained habits pose challenges for adaptation (254). For example, the survey presented in Chapter 5 revealed that in 75% of cases, podiatrists place lateral wedges on an orthosis rather than on the sock liner or a simple insole housed within the shoe. It is unclear if this decision to place lateral wedges on a contoured surface is one borne out of habit or a considered decision with optimal patient outcomes in mind. Findings from Chapter 6 indicate that the contour of the base insole enhances the impact of lateral wedging for COP; however, it reduces the effect on first MPJ extension. The primary function of the contoured orthosis may extend beyond merely serving as a platform for the lateral wedge, as these cases are often complex and multifaceted. However, if the central role of the underfoot intervention is predominantly associated with the lateral wedge, the podiatrist should consider positioning the wedge on the existing sock liner. This approach may prove to be more efficacious in some cases. Aside from enhancing the effect (for COP), a simple, sham insole, such as a sock liner, comes with several other potential benefits. These may require less time for the patient to become familiar with the intervention, do not have the same associated costs for the patient, and have a shorter timeframe for fabrication due to their simplicity. Thus, the findings of this

thesis should prompt podiatrists to critically evaluate their actions and determine whether their decisions are driven by habit or what is genuinely in the best interest of their patients.

7.2.2.4 Aligning Lateral Wedge Use with Purpose and Activity

In line with the suggested specificity concerning wedge design, this thesis encourages clinicians to be cognisant of the intended use when prescribing lateral wedges. Chapter 5 revealed that 68% of NZ podiatrists believe the effect of lateral wedges is the same in both walking and running gait. Furthermore, 59% reported having the same biomechanical objectives regardless of gait type, and 64% used the same wedge design for running and walking gait. Interestingly, 69% of respondents in the clinician survey felt that the 'type of activity it will be used for' was an important consideration when designing and prescribing a lateral wedge. Whilst 'optimal' wedge design for each gait type depends on the biomechanical or clinical intentions, this thesis has demonstrated that the biomechanical outcomes are different for each walking and running gait. Centre of pressure changes occurred later in the stance phase for running gait, compared to walking. The magnitude of kinematic reduction in the first MPJ was also greater in running gait compared to walking gait. While this thesis does not attempt to explain the clinical relevance of these findings, it is important to note that they are different, and this should be considered by clinicians when making decisions regarding lateral wedges. Expanding these findings to other movements or activities would make it reasonable to anticipate differences in outcomes. Therefore, it's likely that the impact of lateral wedges would also vary for activities such as jumping, cutting, and turning. This highlights the need for clinicians to consider the intended use of the lateral wedge when making clinical decisions about its application.

7.2.3 Implications to Education and Industry

Education providers and industry partners who fabricate foot orthoses undeniably influence podiatric practice. Universities that provide undergraduate training for prospective podiatrists teach the theory and practice of foot orthoses. Aside from any prior experiences as users of foot orthoses, this education likely represents the first opportunity for students to understand the scientific principles underlying their use and receive practical instruction on creating the various available modifications. These first experiences can be pivotal in forming early practice habits. Things seemingly as simple as material choice and modification placement will be first learned in these formative lessons and often carried into practice for many years. For this reason, educators teaching foot orthoses must work to instil curiosity in their students and the capacity to continue learning after graduating. Albeit only for lateral wedges, this thesis provides

educators with an enhanced understanding of how design decisions influence biomechanical outcomes. It is recommended that educators reinforce the importance of design characteristics and encourage students to make carefully considered and well-rationalised decisions regarding the design and fabrication of lateral wedges (and, most likely, other orthotic modifications). Students must be aware that material placement and inclination are unlikely to have the same biomechanical impact for all desired outcomes. For example, in the case of lateral wedges, changes in wedge inclination are relevant to COP, and not to first MPJ extension.

The importance of industry partners such as commercial orthotic laboratories and manufacturers of prefabricated orthoses should not be overlooked. The 'standard' design adopted by manufacturers and labs may be seen as the gold standard by practitioners due to the high regard in which the organisations are typically held. Commercial orthosis labs in NZ receive prescriptions via an online portal where the podiatrist designs the CFO using drop-down menu options and tick boxes. In the case of lateral wedges, this is a tick box that allows the podiatrist to either include a lateral wedge in the orthosis or not. The default design and placement of the wedge is chosen by the orthosis lab, presumably based on experience, as evidence is not available to guide this decision. However, the design used by commercial orthotic labs could be seen by a practitioner as something they should aim to replicate in their modifications. For this reason, commercial orthosis labs must provide the ability for a podiatrist to specify design elements, highlighting the fact that lateral wedges are not 'one size fits all'. Based on the findings from this thesis, it is recommended that the option to include a lateral wedge should be more than a yes or no option. Instead, labs should require clinicians to select their preferred length and inclination. Additionally, the lab should be clear about what material (including density and hardness) is used by default and provide the clinician with an option to select alternatives.

Finally, approximately one-third of NZ podiatrists use prefabricated wedges. These are pre-wedged modifications made to a specific size, typically with an adhesive backing, designed to be easily attached to a PFO. The primary limitation of these is that they are prefabricated modifications which come in a size range and a limited number of shapes and inclinations. Accordingly, the clinician's ability to be specific regarding their design decisions is limited by the commercially available range of options. By using these modifications, clinicians are trading design specificity for convenience, which is often an unavoidable reality of limited space and time in practice. Given the high use of prefabricated modifications within the industry, manufacturers have a great deal of influence over patient outcomes. The findings from this thesis should encourage manufacturers to review the breadth of their available range of prefabricated modifications, particularly lateral wedges. Although commercial considerations

will be a factor, from a clinical perspective, the industry and the patients it serves would benefit from the ability to choose between a range of lengths and inclinations.

7.3 Strengths and Limitations of the Thesis

This thesis presents several noteworthy methodological strengths. Foremost among these is its strong clinical foundation. Each research stage was carefully designed to ensure its relevance and applicability to clinical practice. The initial phases identified the frequent use of lateral wedges in clinical settings. Despite their common application, substantial gaps persist in our scientific understanding of their functional mechanisms. Accordingly, the practice habits uncovered in Chapters 3 and 5 were used to develop the protocol for Chapter 6, which ultimately interrogates commonly held clinical assumptions.

Additional strengths of the thesis include the broad range of methodologies and statistical analyses applied. To answer the research questions, this thesis has included an audit of prescription records submitted to commercial orthotic labs, a scoping review, an online survey of clinicians, and a randomised crossover trial, including 3D gait analysis. These diverse methods each contributed vital information that enhanced our understanding of the application of lateral wedges in practice, the existing evidence base, and identified gaps. Additionally, these methods allowed for a critical evaluation of the accuracy of the clinical assumptions that underpin current practice. Statistically, the applied methods needed to be rigorous and clinically useful. Chapter 3 includes a novel analysis of the symmetry of foot orthoses, which was able to draw a clearer picture of clinical practice habits than an intraclass correlation coefficient, which has previously been employed. Chapter 6 utilised SPM to analyse the effects of lateral wedging over the entire stance phase. This analysis method is becoming increasingly common in biomechanical studies (255). Most research on lateral wedging utilises simple statistical methods, often dividing stance into phases and analysing peak or mean values within those sub-sections. The advantage of SPM is that the stance phase is considered as a whole, and regions of significant differences are identified. This prevents effects from being washed out or reduced because they span a section traditionally split in two.

Several limitations must also be acknowledged. Despite efforts to maximise engagement, the clinician survey in Chapter 5 only received 65 complete responses. This may limit the generalisability of findings and could mean that some clinical assumptions investigated thereafter are only held by a subsection of NZ podiatrists. This limitation may, in part, be addressed by Chapter 3, which included 1000 orthotic prescriptions and does not rely on

participant recall. However, this study is limited by the lack of information concerning beliefs and why decisions were made. Chapter 3 aimed to draw associations between the clinical diagnoses for which orthoses were prescribed, and the characteristics included in the prescription. The major limitation of this was, the subjective nature of diagnoses and the lack of information regarding clinical outcomes.

Contradictory data was found between the lab audit and the survey of NZ podiatrists regarding the frequency of lateral wedge use. The lab audit (Chapter 3) identified the inclusion of lateral wedges on 22% of CFO, whereas the survey (Chapter 5) reported lateral wedges were used in 44% of foot orthoses. The variation between the data is likely due to two reasons. Firstly, data from the survey relied on participant recall and may not truly reflect practice habits. It is also possible that a degree of self-selection bias was present in the study, as the title was “The use of lateral wedges in clinical practice”; this may have resulted in those clinicians who regularly use lateral wedges being more likely to respond. Secondly, the findings of Chapter 3 relate only to CFO, whereas Chapter 5 includes all foot orthoses and simple insoles. It has previously been established that NZ podiatrists prescribe significantly more prefabricated orthoses than custom orthoses (102). Thus, if podiatrists are more likely to use lateral wedges on PFO, that could explain the difference.

Chapter 6 was a trial of various wedge combinations derived from Chapters 3, 4, and 5. Although this study was made robust by the randomised crossover design, several challenges and limitations exist, as they do in most orthosis research (105). Like any biomechanical research, providing mean pooled data will inevitably misrepresent outliers. However, we hope the statistical methods employed help reduce this misrepresentation. Regardless, clinicians should be encouraged to consider their patients specifically and expect to encounter cases that do not follow this thesis's findings. Chapter 6 also analysed COP using a force plate and therefore may have included some erroneous data during the initiation and termination of the stance phase when forces are low and it is more difficult to differentiate the signal from background noise (256). As the SPM analysis did not detect any significant differences in COP within the first 10% or final 20% of the stance phase, these low force periods are unlikely to have influenced the findings.

Finally, the major limitation of the 3D gait component is the placement of markers on the shoe, not directly placed on the skin. This placement will not provide an exact representation of foot kinematics and instead details the movement of the shoe (257). Compared to bone pin markers, both shoe- and skin-mounted markers have been shown to overestimate movement (257); however, they are less invasive and, therefore, more commonly used (258). Given the infrequent use of bone pin markers, it is standard practice for researchers to select between markers

positioned directly on the skin (using sandals or holes cut in a shoe) or placed on the upper of the shoe, overlying bony landmarks (257, 258). Radiographic comparison has demonstrated that markers placed on a shoe are generally no more than 3 mm further from the anatomical target than skin-mounted markers, concluding that markers placed on a shoe are anatomically accurate (259). Importantly, both options for marker placement provide an approximation of joint motion and may not be directly comparable. However, shoe-mounted markers tend to underestimate motion compared to skin-mounted markers (260-262). Therefore, as a difference was found using shoe-mounted markers, it is likely that this difference would be exaggerated if the study was repeated using markers placed directly on the skin.

7.4 Future Research Directions

This thesis has raised questions regarding the specificity used in the design of foot orthoses, challenged widely held clinical beliefs, and uncovered the biomechanical nuances of lateral wedges. Considering the limitations of the current thesis, several questions remain, which lead to planned future research directions.

7.4.1 **The Influence of Foot Posture and Strike Pattern on the Outcome of Lateral Wedging for Runners**

Given that this work aims to inform clinical practice and aid clinicians in the selective application of lateral wedging, it is crucial to consider potential covariates such as strike position and FPI. Podiatrists generally believe that a runner's strike position is an important consideration when prescribing lateral wedges (2). Research has demonstrated that a person's foot posture may influence their response to a lateral wedge (10). This study will use data from Chapter 6 to analyse the influence of a runner's strike pattern and FPI on the effect of lateral wedging, employing a similar statistical approach (SPM) as in Chapter 6.

7.4.2 **The Effect of Footwear and Foot Orthoses on First MPJ Kinematics in Gait: A Systematic Review and Meta-analysis**

This thesis identified influencing first MPJ extension as a common objective when prescribing foot orthoses, although findings have challenged clinical assumptions. It is imperative to critically evaluate the broader effects of footwear and foot orthoses on first MPJ kinematics. Despite numerous studies exploring how foot orthoses influence first MPJ kinematics (196, 263-

267), there is no systematic overview of research to date. The review will group findings by orthosis or footwear characteristics and their effects on first MPJ kinematics. The aim is to provide a systematic overview of the literature on how footwear and foot orthoses affect first MPJ kinematics.

7.4.3 Factors Influencing Podiatrists' Prescribing Practices for Foot Orthoses: A Qualitative Study

The prescription of foot orthoses is a complex clinical task. Currently, there is a lack of clear, evidence-based guidelines to support the development of orthotic prescriptions, leaving clinicians to rely on their judgment and experience. While Chapters 3 and 5 of this thesis have outlined standard practices in the prescription of CFO (Chapter 3) and lateral wedges (Chapter 5), further research is needed to explore the clinical reasoning and decision-making processes that underpin these behaviours. Understanding the rationale behind prescription choices will help bridge the gap between practice and evidence.

This study will employ a qualitative methodology, using in-depth interviews with practising podiatrists to explore the decision-making processes involved in prescribing foot orthoses. The primary objective is to deepen understanding of the clinical reasoning underpinning orthotic prescriptions, with a particular focus on the therapeutic goals and the rationale for selecting specific design features. Through examining how and why key elements of orthotic prescriptions are chosen, the research aims to reveal the complex interplay between clinical experience, patient presentation, and treatment goals. The findings will contribute to a more nuanced understanding of podiatric practice and may inform future guidelines for orthotic design and prescription.

7.4.4 Foot Orthoses for Plantar Heel Pain. Consensus-Based Recommendations for Optimal Prescription Characteristics

Plantar heel pain occurs frequently in the adult population and is one of the most common musculoskeletal conditions managed by podiatrists (152, 154, 155). Chapter 3 of this thesis identified that of 1000 consecutive prescriptions gathered from two commercial orthotic laboratories, 11% ($n=110$) were prescribed for a clinical diagnosis of PHP. A statistical association was uncovered in which 'forefoot lateral wedge', 'plantar fascia groove', and 'heel cushion' were more likely to be included in the orthotic prescription if PHP was the diagnosis. Crucially, however, these do not indicate best practice but merely provide insight into what is common.

This proposed study will use a Delphi methodology and gather a pool of international experts. It intends to provide consensus-based recommendations regarding important foot orthosis design characteristics for people with PHP. A potential challenge associated with this work will be the definition and diagnosis of PHP. Riel et al. (268) highlighted the need to consider heel pain as more nuanced than simply inflammation of the plantar fascia, acknowledging that a range of histological and medical influences may also be involved. Considering this, recommendations for orthoses should consider the various tissues involved. They should provide a clinical decision pathway allowing the podiatrist to tailor recommendations based on the specifics of each case they manage. While it is neither possible nor appropriate to apply a 'one size fits all' approach to prescribing foot orthoses, this study will provide clinicians with an evidence-based foundation for managing heel pain, one of the most common conditions encountered in practice.

7.4.5 The Influence of Laterally Wedged Foot Orthoses on Plantar Heel Pain. A Randomised Controlled Trial

This thesis identified that PHP is the most common diagnosis for which CFO are prescribed. A strong association exists between a diagnosis of PHP and the use of lateral wedging in foot orthoses. In Chapter 3 of this thesis, lateral wedges were reported to be included in 35% of orthoses prescribed for PHP, compared to 20% of prescriptions where the diagnosis was not PHP. Chapter 5 also found that PHP ranked third (behind peroneal tendon issues and CAI) as conditions most likely to prompt the inclusion of a lateral wedge in the orthotic design.

However, existing empirical evidence to support the use of lateral wedges in the management of PHP is limited to one in vitro study by Kogler et al. (4). This study contrasted various wedge placements (combinations of rearfoot and forefoot, medial and lateral), and concluded that lateral forefoot wedging most significantly reduced strain on the plantar fascia.

This proposed study aims to establish the effect lateral wedges have on patients with PHP. Participants will be recruited from local podiatry, physiotherapy, and general practice clinics. Diagnostic criteria will be based on self-reported symptoms of first-step pain in the region of the calcaneal medial tubercle, for more than four weeks, and thickening of the plantar fascia at the origin. In line with findings from McMillan et al. (269). An increased thickness of more than 4 mm compared to the contralateral limb will be used as a diagnostic threshold for PHP.

Participants will be divided into two groups, each receiving the recommended 'core approach' of plantar fascia stretching, education and taping (150), and foot orthoses. Foot orthoses prescribed to each group will be digitally scanned and 3D printed, made from 3 mm PA11, and incorporate a Modified Root shell, heel cushion, plantar fascia groove and bilateral 4° rearfoot

varus cast correction. The difference between groups is that orthoses provided to the intervention group will include a forefoot lateral wedge made from high-density EVA, positioned from the calcaneo-cuboid joint to the sulcus, and set at an inclination of 6°.

Assessment will be conducted at baseline, 3 months, and 12 months. Each time, participants will be assessed using a combination of measures including the Manchester Foot Pain and Disability Index (270), visual analogue pain rating associated with first-step discomfort, and ultrasound measurement of plantar fascia thickness.

7.4.6 An Evaluation of the Biomechanical and Morphological Symmetry Between Left and Right Feet in Healthy Adults

Chapter 3 revealed that 58% of CFO prescriptions are symmetrical, with no prescribed differences between the left and right side. This finding prompted the question, why do podiatrists prescribe symmetrical CFO, when human bodies frequently function asymmetrically (149). However, the exact degree of difference from the left to the right foot in healthy adults has not been sufficiently researched.

This proposed study will gather a large cohort of healthy, asymptomatic adults and examine the degree of similarity between their left and right feet for a range of biomechanical and morphological outcomes. These include dimensions of the foot such as length, width and depth as well as medial arch height. Static and walking biomechanical measures will also be compared between the left and right sides including plantar pressure and barefoot kinematics.

7.5 Thesis Conclusion

This thesis presented data that has increased the understanding of how lateral wedges are used in practice, and how they influence first MPJ extension and COP during walking and running gait. The data showed that lateral wedging was common in both PFO and CFO, often with the intention to increase first MPJ extension and to shift the COP medially. In practice, clinicians most often used 3 mm (1.5°-3°) medium to high-density EVA, which they placed under the forefoot of the orthosis. This contrasts with previous research on lateral wedging where the average wedge inclination was 6°, and wedges are positioned along the full length of the insole. Significant gaps in the current body of evidence were identified concerning a lack of consideration for wedge length and placement, no comparison of wedge function between walking and running gait, and minimal investigation of how first MPJ function is influenced by lateral wedging.

Through investigation of walking and running gait, lateral wedging was found to reduce extension of the first MPJ. This effect was not influenced by the inclination or placement of the lateral wedge and was consistent for both walking and running gait. The centre of pressure was shifted medially, which, although in line with the views of NZ podiatrists, conflicts with previous evidence. Unlike first MPJ kinematics, the influence on COP was affected by wedge placement and inclination, with differences only detected using 6° wedges or those placed along the full length of the orthosis. Differences existed between running and walking gait, where the shift in COP occurred later in the stance phase of running gait. Based on this data and the current habits of NZ podiatrists, lateral wedges used in practice are unlikely to achieve their intended outcomes. First MPJ extension is being reduced, not increased, and although the aim to shift the COP medially is valid, low wedge inclinations utilised by podiatrists may be too little to elicit the desired outcome. Therefore, this thesis calls for clinicians and industry partners to critically reflect on their expected outcomes of lateral wedging, particularly in relation to first MPJ kinematics, and to adopt a more nuanced approach to lateral wedge design ensuring that the wedge is tailored specifically for the intended use and desired outcome.

References

1. Philips JW. The functional foot orthosis. Melbourne: Churchill Livingstone; 1990.
2. Jackson A, Sheerin K, Reid D, Carroll M. Beliefs about and use of forefoot lateral wedging in podiatric medical practice: a survey of podiatric physicians in New Zealand. *J Am Podiatr Med Assoc.* 2025;115(1). doi:10.7547/22-022
3. Van Gheluwe B, Dananberg HJ. Changes in plantar foot pressure with in-shoe varus or valgus wedging. *J Am Podiatr Med Assoc.* 2004;94(1):1-11. doi:10.7547/87507315-94-1-1
4. Kogler GF, Veer FB, Solomonidis SE, Paul JP. The influence of medial and lateral placement of orthotic wedges on loading of the plantar aponeurosis: An in vitro study. *J Bone Joint Surg Am.* 1999;81(10):1403-13. doi:10.2106/00004623-199910000-00005
5. Milani TL, Schnabel G, Hennig EM. Rearfoot motion and pressure distribution patterns during running in shoes with varus and valgus wedges. *J Appl Biomech.* 1995;11(2):177-87. doi:10.1123/jab.11.2.177
6. Root ML, Orien WP, Weed JH. Normal and abnormal function of the foot. Los Angeles: Clinical Biomechanics Corporation; 1977.
7. Root ML, Orien WP, Weed JH, Hughes R. Biomechanical examination of the foot. Los Angeles: Clinical Biomechanics Corporation; 1971.
8. Jarvis HL, Nester CJ, Bowden PD, Jones RK. Challenging the foundations of the clinical model of foot function: further evidence that the root model assessments fail to appropriately classify foot function. *J Foot Ankle Res.* 2017;10:7. doi:10.1186/s13047-017-0189-2
9. Harradine P, Gates L, Bowen C. If It doesn't work, why do we still do it? The continuing use of Subtalar Joint Neutral Theory in the face of overpowering critical research. *J Orthop Sports Phys Ther.* 2018;48(3):130-2. doi:10.2519/jospt.2018.0604
10. Tse CTF, Ryan MB, Hunt MA. Influence of foot posture on immediate biomechanical responses during walking to variable-stiffness supported lateral wedge insole designs. *Gait Posture.* 2020;81:21-6. doi:10.1016/j.gaitpost.2020.06.026
11. Jones RK, Zhang M, Laxton P, Findlow AH, Liu A. The biomechanical effects of a new design of lateral wedge insole on the knee and ankle during walking. *Hum Mov Sci.* 2013;32(4):596-604. doi:10.1016/j.humov.2012.12.012
12. Fukuchi CA, Lewinson RT, Worobets JT, Stefanyshyn DJ. Effects of lateral and medial wedged insoles on knee and ankle internal joint moments during walking in healthy men. *J Am Podiatr Med Assoc.* 2016;106(6):411-8. doi:10.7547/15-077
13. Bennell KL, Bowles KA, Payne C, Cicuttini F, Williamson E, Forbes A, et al. Lateral wedge insoles for medial knee osteoarthritis: 12 month randomised controlled trial. *BMJ.* 2011;342:d2912. doi:10.1136/bmj.d2912
14. Shaw KE, Charlton JM, Perry CKL, de Vries CM, Redekopp MJ, White JA, Hunt MA. The effects of shoe-worn insoles on gait biomechanics in people with knee osteoarthritis: a systematic review and meta-analysis. *Br J Sports Med.* 2018;52(4):238-53. doi:10.1136/bjsports-2016-097108
15. Kakihana W, Akai M, Nakazawa K, Takashima T, Naito K, Torii S. Effects of laterally wedged insoles on knee and subtalar joint moments. *Arch Phys Med Rehabil.* 2005;86(7):1465-71. doi:10.1016/j.apmr.2004.09.033
16. Kakihana W, Torii S, Akai M, Nakazawa K, Fukano M, Naito K. Effect of a lateral wedge on joint moments during gait in subjects with recurrent ankle sprain. *Am J Phys Med Rehabil.* 2005;84(11):858-64. doi:10.1097/01.phm.0000179519.65254.37
17. Pascual Huerta J, Ropa Moreno JM, Kirby KA, Garcia Carmona FJ, Orejana Garcia AM. Effect of 7-degree rearfoot varus and valgus wedging on rearfoot kinematics and

- kinetics during the stance phase of walking. *J Am Podiatr Med Assoc.* 2009;99(5):415-21. doi:10.7547/0990415
18. Kluge F, Krinner S, Lochmann M, Eskofier BM. Speed dependent effects of laterally wedged insoles on gait biomechanics in healthy subjects. *Gait Posture.* 2017;55:145-9. doi:10.1016/j.gaitpost.2017.04.012
 19. Nester CJ, van der Linden ML, Bowker P. Effect of foot orthoses on the kinematics and kinetics of normal walking gait. *Gait Posture.* 2003;17(2):180-7. doi:10.1016/s0966-6362(02)00065-6
 20. Weinhandl JT, Sudheimer SE, Van Lunen BL, Stewart K, Hoch MC. Immediate and 1 week effects of laterally wedge insoles on gait biomechanics in healthy females. *Gait Posture.* 2016;45:164-9. doi:10.1016/j.gaitpost.2016.01.025
 21. Rabiei M, Eslami M, Movaghar AF. The assessment of three-dimensional foot pronation using a principal component analysis method in the stance phase of running. *Foot.* 2016;29:11-7. doi:10.1016/j.foot.2016.09.008
 22. Cappellini G, Ivanenko YP, Poppele RE, Lacquaniti F. Motor patterns in human walking and running. *J Neurophysiol.* 2006;95(6):3426-37. doi:10.1152/jn.00081.2006
 23. Draves DJ. *Anatomy of the Lower Extremity.* Baltimore, MD, USA: Williams & Wilkins; 1986. 345 p.
 24. Nester CJ, Jarvis HL, Jones RK, Bowden PD, Liu A. Movement of the human foot in 100 pain free individuals aged 18–45: implications for understanding normal foot function. *J Foot Ankle Res.* 2014;7(1):51. doi:10.1186/s13047-014-0051-8
 25. Behling AV, Rainbow MJ, Welte L, Kelly L. Chasing footprints in time - reframing our understanding of human foot function in the context of current evidence and emerging insights. *Biol Rev Camb Philos Soc.* 2023. doi:10.1111/brv.12999
 26. Tanigawa K, Watanabe D, Saito T, Shimizu H, Kawamoto S, Nagai-Tanima M, Aoyama T. Influence of flat feet on the lateral movements of tennis players. *Sports Biomech.* 2025:1-12. doi:10.1080/14763141.2025.2458487
 27. Sahin FN, Ceylan L, Kucuk H, Ceylan T, Arikan G, Yigit S, et al. Examining the relationship between Pes Planus degree, balance and jump performances in athletes. *Int J Environ Res Public Health.* 2022;19(18). doi:10.3390/ijerph191811602
 28. Ledoux WR, Hillstrom HJ. The distributed plantar vertical force of neutrally aligned and pes planus feet. *Gait Posture.* 2002;15(1):1-9. doi:10.1016/S0966-6362(01)00165-5
 29. Kosashvili Y, Fridman T, Backstein D, Safir O, Bar Ziv Y. The correlation between pes planus and anterior knee or intermittent low back pain. *Foot Ankle Int.* 2008;29(9):910-3. doi:10.3113/FAI.2008.0910
 30. Yu H, Wu W, Tai W, Li J, Zhang R. The arch myth: investigating the impact of flat foot on vertical jump height: a systematic review and meta-analysis. *BMC Sports Sci Med Rehabil.* 2024;16(1):236. doi:10.1186/s13102-024-01018-w
 31. Kennedy B, Tinduh D, Utami DA, Pawana IPA, Melaniani S. Comparison of agility between the flat foot and normal foot in East Java Puslatda athletes. *Bali Med J.* 2023;12(1):369-73. doi:10.15562/bmj.v12i1.3955
 32. Ceysens L, Vanelderen R, Barton C, Malliaras P, Dingenen B. Biomechanical risk factors associated with running-related injuries: a systematic review. *Sports Med.* 2019;49(7):1095-115. doi:10.1007/s40279-019-01110-z
 33. Morton DJ. Mechanism of the normal foot and of flat foot: Part I. *JBS.* 1924;6(2).
 34. Irish WH. Hereditary weak feet. *Am J Surg.* 1929;7(5):714-5. doi:10.1016/S0002-9610(29)90461-X
 35. Harradine P, Bevan L. A review of the theoretical unified approach to podiatric biomechanics in relation to foot orthoses therapy. *J Am Podiatr Med Assoc.* 2009;99(4):317-25. doi:10.7547/0980317
 36. Sacks O. *An Anthropologist on Mars.* New York: Alfred A. Knopf; 1995.
 37. Payne C. Should the baby be thrown out with the bathwater? *Australasian Journal of Podiatric Medicine.* 1997;31(3):73-5.

38. Elveru RA, Rothstein JM, Lamb RL. Goniometric reliability in a clinical setting: subtalar and ankle joint measurements. *Phys Ther.* 1988;68(5):672-7. doi:10.1093/ptj/68.5.672
39. Lattanza L, Gray GW, Kantner RM. Closed versus open kinematic chain measurements of subtalar joint eversion: implications for clinical practice. *J Orthop Sports Phys Ther.* 1988;9(9):310-4. doi:10.2519/jospt.1988.9.9.310
40. McPoil TG, Knecht HG, Schuit D. A survey of foot types in normal females between the ages of 18 and 30 years. *J Orthop Sports Phys Ther.* 1988;9(12):406-9. doi:10.2519/jospt.1988.9.12.406
41. McPoil T, Cornwall MW. Relationship between neutral subtalar joint position and pattern of rearfoot motion during walking. *Foot Ankle Int.* 1994;15(3):141-5. doi:10.1177/107110079401500309
42. Menz HB, Allan JJ, Bonanno DR, Landorf KB, Murley GS. Custom-made foot orthoses: an analysis of prescription characteristics from an Australian commercial orthotic laboratory. *J Foot Ankle Res.* 2017;10(1):23-32. doi:10.1186/s13047-017-0204-7
43. Dananberg HJ. Functional hallux limitus and its relationship to gait efficiency. *J Am Podiatr Med Assoc.* 1986;76(11):648-52.
44. Hicks JH. The mechanics of the foot, part II: the plantar aponeurosis and the arch. *J Anat.* 1954;88:25-30.
45. Kirby KA. Methods for determination of positional variations in the Subtalar Joint axis. *J Am Podiatr Med Assoc.* 1987;77(5):228-34.
46. Kirby KA. Subtalar joint axis location and rotational equilibrium theory of foot function. *J Am Podiatr Med Assoc.* 2001;91(9):465-87. doi:10.7547/87507315-91-9-465
47. Fuller EA. The windlass mechanism of the foot: a mechanical model to explain pathology. *J Am Podiatr Med Assoc.* 2000;90(1):35-46. doi:10.7547/87507315-90-1-35
48. Smith-Oricchio K, Harris BA. Interrater reliability of subtalar neutral, calcaneal inversion and eversion. *J Orthop Sports Phys Ther.* 1990;12(1):10-5. doi:10.2519/jospt.1990.12.1.10
49. McPoil TG, Hunt GC. Evaluation and management of foot and ankle disorders: present problems and future directions. *J Orthop Sports Phys Ther.* 1995;21(6):381-8. doi:10.2519/jospt.1995.21.6.381
50. Cornwall MW. Biomechanics of noncontractile tissue: a review. *Phys Ther.* 1984;64(12):1869-73. doi:10.1093/ptj/64.12.1869
51. Sethi D, Bharti S, Prakash C. A comprehensive survey on gait analysis: history, parameters, approaches, pose estimation, and future work. *Artif Intell Med.* 2022;129:102314. doi:10.1016/j.artmed.2022.102314
52. Pirker W, Katzenschlager R. Gait disorders in adults and the elderly: a clinical guide. *Wien Klin Wochenschr.* 2016;129. doi:10.1007/s00508-016-1096-4
53. Thomas SJ, Zeni JA, Winter DA, Winter DA. *Winter's biomechanics and motor control of human movement.* Fifth edition. ed. Hoboken, NJ: John Wiley & Sons, Inc.; 2023.
54. Kelly LA, Lichtwark G, Cresswell AG. Active regulation of longitudinal arch compression and recoil during walking and running. *J R Soc Interface.* 2014;12(102):20141076-. doi:10.1098/rsif.2014.1076
55. Dicharry J. Kinematics and kinetics of gait: from lab to clinic. *Clin Sports Med.* 2010;29(3):347-64. doi:10.1016/j.csm.2010.03.013
56. Waldron KJ, Schmiedeler J. Kinematics. In: Siciliano B, Khatib O, editors. *Springer Handbook of Robotics.* Cham: Springer International Publishing; 2016. p. 11-36.
57. Hamill J, Knutzen KM, Derrick TR. Biomechanics: 40 years on. *Kinesiology Review.* 2021;10(3):228-37. doi:10.1123/kr.2021-0015
58. Michelini A, Eshraghi A, Andrysek J. Two-dimensional video gait analysis: A systematic review of reliability, validity, and best practice considerations. *Prosthet Orthot Int.* 2020;44(4):245-62. doi:10.1177/0309364620921290

59. McGinley JL, Baker R, Wolfe R, Morris ME. The reliability of three-dimensional kinematic gait measurements: a systematic review. *Gait Posture*. 2009;29(3):360-9. doi:10.1016/j.gaitpost.2008.09.003
60. Scataglini S, Abts E, Van Bocxlaer C, Van den Bussche M, Meletani S, Truijen S. Accuracy, validity, and reliability of markerless camera-based 3D motion capture systems versus marker-based 3D motion capture systems in gait analysis: a systematic review and meta-analysis. *Sensors*. 2024;24(11). doi:10.3390/s24113686
61. Kaufman K, Miller E, Kingsbury T, Russell Esposito E, Wolf E, Wilken J, Wyatt M. Reliability of 3D gait data across multiple laboratories. *Gait Posture*. 2016;49:375-81. doi:10.1016/j.gaitpost.2016.07.075
62. Stief F, Böhm H, Michel K, Schwirtz A, Döderlein L. Reliability and accuracy in three-dimensional gait analysis: a comparison of two lower body protocols. *J Appl Biomech*. 2013;29(1):105-11. doi:10.1123/jab.29.1.105
63. Mueller MJ. Application of plantar pressure assessment in footwear and insert design. *J Orthop Sports Phys Ther*. 1999;29(12):747-55. doi:10.2519/jospt.1999.29.12.747
64. Buldt AK, Forghany S, Landorf KB, Murley GS, Lvinger P, Menz HB. Centre of pressure characteristics in normal, planus and cavus feet. *J Foot Ankle Res*. 2018;11:3. doi:10.1186/s13047-018-0245-6
65. Wong L, Hunt A, Burns J, Crosbie J. Effect of foot morphology on center-of-pressure excursion during barefoot walking. *J Am Podiatr Med Assoc*. 2008;98(2):112-7. doi:10.7547/0980112
66. Sanchez-Rodriguez R, Martinez-Nova A, Escamilla-Martinez E, Pedrera-Zamorano JD. Can the Foot Posture Index or their individual criteria predict dynamic plantar pressures? *Gait Posture*. 2012;36(3):591-5. doi:10.1016/j.gaitpost.2012.05.024
67. Lee SY, Hertel J. Effect of static foot alignment on plantar-pressure measures during running. *J Sport Rehabil*. 2012;21(2):137-43.
68. Wei Z, Zhang Z, Jiang J, Zhang Y, Wang L. Comparison of plantar loads among runners with different strike patterns. *J Sports Sci*. 2019;37(18):2152-8. doi:10.1080/02640414.2019.1623990
69. Mousavi SH, van Kouwenhove L, Rajabi R, Zwerver J, Hijmans JM. The effect of changing mediolateral center of pressure on rearfoot eversion during treadmill running. *Gait Posture*. 2021;83:201-9. doi:10.1016/j.gaitpost.2020.10.032
70. Morin P, Muller A, Pontonnier C, Dumont G. Evaluation of the foot center of pressure estimation from pressure insoles during sidestep cuts, runs and walks. *Sensors*. 2022;22(15). doi:10.3390/s22155628
71. Menz HB, Auhl M, Tan JM, Buldt AK, Munteanu SE. Centre of pressure characteristics during walking in individuals with and without first metatarsophalangeal joint osteoarthritis. *Gait Posture*. 2018;63:91-6. doi:10.1016/j.gaitpost.2018.04.032
72. Zhang X, Li B, Liang K, Wan Q, Vanwanseele B. An optimized design of in-shoe heel lifts reduces plantar pressure of healthy males. *Gait Posture*. 2016;47:43-7. doi:10.1016/j.gaitpost.2016.04.003
73. Zhang X, Li B. Influence of in-shoe heel lifts on plantar pressure and center of pressure in the medial-lateral direction during walking. *Gait Posture*. 2014;39(4):1012-6. doi:10.1016/j.gaitpost.2013.12.025
74. Khoury M, Wolf A, Debbi EM, Herman A, Haim A. Foot center of pressure trajectory alteration by biomechanical manipulation of shoe design. *Foot Ankle Int*. 2013;34(4):593-8. doi:10.1177/1071100713477613
75. Zhang X, Lam WK, Vanwanseele B. Dose-response effects of forefoot and arch orthotic components on the center of pressure trajectory during running in pronated feet. *Gait Posture*. 2022;92:212-7. doi:10.1016/j.gaitpost.2021.11.033
76. Tsung BY, Zhang M, Mak AF, Wong MW. Effectiveness of insoles on plantar pressure redistribution. *J Rehabil Res Dev*. 2004;41(6A):767-74. doi:10.1682/jrrd.2003.09.0139

77. Tse CTF, Ryan MB, Dien J, Scott A, Hunt MA. An exploration of changes in plantar pressure distributions during walking with standalone and supported lateral wedge insole designs. *J Foot Ankle Res.* 2021;14(1):55. doi:10.1186/s13047-021-00493-5
78. Menz HB, Lim PQX, Hurn SE, Mickle KJ, Buldt AK, Cotchett MP, et al. Effectiveness of footwear and foot orthoses in reducing medial metatarsophalangeal joint pressure in women with hallux valgus. *Gait Posture.* 2024;111:156-61. doi:10.1016/j.gaitpost.2024.04.021
79. Ma M, Song Q, Liu H. The effect of personalized orthopedic insoles on plantar pressure during running in subtle cavus foot. *Front Bioeng Biotechnol.* 2024;12:1343001. doi:10.3389/fbioe.2024.1343001
80. Lucas-Cuevas AG, Perez-Soriano P, Llana-Belloch S, Macian-Romero C, Sanchez-Zuriaga D. Effect of custom-made and prefabricated insoles on plantar loading parameters during running with and without fatigue. *J Sports Sci.* 2014;32(18):1712-21. doi:10.1080/02640414.2014.915422
81. Khodaei B, Saeedi H, Jalali M, Farzadi M, Norouzi E. Comparison of plantar pressure distribution in CAD-CAM and prefabricated foot orthoses in patients with flexible flatfeet. *Foot.* 2017;33:76-80. doi:10.1016/j.foot.2017.07.002
82. Jafarzadeh E, Soheilifard R, Ehsani-Seresht A. Design optimization procedure for an orthopedic insole having a continuously variable stiffness/shape to reduce the plantar pressure in the foot of a diabetic patient. *Med Eng Phys.* 2021;98:44-9. doi:10.1016/j.medengphy.2021.10.008
83. Guldmond NA, Leffers P, Sanders AP, Emmen H, Schaper NC, Walenkamp GHIM. Casting methods and plantar pressure: effects of custom-made foot orthoses on dynamic plantar pressure distribution. *J Am Podiatr Med Assoc.* 2006;96(1):9-18. doi:10.7547/0960009
84. Bonanno DR, Zhang CY, Farrugia RC, Bull MG, Raspovic AM, Bird AR, Landorf KB. The effect of different depths of medial heel skive on plantar pressures. *J Foot Ankle Res.* 2012;5:20-9. doi:10.1186/1757-1146-5-20
85. O'Sullivan K, Kennedy N, O'Neill E, Ni Mhainin U. The effect of low-dye taping on rearfoot motion and plantar pressure during the stance phase of gait. *BMC Musculoskelet Disord.* 2008;9:111. doi:10.1186/1471-2474-9-111
86. Fuller EA. Center of pressure and its theoretical relationship to foot pathology. *J Am Podiatr Med Assoc.* 1999;89(6):278-91. doi:10.7547/87507315-89-6-278
87. de Haan A, Hijmans JM, van der Vegt AE, van der Laan HP, van Nes JGH, Werker PMN, et al. Effect of painful Ledderhose disease on dynamic plantar foot pressure distribution during walking: a case-control study. *Foot.* 2023;56:101990. doi:10.1016/j.foot.2023.101990
88. Xu C, Wei W, Li X, Wei J, Zhang Y, Lei W, et al. Application of pedobarographic analysis in neglected congenital clubfoot patients following Ponseti treatment for recurrence prediction. *Heliyon.* 2024;10(4):e25753. doi:10.1016/j.heliyon.2024.e25753
89. Orlin MN, McPoil TG. Plantar pressure assessment. *Phys Ther.* 2000;80(4):399-409. doi:10.1093/ptj/80.4.399
90. Arzehgar A, Nia R, Hoseinkhani M, Masoumi F, Sayyed-Hosseini SH, Eslami S. An overview of plantar pressure distribution measurements and its applications in health and medicine. *Gait Posture.* 2025;117:235-44. doi:10.1016/j.gaitpost.2024.12.022
91. Cornwall M, McPoil TG. Reliability and validity of centre of pressure quantification. *J Am Podiatr Med Assoc.* 2003;93(2):142-9. doi:10.7547/87507315-93-2-142
92. Chesnin KJ, Selby-Silverstein L, Besser MP. Comparison of an in-shoe pressure measurement device to a force plate: concurrent validity of center of pressure measurements. *Gait Posture.* 2000;12(2):128-33. doi:10.1016/S0966-6362(00)00071-0
93. Lewinson RT, Fukuchi CA, Worobets JT, Stefanyshyn DJ. The effects of wedged footwear on lower limb frontal plane biomechanics during running. *Clin J Sport Med.* 2013;23:208-15. doi:10.1097/JSM.0b013e31826b7c83

94. Sawada T, Tokuda K, Tanimoto K, Iwamoto Y, Ogata Y, Anan M, et al. Foot alignments influence the effect of knee adduction moment with lateral wedge insoles during gait. *Gait Posture*. 2016;49:451-6. doi:10.1016/j.gaitpost.2016.08.011
95. Mills K, Blanch P, Chapman AR, McPoil TG, Vicenzino B. Foot orthoses and gait: a systematic review and meta-analysis of literature pertaining to potential mechanisms. *Br J Sports Med*. 2010;44(14):1035-46. doi:10.1136/bjsm.2009.066977
96. Landorf KB, Keenan AM. Efficacy of foot orthoses. What does the literature tell us? *J Am Podiatr Med Assoc*. 2000;90(3):149-58. doi:10.7547/87507315-90-3-149
97. Heiderscheit B, Hamill J, Tiberio D. A biomechanical perspective: do foot orthoses work? *Br J Sports Med*. 2001;35(1):4. doi:10.1136/bjsm.35.1.4
98. Kirby KA. Evolution of Foot Orthoses in Sports. In: Werd MB, Knight EL, Langer PR, editors. *Athletic Footwear and Orthoses in Sports Medicine*. Cham: Springer International Publishing; 2017. p. 19-40.
99. Kohler R. Nicolas Andry de Bois-Regard (Lyon 1658-Paris 1742): the inventor of the word "orthopaedics" and the father of parasitology. *J Child Orthop*. 2010;4(4):349-55. doi:10.1007/s11832-010-0255-9
100. Starrett CJ. Historical review and current use of the Whiteman/Robert's orthoses in biomechanical therapy. *Clin Podiatr Med Surg*. 1994;11(2):231-9. doi:10.1016/S0891-8422(23)00725-5
101. Nicolopoulos CS, Scott BW, Giannoudis PV. Biomechanical basis of foot orthotic prescription. *Curr Orthop*. 2000;14(6):464-9. doi:10.1054/cuor.2000.0150
102. Chapman LS, Redmond AC, Landorf KB, Rome K, Keenan AM, Waxman R, et al. A survey of foot orthoses prescription habits amongst podiatrists in the UK, Australia and New Zealand. *J Foot Ankle Res*. 2018;11:64. doi:10.1186/s13047-018-0304-z
103. Menz HB. Foot orthoses: how much customisation is necessary? *J Foot Ankle Res*. 2009;2:23. doi:10.1186/1757-1146-2-23
104. Landorf K, Keenan A-M, Rushworth RL. Foot orthosis prescription habits of Australian and New Zealand podiatric physicians. *J Am Podiatr Med Assoc*. 2001;91(4):174-83. doi:10.7547/87507315-91-4-174
105. Griffiths IB, Spooner SK. Foot orthoses research: identifying limitations to improve translation to clinical knowledge and practice. *Br J Sports Med*. 2018;52(6):350. doi:10.1136/bjsports-2016-096269
106. Dolan MG. The use of foot orthotic devices in clinical practice. *Athl Ther Today*. 2000;5(1):17-21. doi:10.1123/att.5.1.17
107. Williams DS, McClay Davis I, Baitch SP. Effect of inverted orthoses on lower-extremity mechanics in runners. *Med Sci Sports Exerc*. 2003;35(12):2060-8. doi:10.1249/01.MSS.0000098988.17182.8A
108. Nester CJ, Graham A, Martinez-Santos A, Williams AE, McAdam J, Newton V. National profile of foot orthotic provision in the United Kingdom, part 1: practitioners and scope of practice. *J Foot Ankle Res*. 2017;10:35-46. doi:10.1186/s13047-017-0215-4
109. Gross MT, Mercer VS, Lin FC. Effects of foot orthoses on balance in older adults. *J Orthop Sports Phys Ther*. 2012;42(7):649-57. doi:10.2519/jospt.2012.3944
110. Murley GS, Bird AR. The effect of three levels of foot orthotic wedging on the surface electromyographic activity of selected lower limb muscles during gait. *Clin Biomech*. 2006;21(10):1074-80. doi:10.1016/j.clinbiomech.2006.06.007
111. Hsu WH, Lewis CL, Monaghan GM, Saltzman E, Hamill J, Holt KG. Orthoses posted in both the forefoot and rearfoot reduce moments and angular impulses on lower extremity joints during walking. *J Biomech*. 2014;47(11):2618-25. doi:10.1016/j.jbiomech.2014.05.021
112. Erhart JC, Mündermann A, Mündermann L, Andriacchi TP. Predicting changes in knee adduction moment due to load-altering interventions from pressure distribution at the foot in healthy subjects. *J Biomech*. 2008;41(14):2989-94. doi:10.1016/j.jbiomech.2008.07.021

113. Thong-On S, Harutaichun P. Effects of customized insoles with medial wedges on lower extremity kinematics and ultrasonographic findings in plantar fasciitis persons. *Sci Rep.* 2023;13(1):8642. doi:10.1038/s41598-023-35862-6
114. Braga UM, Mendonça LD, Mascarenhas RO, Alves COA, Filho RGT, Resende RA. Effects of medially wedged insoles on the biomechanics of the lower limbs of runners with excessive foot pronation and foot varus alignment. *Gait Posture.* 2019;74:242-9. doi:10.1016/j.gaitpost.2019.09.023
115. Dami A, Payen E, Farahpour N, Robb K, Isabelle PL, Moisan G. Medially wedged foot orthoses generate greater biomechanical effects than thin-flexible foot orthoses during a unilateral drop jump task on level and inclined surfaces. *Clin Biomech.* 2024;112:106193. doi:10.1016/j.clinbiomech.2024.106193
116. Costa BL, Magalhaes FA, Araujo VL, Richards J, Vieira FM, Souza TR, Trede R. Is there a dose-response of medial wedge insoles on lower limb biomechanics in people with pronated feet during walking and running? *Gait Posture.* 2021;90:190-6. doi:10.1016/j.gaitpost.2021.09.163
117. Jackson A, Sheerin K, Reid D, Ganley T, Lamb B, Carroll M. Custom foot orthoses: a retrospective analysis of 1000 prescriptions from New Zealand podiatrists. *J Foot Ankle Res.* 2025;18(2). doi:10.1002/jfa2.70044
118. Martinez-Rico M, Deschamps K, Gijon-Nogueron G, Ortega-Avila AB. Impact of in shoe and barefoot placed frontal wedges on plantar loading: a systematic review. *Gait Posture.* 2022;97:62-72. doi:10.1016/j.gaitpost.2022.07.233
119. Reeves J, Jones R, Liu A, Bent L, Nester C. The immediate effects of foot orthosis geometry on lower limb muscle activity and foot biomechanics. *J Biomech.* 2021;128:110716. doi:10.1016/j.jbiomech.2021.110716
120. Lawrence RC, Felson DT, Helmick CG, Arnold LM, Choi H, Deyo RA, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis Rheum.* 2008;58(1):26-35. doi:10.1002/art.23176
121. Felson DT, Parkes M, Carter S, Liu A, Callaghan MJ, Hodgson R, et al. The efficacy of a lateral wedge insole for painful medial knee osteoarthritis after prescreening: a randomized clinical trial. *Arthritis Rheumatol.* 2019;71(6):908-15. doi:10.1002/art.40808
122. Parkes MJ, Maricar N, Lunt M, LaValley MP, Jones RK, Segal NA, et al. Lateral wedge insoles as a conservative treatment for pain in patients with medial knee osteoarthritis: a meta-analysis. *JAMA.* 2013;310(7):722-30. doi:10.1001/jama.2013.243229
123. Healy A, Dunning DN, Chockalingam N. Materials used for footwear orthoses: a review. *Footwear Sci.* 2010;2(2):93-110. doi:10.1080/19424280.2010.486045
124. Gerrard JM, Bonanno DR, Whittaker GA, Landorf KB. Effect of different orthotic materials on plantar pressures: a systematic review. *J Foot Ankle Res.* 2020;13(1):35. doi:10.1186/s13047-020-00401-3
125. Shi QQ, Li PL, Yick KL, Jiao J, Liu QL. Influence of contoured insoles with different materials on kinematics and kinetics changes in diabetic elderly during gait. *Int J Environ Res Public Health.* 2022;19(19). doi:10.3390/ijerph191912502
126. Bousie JA, Blanch P, McPoil TG, Vicenzino B. Hardness and posting of foot orthoses modify plantar contact area, plantar pressure, and perceived comfort when cycling. *J Sci Med Sport.* 2018;21(7):691-6. doi:10.1016/j.jsams.2017.11.013
127. Brodsky JW, Pollo FE, Cheleuitte D, Baum BS. Physical properties, durability, and energy-dissipation function of dual-density orthotic materials used in insoles for diabetic patients. *Foot Ankle Int.* 2007;28(8):880-9. doi:10.3113/FAI.2007.0880
128. Rome K. Behavior of orthotic materials in chiropody. *J Am Podiatr Med Assoc.* 1990;80(9):471-8. doi:10.7547/87507315-80-9-471
129. Rome K. A study of the properties of materials used in podiatry. *J Am Podiatr Med Assoc.* 1991;81(2):73-83. doi:10.7547/87507315-81-2-73

130. Qi HJ, Joyce K, Boyce MC. Durometer hardness and the stress-strain behavior of elastomeric materials. *Rubber Chemistry and Technology*. 2003;76(2):419-35. doi:10.5254/1.3547752
131. Kermen E, Mohammadi H. Mechanics of foot orthotics: material properties. *J Med Eng Technol*. 2021;45(8):627-41. doi:10.1080/03091902.2021.1940332
132. Nouri A, Wang L, Li Y, Wen C. Materials and manufacturing for ankle-foot orthoses: a review. *Adv Eng Mater*. 2023;25(20). doi:10.1002/adem.202300238
133. Van Alsenoy K, van der Linden ML, Ryu JH, Girard O, Al Raisi L, Santos D. Isolated and combined effects of EVA and TPU custom foot orthoses on constant speed, treadmill running kinematics. *Frontiers in Earth Science*. 2023;11. doi:10.3389/feart.2023.1170661
134. Barrios-Muriel J, Romero-Sanchez F, Alonso-Sanchez FJ, Rodriguez Salgado D. Advances in orthotic and prosthetic manufacturing: a technology review. *Materials*. 2020;13(2). doi:10.3390/ma13020295
135. Jor A, Lau NWK, Daryabor A, Koh MWP, Lam W-K, Hobara H, Kobayashi T. Effects of foot orthoses on running kinetics and kinematics: a systematic review and meta-analysis. *Gait Posture*. 2024;109:240-58. doi:10.1016/j.gaitpost.2024.02.003
136. Jackson A, Sheerin K, Reid D, Molyneux P, Carroll MR. Lateral wedging of the foot: a scoping review. *J Am Podiatr Med Assoc*. 2023;113(5). doi:10.7547/21-180
137. Mo S, Leung SHS, Chan ZYS, Sze LKY, Mok KM, Yung PSH, et al. The biomechanical difference between running with traditional and 3D printed orthoses. *J Sports Sci*. 2019;1-7. doi:10.1080/02640414.2019.1626069
138. Bonifacio D, Richards J, Selfe J, Curran S, Trede R. Influence and benefits of foot orthoses on kinematics, kinetics and muscle activation during step descent task. *Gait Posture*. 2018;65:106-11. doi:10.1016/j.gaitpost.2018.07.041
139. Kosonen J, Kulmala JP, Muller E, Avela J. Effects of medially posted insoles on foot and lower limb mechanics across walking and running in overpronating men. *J Biomech*. 2017;54:58-63. doi:10.1016/j.jbiomech.2017.01.041
140. Banwell HA, Thewlis D, Mackintosh S. Adults with flexible pes planus and the approach to the prescription of customised foot orthoses in clinical practice: a clinical records audit. *Foot*. 2015;25(2):101-9. doi:10.1016/j.foot.2015.03.005
141. Holm S. A simple sequentially rejective multiple test procedure. *Scand J Stat*. 1979;6(2):65-70.
142. Herzog BD, Kohan MI, Mestemacher SAP, Pagilagan RU, Redmond K, Sarbandi R. Polyamides. *Ullmann's Encyclopedia of Industrial Chemistry*. 2020.
143. Root ML. Development of the functional foot orthosis. *Clin Podiatr Med Surg*. 1994;11(2):183-210. doi:10.1016/S0891-8422(23)00722-X
144. Reed L, Bennett PJ. Changes in foot function with the use of root and blake orthoses. *J Am Podiatr Med Assoc*. 2001;91(4):184-93. doi:10.7547/87507315-91-4-184
145. Mills K, Blanch P, Vicenzino B. Influence of contouring and hardness of foot orthoses on ratings of perceived comfort. *Med Sci Sports Exerc*. 2011;43(8):1507-12. doi:10.1249/MSS.0b013e31820e783f
146. Mundermann A, Stefanyshyn DJ, Nigg BM. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Med Sci Sports Exerc*. 2001;33(11):1939-45. doi:10.1097/00005768-200111000-00021
147. Swinnen E, Kerckhofs E. Compliance of patients wearing an orthotic device or orthopedic shoes: A systematic review. *J Bodyw Mov Ther*. 2015;19(4):759-70. doi:10.1016/j.jbmt.2015.06.008
148. Lucas-Cuevas AG, Perez-Soriano P, Priego-Quesada JI, Llana-Belloch S. Influence of foot orthosis customisation on perceived comfort during running. *Ergonomics*. 2014;57(10):1590-6. doi:10.1080/00140139.2014.938129
149. Sadeghi H, Allard P, Prince F, Labelle H. Symmetry and limb dominance in able-bodied gait: a review. *Gait Posture*. 2000;12(1):34-45. doi:10.1016/S0966-6362(00)00070-9

150. Morrissey D, Cotchett M, Said J'Bari A, Prior T, Griffiths IB, Rathleff MS, et al. Management of plantar heel pain: a best practice guide informed by a systematic review, expert clinical reasoning and patient values. *Br J Sports Med*. 2021. doi:10.1136/bjsports-2019-101970
151. Dunn JE, Link CL, Felson DT, Crincoli MG, Keysor JJ, McKinlay JB. Prevalence of foot and ankle conditions in a multiethnic community sample of older adults. *Am J Epidemiol*. 2004;159(5):491-8. doi:10.1093/aje/kwh071
152. Menz HB, Tiedemann A, Kwan MM, Plumb K, Lord SR. Foot pain in community-dwelling older people: an evaluation of the Manchester Foot Pain and Disability Index. *Rheumatology*. 2006;45(7):863-7. doi:10.1093/rheumatology/kei002
153. Hill CL, Gill TK, Menz HB, Taylor AW. Prevalence and correlates of foot pain in a population-based study: the North West Adelaide health study. *J Foot Ankle Res*. 2008;1(1):2. doi:10.1186/1757-1146-1-2
154. Thomas MJ, Whittle R, Menz HB, Rathod-Mistry T, Marshall M, Roddy E. Plantar heel pain in middle-aged and older adults: population prevalence, associations with health status and lifestyle factors, and frequency of healthcare use. *BMC Musculoskelet Disord*. 2019;20(1):337. doi:10.1186/s12891-019-2718-6
155. Bennett PJ. Types of foot problems seen by Australian podiatrists. *Foot*. 2012;22(1):40-5. doi:10.1016/j.foot.2011.11.002
156. Whittaker GA, Munteanu SE, Menz HB, Tan JM, Rabusin CL, Landorf KB. Foot orthoses for plantar heel pain: a systematic review and meta-analysis. *Br J Sports Med*. 2018;52(5):322-8. doi:10.1136/bjsports-2016-097355
157. Whittaker GA, Munteanu SE, Menz HB, Landorf KB. Should foot orthoses be used for plantar heel pain? *Br J Sports Med*. 2018;52(19):1224-5. doi:10.1136/bjsports-2018-099426
158. Banwell HA, Mackintosh S, Thewlis D. Foot orthoses for adults with flexible pes planus: a systematic review. *J Foot Ankle Res*. 2014;7(1):23. doi:10.1186/1757-1146-7-23
159. Jung JY, Yang CM, Kim JJ. Decision tree-based foot orthosis prescription for patients with Pes Planus. *Int J Environ Res Public Health*. 2022;19(19). doi:10.3390/ijerph191912484
160. Hirano T, McCullough MB, Kitaoka HB, Ikoma K, Kaufman KR. Effects of foot orthoses on the work of friction of the posterior tibial tendon. *Clin Biomech*. 2009;24(9):776-80. doi:10.1016/j.clinbiomech.2009.07.009
161. Banwell HA, Mackintosh S, Thewlis D, Landorf KB. Consensus-based recommendations of Australian podiatrists for the prescription of foot orthoses for symptomatic flexible pes planus in adults. *J Foot Ankle Res*. 2014;7(1):49. doi:10.1186/s13047-014-0049-2
162. Desmyttere G, Hajizadeh M, Bleau J, Begon M. Effect of foot orthosis design on lower limb joint kinematics and kinetics during walking in flexible pes planovalgus: A systematic review and meta-analysis. *Clin Biomech*. 2018;59:117-29. doi:10.1016/j.clinbiomech.2018.09.018
163. Herchenroder M, Wilfling D, Steinhäuser J. Evidence for foot orthoses for adults with flatfoot: a systematic review. *J Foot Ankle Res*. 2021;14(1):57. doi:10.1186/s13047-021-00499-z
164. Richie DH. Effects of foot orthoses on patients with chronic ankle instability. *J Am Podiatr Med Assoc*. 2007;97(1):19-30. doi:10.7547/0970019
165. Arnold JB, Wong DX, Jones RK, Hill CL, Thewlis D. Lateral wedge insoles for reducing biomechanical risk factors for medial knee osteoarthritis progression: a systematic review and meta-analysis. *Arthritis Care Res*. 2016;68(7):936-51. doi:10.1002/acr.22797
166. Xing F, Lu B, Kuang MJ, Wang Y, Zhao YL, Zhao J, et al. A systematic review and meta-analysis into the effect of lateral wedge arch support insoles for reducing knee joint load in patients with medial knee osteoarthritis. *Medicine*. 2017;96(24). doi:10.1097/MD.0000000000007168

167. Reilly KA, Barker KL, Shamley D. A systematic review of lateral wedge orthotics--how useful are they in the management of medial compartment osteoarthritis? *The Knee*. 2006;13(3):177-83. doi:10.1016/j.knee.2006.02.003
168. Penny P, Geere J, Smith TO. A systematic review investigating the efficacy of laterally wedged insoles for medial knee osteoarthritis. *Rheumatol Int*. 2013;33(10):2529-38. doi:10.1007/s00296-013-2760-x
169. Baert IA, Nijs J, Meeus M, Lluch E, Struyf F. The effect of lateral wedge insoles in patients with medial compartment knee osteoarthritis: balancing biomechanics with pain neuroscience. *Clin Rheumatol*. 2014;33(11):1529-38. doi:10.1007/s10067-014-2668-1
170. Zhang J, Wang Q, Zhang C. Ineffectiveness of lateral-wedge insoles on the improvement of pain and function for medial knee osteoarthritis: a meta-analysis of controlled randomized trials. *Arch Orthop Trauma Surg*. 2018;138(10):1453-62. doi:10.1007/s00402-018-3004-z
171. Zafar AQ, Zamani R, Akrami M. The effectiveness of foot orthoses in the treatment of medial knee osteoarthritis: A systematic review. *Gait Posture*. 2020;76:238-51. doi:10.1016/j.gaitpost.2019.12.016
172. Rodriguez-Merchan EC, De La Corte-Rodriguez H. The role of orthoses in knee osteoarthritis. *Hosp Pract*. 2019;47(1):1-5. doi:10.1080/21548331.2018.1527168
173. Jamali A, Forghany S, Bapirzadeh K, Nester C. The effect of three different insoles on ankle movement variability during walking in athletes with functional ankle instability. *Adv Biomed Res*. 2019;8:42. doi:10.4103/abr.abr_69_19
174. Buonomo LJ, Klein JS, Keiper TL. Orthotic devices: custom-made, prefabricated, and material selection. *Foot and Ankle Clinics*. 2001;6(2):249-52. doi:10.1016/s1083-7515(03)00093-7
175. Lo WT, Yick KL, Ng SP, Yip J. New methods for evaluating physical and thermal comfort properties of orthotic materials used in insoles for patients with diabetes. *J Rehabil Res Dev*. 2014;51(2):311-24. doi:10.1682/JRRD.2013.01.0012
176. Nicolopoulos CS, Black J, Anderson EG. Foot orthoses materials. *The Foot*. 2000;10(1):1-3. doi:10.1054/foot.1999.0531
177. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol*. 2005;8(1):19-32. doi:10.1080/1364557032000119616
178. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for Scoping Reviews (PRISMA-ScR): Checklist and explanation. *Ann Intern Med*. 2018;169(7):467-73. doi:10.7326/M18-0850
179. Telfer S, Abbott M, Steultjens M, Rafferty D, Woodburn J. Dose-response effects of customised foot orthoses on lower limb muscle activity and plantar pressures in pronated foot type. *Gait Posture*. 2013;38(3):443-9. doi:10.1016/j.gaitpost.2013.01.012
180. Lilley K, Stiles V, Dixon S. The influence of design variations in footwear medial-lateral support on the running biomechanics of older female runners. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*. 2022;236(1):53-9. doi:10.1177/1754337120984619
181. Møller Mølgaard C, Kersting UG. The effect of shoe design and lateral wedges on knee load and neuromuscular control in healthy subjects during walking. *Footwear Sci*. 2014;6(1):51-8. doi:10.1080/19424280.2013.851285
182. Kakihana W, Akai M, Yamasaki N, Takashima T, Nakazawa K. Changes of joint moments in the gait of normal subjects wearing laterally wedged insoles. *Am J Phys Med Rehabil*. 2004;83(4):273-8. doi:10.1097/01.PHM.0000118035.71195.DE
183. Forghany S, Jones R, Preece S, Nester C, Tyson S. Early observations of the effects of lateral wedge orthoses on lower limb muscle length and potential for exacerbating spasticity. *Prosthet Orthot Int*. 2010;34(3):319-26. doi:10.3109/03093646.2010.504976

184. Jin H, Xu R, Wang J. The effects of short-term wearing of customized 3D printed single-sided lateral wedge insoles on lower limbs in healthy males: a randomized controlled trial. *Med Sci Monit.* 2019;25:7720-7. doi:10.12659/MSM.919400
185. Schmalz T, Blumentritt S, Drewitz H, Freslier M. The influence of sole wedges on frontal plane knee kinetics, in isolation and in combination with representative rigid and semi-rigid ankle-foot-orthoses. *Clin Biomech.* 2006;21(6):631-9. doi:10.1016/j.clinbiomech.2006.02.004
186. Moio KC, Sumner DR, Shott S, Hurwitz DE. Normalization of joint moments during gait: a comparison of two techniques. *J Biomech.* 2003;36(4):599-603. doi:10.1016/s0021-9290(02)00433-5
187. Brouwer RW, Jakma TSC, Verhagen AP, Verhaar JAN, Bierma-Zeinstra SMA. Braces and orthoses for treating osteoarthritis of the knee. The Cochrane database of systematic reviews. 2005(1):CD004020. doi:10.1002/14651858.CD004020.pub2
188. Zhang B, Yu X, Liang L, Zhu L, Dong X, Xiong Y, et al. Is the wedged insole an effective treatment option when compared with a flat (placebo) insole: a systematic review and meta-analysis. *Evid Based Complement Alternat Med.* 2018:1-13. doi:10.1155/2018/8654107
189. Fischer AG, Ulrich B, Hoffmann L, Jolles BM, Favre J. Effect of lateral wedge length on ambulatory knee kinetics. *Gait Posture.* 2018;63:114-8. doi:10.1016/j.gaitpost.2018.04.044
190. Hinman RS, Bowles KA, Payne C, Bennell KL. Effect of length on laterally-wedged insoles in knee osteoarthritis. *Arthritis Rheum.* 2008;59(1):144-7. doi:10.1002/art.23249
191. Butler RJ, Marchesi S, Royer T, Davis IS. The effect of a subject-specific amount of lateral wedge on knee mechanics in patients with medial knee osteoarthritis. *J Orthop Res.* 2007;25(9):1121-7. doi:10.1002/jor.20423
192. Tipnis RA, Anloague PA, Laubach LL, Barrios JA. The dose-response relationship between lateral foot wedging and the reduction of knee adduction moment. *Clin Biomech.* 2014;29(9):984-9. doi:10.1016/j.clinbiomech.2014.08.016
193. Kerrigan D, Lelas J, Goggins J, Merriman G, Kaplan R, Felson D. Effectiveness of a lateral-wedge insole on knee varus torque in patients with knee osteoarthritis. *Arch Phys Med Rehabil.* 2002;83(7):889-93. doi:10.1053/apmr.2002.33225
194. Cai J, Sun D, Xu Y, Chen H, Zhang Q, Baker JS, Gu Y. The influence of medial and lateral forefoot height discrepancy on lower limb biomechanical characteristics during the stance phase of running. *Appl Sci Res.* 2024;14(13). doi:10.3390/app14135807
195. Cho YJ, Lee DH, Kang HW, Kim DY, Lee DO, Lee DY. Pressure properties of three different types of prefabricated insoles related to plantar pressure in asymptomatic men. *Clin Orthop Surg.* 2022;14(4):622-30. doi:10.4055/cios20280
196. Du W, Guo Y, Wang C, Cui W, Chen W, Li X. Biomechanical response of lower limb joints to lateral wedge insoles. *Sci Rep.* 2024;14(1). doi:10.1038/s41598-023-50693-1
197. Arnold JB, Wong DX, Jones RK, Hill CL, Thewlis D. Lateral wedge insoles for reducing biomechanical risk factors for medial knee osteoarthritis progression: a systematic review and meta-analysis. *Arthritis Care Res.* 2016;68(7):936-51. doi:10.1002/acr.22797
198. Arnold JB. Lateral wedge insoles for people with medial knee osteoarthritis: one size fits all, some or none? *Osteoarthritis Cartilage.* 2016;24(2):193-5. doi:10.1016/j.joca.2015.09.016
199. Butler RJ, Barrios JA, Royer T, Davis IS. Effect of laterally wedged foot orthoses on rearfoot and hip mechanics in patients with medial knee osteoarthritis. *Prosthet Orthot Int.* 2009;33(2):107-16. doi:10.1080/03093640802613237
200. Eysenbach G. Improving the quality of web surveys: the checklist for reporting results of internet e-surveys (CHERRIES). *J Med Internet Res.* 2004;6(3):e34. doi:10.2196/jmir.6.3.e34

201. Moisan G, Descarreaux M, Cantin V. Effects of chronic ankle instability on kinetics, kinematics and muscle activity during walking and running: A systematic review. *Gait Posture*. 2017;52:381-99. doi:10.1016/j.gaitpost.2016.11.037
202. Bavdek R, Zdolsek A, Strojnik V, Dolenc A. Peroneal muscle activity during different types of walking. *J Foot Ankle Res*. 2018;11:50. doi:10.1186/s13047-018-0291-0
203. Welte L, Kelly LA, Kessler SE, Lieberman DE, D'Andrea SE, Lichtwark GA, Rainbow MJ. The extensibility of the plantar fascia influences the windlass mechanism during human running. *Proc Biol Sci*. 2021;288(1943):20202095. doi:10.1098/rspb.2020.2095
204. Sichtung F, Ebrecht F. The rise of the longitudinal arch when sitting, standing, and walking: contributions of the windlass mechanism. *PLoS One*. 2021;16(4):e0249965. doi:10.1371/journal.pone.0249965
205. Eng JJ, Pierrynowski MR. The effect of soft foot orthotics on three-dimensional lower-limb kinematics during walking and running. *Phys Ther*. 1994;74(9):836-44.
206. Carroll M, Jepson H, Molyneux P, Brenton-Rule A. The New Zealand podiatry profession - a workforce in crisis? *J Foot Ankle Res*. 2020;13(1):62. doi:10.1186/s13047-020-00430-y
207. Dessery Y, Belzile E, Turmel S, Corbeil P. Effects of foot orthoses with medial arch support and lateral wedge on knee adduction moment in patients with medial knee osteoarthritis. *Prosthet Orthot Int*. 2017;41(4):356-63. doi:10.1177/0309364616661254
208. Rubin R, Menz HB. Use of laterally wedged custom foot orthoses to reduce pain associated with medial knee osteoarthritis: a preliminary investigation. *J Am Podiatr Med Assoc*. 2005;95(4):347-52. doi:10.7547/0950347
209. Liu X, Duan Y, Hitzmann A, Xu Y, Chen T, Ikemoto S, Hosoda K. Using the foot windlass mechanism for jumping higher: A study on bipedal robot jumping. *Rob Auton Syst*. 2018;110:85-91. doi:10.1016/j.robot.2018.09.006
210. Bolgla LA, Malone TR. Plantar fasciitis and the windlass mechanism: a biomechanical link to clinical practice. *J Athl Train*. 2004;39(1):77-82.
211. Matsumoto Y, Ogihara N. Direct visualization and measurement of the plantar aponeurosis behavior in foot arch deformation via the windlass mechanism. *Clin Anat*. 2024;38(2):116-26. doi:10.1002/ca.24171
212. Cobden A, Camurcu Y, Sofu H, Ucpunar H, Duman S, Kocabiyik A. Evaluation of the association between plantar fasciitis and hallux valgus. *J Am Podiatr Med Assoc*. 2020;110(2):02. doi:10.7547/17-150
213. Yamagiwa D, Iwamoto Y, Nishihara S, Kito N. Evaluation of the relationship between truss/windlass mechanisms and foot stiffness while walking. *J Bodyw Mov Ther*. 2024;37:265-70. doi:10.1016/j.jbmt.2023.11.059
214. Gomez-Carrion A, Sanchez-Gomez R, Reguera-Medina JM, Martinez-Sebastian C, Marquez-Reina S, Cohena-Jimenez M, Moisan G. Effect of using a kinetic wedge during the hallux dorsiflexion resistance test in asymptomatic individuals. *BMC Musculoskelet Disord*. 2024;25(1):409. doi:10.1186/s12891-024-07520-z
215. Zhang Q, Sun D, Wang M, Tafferner-Gulyás V, Chen H, Bíró I, Gu Y. Effect of plantar fascia stiffness on plantar windlass mechanism and arch: Finite element method and dual fluoroscopic imaging system verification. *Med Eng Phys*. 2024;134. doi:10.1016/j.medengphy.2024.104259
216. Moisan G, Chicoine D, McBride S, Isabelle PL, Gomez-Carrion A, Farahpour N. First metatarsophalangeal joint dorsiflexion resistance in individuals with plantar fasciopathy. *Foot*. 2024;60:102121. doi:10.1016/j.foot.2024.102121
217. Irving DB, Cook JL, Menz HB. Factors associated with chronic plantar heel pain: a systematic review. *J Sci Med Sport*. 2006;9(1-2):11-22. doi:10.1016/j.jsams.2006.02.004
218. Clough JG. Functional hallux limitus and lesser-metatarsal overload. *J Am Podiatr Med Assoc*. 2005;95(6):593-601. doi:10.7547/0950593

219. Durrant B, Chockalingam N. Functional hallux limitus: a review. *J Am Podiatr Med Assoc.* 2009;99(3):236-43. doi:10.7547/0980236
220. Hall C, Nester CJ. Sagittal plane compensations for artificially induced limitation of the first metatarsophalangeal joint: a preliminary study. *J Am Podiatr Med Assoc.* 2004;94(3):269-74. doi:10.7547/0940269
221. Krell JB, Stefanyshyn DJ. The relationship between extension of the metatarsophalangeal joint and sprint time for 100 m Olympic athletes. *J Sports Sci.* 2006;24(2):175-80. doi:10.1080/02640410500131621
222. Zulkifli SS, Loh WP. A state-of-the-art review of foot pressure. *Foot Ankle Surg.* 2020;26(1):25-32. doi:10.1016/j.fas.2018.12.005
223. Chiu MC, Wu HC, Chang LY, Wu MH. Center of pressure progression characteristics under the plantar region for elderly adults. *Gait Posture.* 2013;37(3):408-12. doi:10.1016/j.gaitpost.2012.08.010
224. De Cock A, Vanrenterghem J, Willems T, Witvrouw E, De Clercq D. The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. *Gait Posture.* 2008;27(4):669-75. doi:10.1016/j.gaitpost.2007.08.013
225. Kirby KA, Spooner SK, Scherer PR, Schubert JM. Foot orthoses. *Foot Ankle Spec.* 2012;5(5):334-43. doi:10.1177/1938640012458900
226. Wegener C, Greene A, Burns J, Hunt AE, Vanwanseele B, Smith RM. In-shoe multi-segment foot kinematics of children during the propulsive phase of walking and running. *Hum Mov Sci.* 2015;39:200-11. doi:10.1016/j.humov.2014.11.002
227. Yamato TP, Saragiotto BT, Lopes AD. A consensus definition of running-related injury in recreational runners: a modified Delphi approach. *J Orthop Sports Phys Ther.* 2015;45(5):375-80. doi:10.2519/jospt.2015.5741
228. Turner DE, Helliwell PS, Burton AK, Woodburn J. The relationship between passive range of motion and range of motion during gait and plantar pressure measurements. *Diabet Med.* 2007;24(11):1240-6. doi:10.1111/j.1464-5491.2007.02233.x
229. Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index. *Clin Biomech.* 2006;21(1):89-98. doi:10.1016/j.clinbiomech.2005.08.002
230. Leardini A, Benedetti MG, Berti L, Bettinelli D, Nativo R, Giannini S. Rear-foot, mid-foot and fore-foot motion during the stance phase of gait. *Gait Posture.* 2007;25(3):453-62. doi:10.1016/j.gaitpost.2006.05.017
231. Weir G, Jewell C, Wyatt H, Trudeau MB, Rohr E, Brüggemann G-P, Hamill J. The influence of prolonged running and footwear on lower extremity biomechanics. *Footwear Sci.* 2018;11(1):1-11. doi:10.1080/19424280.2018.1539127
232. Winter D. Signal Processing. *Biomechanics and Motor Control of Human Movement* 2009. p. 14-44.
233. Pataky TC. Generalized n-dimensional biomechanical field analysis using statistical parametric mapping. *J Biomech.* 2010;43(10):1976-82. doi:10.1016/j.jbiomech.2010.03.008
234. Houston VL, Luo G, Mason CP, Mussman M, Garbarini M, Beattie AC. Changes in male foot shape and size with weightbearing. *J Am Podiatr Med Assoc.* 2006;96(4):330-43. doi:10.7547/0960330
235. Cao B, Wang J, Shi W, Lu X, Zhou K. 3D foot anthropometric measurements under two weight-bearing conditions for ergonomic design of foot-related products. *Int J Morphol.* 2023;41(4):1209-18. doi:10.4067/S0717-95022023000401209
236. Alsenoy KV, van der Linden ML, Girard O, Ryu JH, Raisi LA, Santos D. Effects of hybrid custom foot orthoses on running economy, running mechanics and comfort: A double-blinded randomized crossover study. *Gait Posture.* 2025;118:45-50. doi:10.1016/j.gaitpost.2025.01.030

237. Becerro de Bengoa Vallejo R, Sanchez Gomez R, Losa Iglesias ME. Clinical improvement in functional hallux limitus using a cut-out orthosis. *Prosthet Orthot Int*. 2016;40(2):215-23. doi:10.1177/0309364614550262
238. Kilmartin TE, Wallace WA, Hill TW. Orthotic effect on metatarsophalangeal joint extension. A preliminary study. *J Am Podiatr Med Assoc*. 1991;81(8):414-7. doi:10.7547/87507315-81-8-414
239. Scherer PR, Sanders J, Eldredge DE, Duffy SJ, Lee RY. Effect of functional foot orthoses on first metatarsophalangeal joint dorsiflexion in stance and gait. *J Am Podiatr Med Assoc*. 2006;96(6):474-81. doi:10.7547/0960474
240. Martinez-Rico M, Gijon-Nogueron G, Ortega-Avila AB, Roche-Seruendo LE, Climent-Pedrosa A, Sanchis-Sales E, Deschamps K. Effect of custom-made foot orthotics on multi-segment foot kinematics and kinetics in individuals with structural hallux limitus. *Sensors*. 2024;24(19):6430. doi:10.3390/s24196430
241. Roukis TS, Scherer PR, Anderson CF. Position of the first ray and motion of the first metatarsophalangeal joint. *J Am Podiatr Med Assoc*. 1996;86(11):538-46. doi:10.7547/87507315-86-11-538
242. Williams LR, Arch ES, Bruening DA. Kinetic coupling in distal foot joints during walking. *J Foot Ankle Res*. 2023;16(1):44. doi:10.1186/s13047-023-00643-x
243. Manfredi-Marquez MJ, Tavara-Vidalon SP, Tavaruela-Carrion N, Gomez Benitez MA, Fernandez-Seguín LM, Ramos-Ortega J. Study of windlass mechanism in the lower limb using inertial sensors. *Int J Environ Res Public Health*. 2023;20(4). doi:10.3390/ijerph20043220
244. Gomez Carrion A, Atin Arratibe MLA, Morales Lozano MR, Martinez Rincon C, Martinez Sebastian C, Saura Sempere A, et al. Changes in the kinematics of midfoot and rearfoot joints with the use of lateral wedge insoles. *J Clin Med*. 2022;11(15). doi:10.3390/jcm11154536
245. Giacomozzi C, Macellari V, Leardini A, Benedetti MG. Integrated pressure-force-kinematics measuring system for the characterisation of plantar foot loading during locomotion. *Med Biol Eng Comput*. 2000;38(2):156-63. doi:10.1007/BF02344770
246. Paterson KL, Hinman RS, Metcalf BR, McManus F, Jones SE, Menz HB, et al. Effect of foot orthoses vs sham insoles on first metatarsophalangeal joint osteoarthritis symptoms: a randomized controlled trial. *Osteoarthr Cartil*. 2022;30(7):956-64. doi:10.1016/j.joca.2022.01.014
247. Hatton AL, Hug F, Brown BC, Green LP, Hughes JR, King J, et al. A study of the immediate effects of glycerine-filled insoles, contoured prefabricated orthoses and flat insoles on single-leg balance, gait patterns and perceived comfort in healthy adults. *J Foot Ankle Res*. 2015;8:47. doi:10.1186/s13047-015-0107-4
248. Yurt Y, Sener G, Yakut Y. The effect of different foot orthoses on pain and health related quality of life in painful flexible flat foot: a randomized controlled trial. *Eur J Phys Rehabil Med*. 2019;55(1):95-102. doi:10.23736/S1973-9087.18.05108-0
249. Almeida MO, Davis IS, Lopes AD. Biomechanical differences of foot-strike patterns during running: A systematic review with meta-analysis. *J Orthop Sports Phys Ther*. 2015;45(10):738-55. doi:10.2519/jospt.2015.6019
250. Mager F, Richards J, Hennies M, Dotzel E, Chohan A, Mbuli A, Capanni F. Determination of ankle and metatarsophalangeal stiffness during walking and jogging. *J Appl Biomech*. 2018;1-6. doi:10.1123/jab.2017-0265
251. Morio C, Lake MJ, Gueguen N, Rao G, Baly L. The influence of footwear on foot motion during walking and running. *J Biomech*. 2009;42(13):2081-8. doi:10.1016/j.jbiomech.2009.06.015
252. Sinclair J, Taylor P, Hebron J, Chockalingam N. Differences in multi-segment foot kinematics measured using skin and shoe mounted markers. *Foot Ankle Online J*. 2014;7(2):7.

253. Richie DH. Biomechanics and orthotic treatment of the adult acquired flatfoot. *Clin Podiatr Med Surg.* 2020;37(1):71-89. doi:10.1016/j.cpm.2019.08.007
254. Potthoff S, Rasul O, Sniehotta FF, Marques M, Beyer F, Thomson R, et al. The relationship between habit and healthcare professional behaviour in clinical practice: a systematic review and meta-analysis. *Health Psychol Rev.* 2019;13(1):73-90. doi:10.1080/17437199.2018.1547119
255. Yona T, Kamel N, Cohen-Eick G, Ovadia I, Fischer A. One-dimensional statistical parametric mapping in lower limb biomechanical analysis: a systematic scoping review. *Gait Posture.* 2024;109:133-46. doi:10.1016/j.gaitpost.2024.01.018
256. Schmiedmayer H-B, Kastner J. Parameters influencing the accuracy of the point of force application determined with piezoelectric force plates. *J Biomech.* 1999;32(11):1237-42. doi:10.1016/S0021-9290(99)00109-8
257. Arnold JB, Bishop C. Quantifying foot kinematics inside athletic footwear: a review. *Footwear Sci.* 2013;5(1):55-62. doi:10.1080/19424280.2012.735257
258. Hebert-Losier K, Dai B, Nunome H, Kong PW, Hobara H, Hsu WC, et al. Reporting guidelines for running biomechanics and footwear studies using three-dimensional motion capture. *Sports Biomech.* 2023;22(3):473-84. doi:10.1080/14763141.2022.2110149
259. Bishop C, Thewlis D, Uden H, Ogilvie D, Paul G. A radiological method to determine the accuracy of motion capture marker placement on palpable anatomical landmarks through a shoe. *Footwear Sci.* 2011;3(3):169-77. doi:10.1080/19424280.2011.635386
260. Alcantara RS, Trudeau MB, Rohr ES. Calcaneus range of motion underestimated by markers on running shoe heel. *Gait Posture.* 2018;63:68-72. doi:10.1016/j.gaitpost.2018.04.035
261. Sinclair J, Greenhalgh A, Taylor PJ, Edmundson CJ, Brooks D, Hobbs SJ. Differences in tibio-calcaneal kinematics measured with skin- and shoe-mounted markers. *Human Movement.* 2013;14(1):64-9. doi:10.2478/humo-2013-0005
262. Trudeau MB, Jewell C, Rohr E, Fischer KM, Willwacher S, Brueggemann G-P, Hamill J. The calcaneus adducts more than the shoe's heel during running. *Footwear Sci.* 2017;9(2):79-85. doi:10.1080/19424280.2017.1334712
263. Nawoczenski DA, Ludewig PM. The effect of forefoot and arch posting orthotic designs on first metatarsophalangeal joint kinematics during gait. *J Orthop Sports Phys Ther.* 2004;34(6):317-27. doi:10.2519/jospt.2004.34.6.317
264. Michaud TC, Nawoczenski DA. The influence of two different types of foot orthoses on first metatarsophalangeal joint kinematics during gait in a single subject. *J Manipulative Physiol Ther.* 2006;29(1):60-5. doi:10.1016/j.jmpt.2005.11.009
265. Menz HB, Auhl M, Tan JM, Levinger P, Roddy E, Munteanu SE. Biomechanical effects of prefabricated foot orthoses and rocker-sole footwear in individuals with first metatarsophalangeal joint osteoarthritis. *Arthritis Care Res.* 2016;68(5):603-11. doi:10.1002/acr.22743
266. Arnold JB, May T, Bishop C. Predictors of the biomechanical effects of customized foot orthoses in adults with flat-arched feet. *Clin J Sport Med.* 2018;28(4).
267. McClelland JA, Allan JJ, Auhl M, Buldt AK, Landorf KB, Cicuttini FM, et al. Effects of shoe-stiffening inserts on lower extremity kinematics in individuals with first metatarsophalangeal joint osteoarthritis. *Arthritis Care Res.* 2022;74(11):1849-56. doi:10.1002/acr.24647
268. Riel H, Cotchett M, Delahunt E, Rathleff MS, Vicenzino B, Weir A, Landorf KB. Is 'plantar heel pain' a more appropriate term than 'plantar fasciitis'? Time to move on. *Br J Sports Med.* 2017;51(22):1576-7. doi:10.1136/bjsports-2017-097519
269. McMillan AM, Landorf KB, Barrett JT, Menz HB, Bird AR. Diagnostic imaging for chronic plantar heel pain: a systematic review and meta-analysis. *J Foot Ankle Res.* 2009;2:32. doi:10.1186/1757-1146-2-32

270. Garrow AP, Papageorgiou AC, Silman AJ, Thomas E, Jayson MIV, Macfarlane GJ. Development and validation of a questionnaire to assess disabling foot pain. *Pain*. 2000;85(1). doi:10.1016/s0304-3959(99)00263-8

Chapter 8: Appendices

8.1 Appendix 1: Diagnostic groupings applied in Chapter 3

Most prescriptions (n=937, 94%) gathered from CFO labs in Chapter 3 included a clinical diagnosis. A complete list of diagnostic groups and the clinical diagnoses included is available below.

Diagnosis	n (%)	Description
PHP	110 (11)	Plantar heel pain including all references to the plantar fascia or heel pain
Pes Planus	81 (8)	Pes Planus including pes planovalgus, flat foot and 'collapsed arches'
Posterior tibial tendon (Incl PTTD)	61 (6)	Tibialis posterior tendon pain, tendinopathy, insufficiency, or PTTD (any stage)
Ankle sprain	50 (5)	Lateral ankle sprain or lateral ankle instability
Achilles	45 (5)	Achilles tear, strain, rupture, tendinopathy or tendinosis
Forefoot pain	41 (4)	Forefoot pain including MPJ pain, forefoot discomfort, metatarsalgia, excluding bursitis, mortons neuroma, and first MPJ joint sprain
Knee injury/pain	34 (3)	Knee injury or pain including osteoarthritis, PFPS, ITB, Meniscus injury
Replacement orthotics	30 (3)	Replacement pairs of orthotics without mention of pathology or another clinical diagnosis
Ankle pain (Excluding ligament injury, sprain or ankle surgery/reconstruction)	30 (3)	Ankle fracture or ankle pain with no reference to ligaments
HAV	28 (3)	Hallux abducto valgus
Arch pain or medial midfoot pain	28 (3)	Arch pain or generalised midfoot pain
Overpronation	28 (3)	Pronation, overpronation, valgus rearfoot
Ankle surgery	27 (3)	Orthoses prescribed post ankle reconstructions or stabilisation surgery
Hallux Limitus	22 (2)	Structural hallux limitus/rigidus or functional hallux limitus/rigidus
Shin injury/pain	20 (2)	Shin pain, shin splints, MTSS
Lisfranc	19 (2)	Lisfranc fracture or injury
Mortons Neuroma	19 (2)	Neuroma or mortons neuroma
Peroneal tendon issue	17 (2)	Peroneal tendon injury, tendinopathy or strain
Pes Cavus	17 (2)	Pes Cavus, High Arch, Cavovarus, or any description of a high arched foot

Diagnosis	n (%)	Description
First MPJ pain/injury	16 (2)	First MPJ joint sprain
Kinematic/Anatomical Dx	15 (2)	Broad category including diagnoses of poor biomechanics with no reference to pain or symptoms
Foot injury (no more specific)	15 (2)	Generalised foot pain or tender feet
Neuropathy or neurological conditions	15 (2)	Neuropathy or neurological condition
Post surgical	14 (1)	A broad range of post surgical cases including bunionectomy, reconstructions, skin grafts, and amputations
Diabetes	14 (1)	Diabetes foot
Lateral midfoot pain	13 (1)	Lateral foot pain including cuboid pain/syndrome
Other	12 (1)	Non specific fractures, blistering
Rheumatoid Arthritis	12 (1)	Rheumatoid arthritis
Instability	7 (1)	Instability (excluding lateral ankle instability)
Back pain	7 (1)	Back pain
Motor vehicle accident	7 (1)	Motor vehicle accident
Hip injury/pain	7 (1)	Hip pain or hip surgery
Bursitis	7 (1)	Forefoot bursitis
Calcaneus fracture	7 (1)	Calcaneal fracture
Rearfoot pain	6 (1)	General rearfoot pain excluding calcaneal fractures and PHP or any reference to the plantar fascia
Sesamoiditis	6 (1)	Sesamoiditis
Limb length discrepancy	6 (1)	Limb length discrepancy
Sinus tarsi syndrome	6 (1)	Sinus tarsi syndrome
Paediatric Flatfoot	3 (0)	Paediatric flatfoot
Tibialis Anterior	2 (0)	Tibialis anterior strain or injury
Clubfoot	1 (0)	Clubfoot
Calf injury/pain	1 (0)	Gastroc strain

8.2 Appendix 2: Diagnostic associations from Chapter 3

Results of the significant associations between diagnosis and orthotic inclusions as part of the association analysis are presented in Chapter 3 (Table 3.3). Complete results of the cross tabulations and association analysis of all orthosis characteristics in relation to each of the top four diagnoses are presented below including both non-significant and significant findings.

- | |
|---|
| - Comparisons which meet the criteria for significance after Holm-Bonferroni correction are highlighted in green. |
| - Comparisons which have a P value < 0.05 but are not significant after Holm-Bonferroni correction are highlighted in yellow. |

Plantar heel pain

Characteristic	Qualifier	PHP (%)	Not PHP (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Shell thickness	Not reported	7 (6.4)	75 (8.4)	6.693	0.462	0.005	No
	2 mm	2 (1.8)	35 (3.9)				
	2.5 mm	7 (6.4)	53 (6)				
	3 mm	58 (52.7)	484 (54.4)				
	3.5 mm	24 (21.8)	126 (14.2)				
	4 mm	7 (6.4)	78 (8.8)				
	4.5 mm	5 (4.5)	36 (4)				
	5 mm	0 (0)	3 (0.3)				
Shell style	Mod Root	74 (67.3)	54 (60.7)	14.701	0.002	0.002	Yes
	Sagittal Plane	23 (20.9)	111 (12.5)				
	Medial STJ	6 (5.5)	103 (11.6)				
	Other	7 (6.4)	136 (15.3)				
Varus cast correction	No	29 (26.4)	331 (37.2)	4.981	0.026	0.002	No
	Yes	81 (73.6)	559 (62.8)				
Valgus cast correction	No	108 (98.2)	836 (93.9)	3.344	0.067	0.003	No
	Yes	2 (1.8)	54 (6.1)				
Kirby Skive	No	68 (61.8)	576 (64.7)	0.359	0.549	0.006	No
	Yes	42 (38.2)	314 (35.3)				

Characteristic	Qualifier	PHP (%)	Not PHP (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Heel raise	No	106 (96.4)	828 (93)	1.761	0.184	0.003	No
	Yes	4 (3.6)	62 (7)				
1 st Ray cutout	No	84 (76.4)	740 (83.1)	3.105	0.078	0.003	No
	Yes	26 (23.6)	150 (16.9)				
Lateral side high	No	102 (92.7)	702 (78.9)	11.919	< 0.001	0.002	Yes
	Yes	8 (7.3)	188 (21.1)				
Medial side high	No	86 (78.2)	747 (83.9)	2.327	0.127	0.003	No
	Yes	24 (21.8)	143 (16.1)				
Deep heel cup	No	66 (60)	574 (64.5)	0.858	0.354	0.004	No
	Yes	44 (40)	316 (35.5)				
Shallow heel cup	No	101 (91.8)	831 (93.4)	0.372	0.542	0.006	No
	Yes	9 (8.2)	59 (6.6)				
Plantar fascia groove	No	87 (79.1)	850 (95.5)	44.686	< 0.001	0.002	Yes
	Yes	23 (20.9)	40 (4.5)				
Forefoot lateral wedge	No	72 (65.5)	710 (79.8)	11.777	< 0.001	0.002	Yes
	Yes	38 (34.5)	180 (20.2)				
Medial forefoot wedge	No	93 (84.5)	789 (88.7)	1.586	0.208	0.003	No
	Yes	17 (15.5)	101 (11.3)				

Characteristic	Qualifier	PHP (%)	Not PHP (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Reverse mortons extension	No	98 (89.1)	812 (91.2)	0.550	0.458	0.005	No
	Yes	12 (10.9)	78 (8.8)				
Kinetic wedge	No	108 (98.2)	879 (98.8)	0.259	0.611	0.008	No
	Yes	2 (1.8)	11 (1.2)				
Metatarsal dome	No	106 (96.4)	827 (92.9)	1.856	0.173	0.003	No
	Yes	4 (3.6)	63 (7.1)				
PMP	No	105 (95.5)	837 (94)	0.356	0.551	0.007	No
	Yes	5 (4.5)	53 (6)				
Plantar cover	No	106 (96.4)	835 (93.8)	1.141	0.286	0.004	No
	Yes	4 (3.6)	55 (6.2)				
Heel Cushion	No	65 (59.1)	819 (92)	103.537	< 0.001	0.002	Yes
	Yes	45 (40.9)	71 (8)				
Arch pad	No	98 (89.1)	780 (87.6)	0.192	0.661	0.010	No
	Yes	12 (10.9)	110 (12.4)				
Mortons extension	No	109 (99.1)	869 (97.6)	0.957	0.328	0.004	No
	Yes	1 (0.9)	21 (2.4)				
Symmetrical	No	46 (41.8)	379 (42.6)	0.024	0.878	0.013	No
	Yes	64 (58.2)	511 (57.4)				

Pes Planus

Characteristic	Qualifier	PP (%)	Not PP (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Shell thickness	Not reported	10 (12.3)	72 (7.8)	12.244	0.093	0.004	No
	2 mm	0 (0)	37 (4)				
	2.5 mm	4 (4.9)	56 (6.1)				
	3 mm	40 (49.4)	502 (54.6)				
	3.5 mm	15 (18.5)	135 (14.7)				
	4 mm	10 (12.3)	75 (8.2)				
	4.5 mm	1 (1.2)	40 (4.4)				
5 mm	1 (1.2)	2 (0.2)					
Shell style	Mod Root	40 (49.4)	574 (62.5)	47.183	< 0.001	0.002	Yes
	Sagittal Plane	9 (11.1)	125 (13.6)				
	Medial STJ	27 (33.3)	82 (8.9)				
	Other	5 (6.2)	138 (15)				
Varus cast correction	No	24 (29.6)	336 (36.6)	1.552	0.213	0.004	No
	Yes	57 (70.4)	583 (63.4)				
Valgus cast correction	No	80 (98.8)	864 (94)	3.177	0.075	0.003	No
	Yes	1 (1.2)	55 (6)				
Kirby Skive	No	44 (54.3)	600 (65.3)	3.905	0.048	0.003	No
	Yes	37 (45.7)	319 (34.7)				
Heel raise	No	77 (95.1)	857 (93.3)	0.395	0.530	0.013	No
	Yes	4 (4.9)	62 (6.7)				
1 st Ray cutout	No	70 (86.4)	754 (82)	0.982	0.322	0.006	No
	Yes	11 (13.6)	165 (18)				
Lateral side high	No	79 (97.5)	725 (78.9)	16.414	< 0.001	0.002	Yes
	Yes	2 (2.5)	194 (21.1)				
Medial side high	No	57 (70.4)	776 (84.4)	10.592	0.001	0.002	Yes
	Yes	24 (29.6)	143 (15.6)				

Characteristic	Qualifier	PP (%)	Not PP (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Deep heel cup	No	40 (49.4)	600 (65.3)	8.174	0.004	0.003	No
	Yes	41 (50.6)	319 (34.7)				
Shallow heel cup	No	77 (95.1)	855 (93)	0.482	0.488	0.010	No
	Yes	4 (4.9)	64 (7)				
Plantar fascia groove	No	80 (98.8)	857 (93.3)	3.831	0.050	0.003	No
	Yes	1 (1.2)	62 (6.7)				
Forefoot lateral wedge	No	76 (93.8)	706 (76.8)	12.626	< 0.001	0.002	Yes
	Yes	5 (6.2)	213 (23.2)				
Medial forefoot wedge	No	63 (77.8)	819 (89.1)	9.199	0.002	0.002	Yes
	Yes	18 (22.2)	100 (10.9)				
Reverse mortons extension	No	80 (98.8)	830 (90.3)	6.490	0.011	0.003	No
	Yes	1 (1.2)	89 (9.7)				
Kinetic wedge	No	78 (96.3)	909 (98.9)	3.969	0.046	0.003	No
	Yes	3 (3.7)	10 (1.1)				
Metatarsal dome	No	78 (96.3)	855 (93)	1.266	0.261	0.005	No
	Yes	3 (3.7)	64 (7)				
PMP	No	78 (96.3)	864 (94)	0.709	0.400	0.008	No
	Yes	3 (3.7)	55 (6)				
Plantar cover	No	78 (96.3)	863 (93.9)	0.766	0.382	0.007	No
	Yes	3 (3.7)	56 (6.1)				
Heel Cushion	No	75 (92.6)	809 (88)	1.511	0.219	0.005	No
	Yes	6 (7.4)	110 (12)				
Arch pad	No	55 (67.9)	823 (89.6)	32.581	< 0.001	0.002	Yes
	Yes	26 (32.1)	96 (10.4)				
Mortons extension	No	78 (96.3)	900 (97.9)	0.926	0.336	0.006	No
	Yes	3 (3.7)	19 (2.1)				
Symmetrical	No	28 (34.6)	397 (43.2)	2.269	0.132	0.004	No
	Yes	53 (65.4)	522 (56.8)				

Posterior tibial tendon

Characteristic	Qualifier	PT (%)	Not PT (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Shell thickness	Not reported	4 (6.6)	78 (8.3)	7.300	0.398	0.003	No
	2 mm	2 (3.3)	35 (3.7)				
	2.5 mm	2 (3.3)	58 (6.2)				
	3 mm	36 (59)	506 (53.9)				
	3.5 mm	14 (23)	136 (14.5)				
	4 mm	2 (3.3)	83 (8.8)				
	4.5 mm	1 (1.6)	40 (4.3)				
5 mm	0 (0)	3 (0.3)					
Shell style	Mod Root	24 (39.3)	590 (62.8)	51.127	< 0.001	0.002	Yes
	Sagittal Plane	10 (16.4)	124 (13.2)				
	Medial STJ	23 (37.7)	86 (9.2)				
	Other	4 (6.6)	139 (14.8)				
Varus cast correction	No	8 (13.1)	352 (37.5)	14.767	< 0.001	0.002	Yes
	Yes	53 (86.9)	587 (62.5)				
Valgus cast correction	No	61 (100)	883 (94)	3.854	0.050	0.002	No
	Yes	0 (0)	56 (6)				
Kirby Skive	No	21 (34.4)	623 (66.3)	25.457	< 0.001	0.002	Yes
	Yes	40 (65.6)	316 (33.7)				
Heel raise	No	59 (96.7)	875 (93.2)	1.162	0.281	0.003	No
	Yes	2 (3.3)	64 (6.8)				
1 st Ray cutout	No	53 (86.9)	771 (82.1)	0.901	0.342	0.003	No
	Yes	8 (13.1)	168 (17.9)				
Lateral side high	No	51 (83.6)	753 (80.2)	0.424	0.515	0.003	No
	Yes	10 (16.4)	186 (19.8)				
Medial side high	No	49 (80.3)	784 (83.5)	0.413	0.521	0.003	No
	Yes	12 (19.7)	155 (16.5)				

Characteristic	Qualifier	PT (%)	Not PT (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Deep heel cup	No	37 (60.7)	603 (64.2)	0.315	0.574	0.004	No
	Yes	24 (39.3)	336 (35.8)				
Shallow heel cup	No	56 (91.8)	876 (93.3)	0.200	0.655	0.004	No
	Yes	5 (8.2)	63 (6.7)				
Plantar fascia groove	No	60 (98.4)	877 (93.4)	2.390	0.122	0.002	No
	Yes	1 (1.6)	62 (6.6)				
Forefoot lateral wedge	No	52 (85.2)	730 (77.7)	1.892	0.169	0.002	No
	Yes	9 (14.8)	209 (22.3)				
Medial forefoot wedge	No	45 (73.8)	837 (89.1)	12.996	< 0.001	0.002	Yes
	Yes	16 (26.2)	102 (10.9)				
Reverse mortons extension	No	56 (91.8)	854 (90.9)	0.051	0.821	0.006	No
	Yes	5 (8.2)	85 (9.1)				
Kinetic wedge	No	60 (98.4)	927 (98.7)	0.058	0.809	0.006	No
	Yes	1 (1.6)	12 (1.3)				
Metatarsal dome	No	58 (95.1)	875 (93.2)	0.330	0.566	0.003	No
	Yes	3 (4.9)	64 (6.8)				
PMP	No	58 (95.1)	884 (94.1)	0.092	0.761	0.005	No
	Yes	3 (4.9)	55 (5.9)				
Plantar cover	No	58 (95.1)	883 (94)	0.113	0.737	0.004	No
	Yes	3 (4.9)	56 (6)				
Heel Cushion	No	59 (96.7)	825 (87.9)	4.387	0.036	0.002	No
	Yes	2 (3.3)	114 (12.1)				
Arch pad	No	42 (68.9)	836 (89)	21.773	< 0.001	0.002	Yes
	Yes	19 (31.1)	103 (11)				
Mortons extension	No	60 (98.4)	918 (97.8)	0.095	0.758	0.005	No
	Yes	1 (1.6)	21 (2.2)				
Symmetrical	No	40 (65.6)	385 (41)	14.153	< 0.001	0.002	Yes
	Yes	21 (34.4)	554 (59)				

Ankle sprain

Characteristic	Qualifier	ASpr (%)	Not ASpr (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Shell thickness	Not reported	1 (2)	81 (8.5)	12.273	0.092	0.002	No
	2 mm	2 (4)	35 (3.7)				
	2.5 mm	0 (0)	60 (6.3)				
	3 mm	32 (64)	510 (53.7)				
	3.5 mm	4 (8)	146 (15.4)				
	4 mm	7 (14)	78 (8.2)				
	4.5 mm	4 (8)	37 (3.9)				
5 mm	0 (0)	3 (0.3)					
Shell style	Mod Root	31 (62)	583 (61.4)	6.219	0.101	0.003	No
	Sagittal Plane	5 (10)	129 (13.6)				
	Medial STJ	2 (4)	107 (11.3)				
	Other	12 (24)	131 (13.8)				
Varus cast correction	No	27 (54)	333 (35.1)	7.401	0.007	0.002	No
	Yes	23 (46)	617 (64.9)				
Valgus cast correction	No	38 (76)	906 (95.4)	33.707	< 0.001	0.002	Yes
	Yes	12 (24)	44 (4.6)				
Kirby Skive	No	36 (72)	608 (64)	1.326	0.250	0.004	No
	Yes	14 (28)	342 (36)				
Heel raise	No	48 (96)	886 (93.3)	0.577	0.447	0.007	No
	Yes	2 (4)	64 (6.7)				
1 st Ray cutout	No	39 (78)	785 (82.6)	0.703	0.402	0.005	No
	Yes	11 (22)	165 (17.4)				
Lateral side high	No	20 (40)	784 (82.5)	54.513	< 0.001	0.002	Yes
	Yes	30 (60)	166 (17.5)				
Medial side high	No	45 (90)	788 (82.9)	1.698	0.193	0.003	No
	Yes	5 (10)	162 (17.1)				

Characteristic	Qualifier	ASpr (%)	Not ASpr (%)	Peason Chi-Square	P value	Holm-Bonferroni corrected threshold	Significance after multiple tests correction
Deep heel cup	No	27 (54)	613 (64.5)	2.284	0.131	0.003	No
	Yes	23 (46)	337 (35.5)				
Shallow heel cup	No	50 (100)	882 (92.8)	3.840	0.050	0.003	No
	Yes	0 (0)	68 (7.2)				
Plantar fascia groove	No	49 (98)	888 (93.5)	1.649	0.199	0.003	No
	Yes	1 (2)	62 (6.5)				
Forefoot lateral wedge	No	26 (52)	756 (79.6)	21.193	< 0.001	0.002	Yes
	Yes	24 (48)	194 (20.4)				
Medial forefoot wedge	No	48 (96)	834 (87.8)	3.077	0.079	0.002	No
	Yes	2 (4)	116 (12.2)				
Reverse mortons extension	No	43 (86)	867 (91.3)	1.607	0.205	0.003	No
	Yes	7 (14)	83 (8.7)				
Kinetic wedge	No	50 (100)	937 (98.6)	0.693	0.405	0.006	No
	Yes	0 (0)	13 (1.4)				
Metatarsal dome	No	48 (96)	885 (93.2)	0.614	0.433	0.006	No
	Yes	2 (4)	65 (6.8)				
PMP	No	49 (98)	893 (94)	1.391	0.238	0.004	No
	Yes	1 (2)	57 (6)				
Plantar cover	No	49 (98)	892 (93.9)	1.442	0.230	0.004	No
	Yes	1 (2)	58 (6.1)				
Heel Cushion	No	47 (94)	837 (88.1)	1.610	0.205	0.003	No
	Yes	3 (6)	113 (11.9)				
Arch pad	No	49 (98)	829 (87.3)	5.112	0.024	0.002	No
	Yes	1 (2)	121 (12.7)				
Mortons extension	No	50 (100)	928 (97.7)	1.184	0.277	0.005	No
	Yes	0 (0)	22 (2.3)				
Symmetrical	No	23 (46)	402 (42.3)	0.264	0.608	0.008	No
	Yes	27 (54)	548 (57.7)				

8.3 Appendix 3: Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist

For the scoping review in Chapter 4 the PRISMA-ScR preferred reporting guidelines (178) were adhered to, to ensure methodological quality and transparent reporting. The checklist detailing each component and where this is available in the thesis is available below.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Page 51
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Page 52
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Page 53
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	Page 53
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	NA
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Page 54
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Page 54
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Table 4.1
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Page 53-54

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Page 55
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Page 55
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	NA
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	Page 55
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Figure 4.1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Table 4.2 & 4.3
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	NA
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Appendix 4
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Page 58-61
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Page 60-63

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Limitations	20	Discuss the limitations of the scoping review process.	NA
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Page 65-66
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	NA

JBIG = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Ann Intern Med.* 2018;169:467–473. doi: [10.7326/M18-0850](https://doi.org/10.7326/M18-0850).

8.4 Appendix 4: Kinematic and Kinetic Outcomes of the studies included in Chapter 4

The table below details all kinematic and kinetic outcomes of interest to the scoping review presented in Chapter 4.

Reference	Intervention	Outcome
Kakihana et al. (16)	2 conditions – Neutral, laterally wedged insole 6°	<ul style="list-style-type: none"> - STJ valgus moment increased in the laterally wedged condition ($p < 0.001$) - No significant change in STJ angle between conditions ($p = 0.215$) - COP shifted laterally in the wedged condition. The valgus moment arm of the STJ was greater in the wedged condition ($p < 0.001$)
Kakihana et al. (15)	2 conditions – Neutral, laterally wedged insole 6°	<ul style="list-style-type: none"> - STJ valgus moment increased in the laterally wedged condition ($p < 0.001$) - No significant change in STJ angle ($p = 0.142$) - COP shifted laterally in the wedged condition. The valgus moment arm of the STJ was greater in the wedged condition ($p < 0.001$)
Telfer et al. (179)	9 conditions - 6° lateral to 10° medial wedges, in 2° increments	<ul style="list-style-type: none"> - Mean lateral rearfoot plantar pressure is increased by lateral wedging ($p = 0.002$) - Midfoot peak and midfoot mean plantar pressure increased with lateral wedging ($p < 0.001$) - Lateral forefoot peak ($p = 0.042$) and mean ($p = 0.002$) plantar pressure decreased with lateral wedging - No significant change was found for the following plantar pressures: Peak medial rearfoot ($p = 0.231$); mean medial rearfoot ($p = 0.313$); peak lateral rearfoot ($p = 0.179$); peak 1st ray ($p = 0.796$); and mean 1st ray ($p = 0.337$)
Tse, Ryan and Hunt (10)	6 conditions – Flat (control), 5° lateral wedge, variable stiffness contoured arch support, uniform stiffness contoured arch support, variable stiffness contoured arch support with 5° lateral wedge, uniform stiffness contoured arch support with 5° lateral wedge	<ul style="list-style-type: none"> - Ankle/STJ eversion moment and eversion moment impulse increased with lateral wedging ($p < 0.05$) - Ankle/STJ eversion angle peak was increased with lateral wedging ($p < 0.05$) - Ankle/STJ eversion excursion was not significantly changed ($p = 0.52$)
Fukuchi et al. (12)	5 conditions – Neutral, laterally wedged insoles 6° and 9°, medially wedged insoles 6° and 9°	<ul style="list-style-type: none"> - Lateral wedges increased the internal ankle inversion moments relative to the neutral condition (6° wedge, $p = 0.02$; 9° wedge, $p < 0.001$) - 9° lateral wedge increased the ankle inversion impulse, relative to the neutral condition ($p = 0.12$) - 9° lateral wedge shifted the COP laterally relative to the neutral condition ($p < 0.001$)
Kluge et al. (18)	2 conditions – Individualised arch support to STJ neutral, laterally wedged insole 4mm (4-5°)	<ul style="list-style-type: none"> - Ankle eversion increased in the wedged condition ($p < 0.001$) - No significant change in COP position ($p = 0.509$) - No significant change in either the vertical ($p = 0.151$) or medial ($p = 0.069$) components of GRF
Lewinson et al. (93)	6 conditions – laterally wedged insoles 3°, 6°, 9° and medially wedged insoles, 3°, 6° and 9°	<ul style="list-style-type: none"> - Ankle inversion moment was increased by lateral wedging ($p = 0.041$) - COP was also shifted laterally by lateral wedging ($p < 0.001$)
Lilley, Stiles and Dixon (180)	4 conditions – Control, 4° medial or 4° lateral rearfoot wedge, 5° lateral wedge on a contoured insole (called here ‘combined insole’)	<ul style="list-style-type: none"> - Lateral wedging demonstrated no significant change in either the magnitude or velocity of rearfoot eversion, compared to control (p-value not reported) - The combined insole achieved the largest reduction in peak rearfoot eversion ($p < 0.05$)

Reference	Intervention	Outcome
Møller Mølgaard and Kersting (181)	7 conditions – barefoot walking (control), 3 different types of shoe each with and without a 10° full length lateral wedge	<ul style="list-style-type: none"> - The lateral wedge produced a significant reduction in ankle abduction moment ($p < 0.001$) - Lateral wedging increased ankle power during propulsion ($p = 0.001$)
Kakahana et al. (182)	2 conditions – Neutral, laterally wedged insole 6°	<ul style="list-style-type: none"> - STJ valgus moment increased in the laterally wedged condition (significance not reported) - The valgus moment arm of the STJ significantly increased with use of the lateral wedge. - Kinematics of the STJ displayed no significant change.
Forghany et al. (183)	3 conditions – Neutral, laterally wedged insoles 5° and 8.5°	<ul style="list-style-type: none"> - Lateral wedging increased ankle eversion ($p < 0.0001$)
Sawada et al. (94)	2 conditions – barefoot (control) and 7mm (approx. 5.3°) lateral wedge	<ul style="list-style-type: none"> - The lateral wedge significantly increased ankle eversion ($p < 0.05$) - No significant change in rearfoot eversion ($p = 0.49$) - COP offset shifted laterally when using the lateral wedge ($p < 0.01$)
Nester, van der Linden and Bowker (19)	3 conditions – Control, 10° lateral wedge, 10° medial wedge	<ul style="list-style-type: none"> - The lateral wedge increased the degree of rearfoot plantarflexion at heel strike ($p = 0.001$) - The lateral wedge decreased the first peak in the rearfoot external rotation moment (transverse plane) ($p = 0.04$) - No significant change was exhibited in frontal or sagittal plane moments at the rearfoot, with the use of lateral wedging.
Weinhandl et al. (20)	2 conditions – Neutral, 9° lateral wedge	<ul style="list-style-type: none"> - There was no effect on GRF except for an increase in vertical GRF at the point of peak knee adduction moment ($p = 0.01$) - No significant change in ankle eversion ($p = 0.14$)
Pascual Huerta et al. (17)	3 conditions – Control, 7° lateral wedge, 7° medial wedge	<ul style="list-style-type: none"> - No significant change was reported in net ankle inversion moments ($p = 0.147$)
Van Gheluwe and Dananberg (3)	8 conditions – Forefoot wedging 3° valgus, flat, 3° varus or 6° varus. Rearfoot wedging 4° valgus, flat, 4° varus or 8° varus	<ul style="list-style-type: none"> - Lateral wedging increased peak pressure and maximal loading rate at the lateral forefoot and rearfoot (p-value not reported) - COP shifted laterally with lateral wedging and medially with medial wedging (p-value not reported) - No significant change was found in timing between initial impact and peak load for any of the wedge conditions (p-value not reported)
Erhart et al. (112)	3 conditions – Neutral, Laterally wedged midsoles 4° and 8°	<ul style="list-style-type: none"> - Ankle eversion moment increased by laterally wedged shoes ($p < 0.001$) - Both the 4° wedge ($p = 0.002$) and 8° wedge ($p < 0.001$) increased the maximum medial-to-lateral heel pressure ratio
Jin, Xu and Wang (184)	3 conditions – No insole, Neutral insole, laterally wedged insole 6°	<ul style="list-style-type: none"> - Lateral wedges reduced the ankle valgus moment, at the first peak, as soon as they are placed in the shoe ($p < 0.05$)

Reference	Intervention	Outcome
Jones et al. (11)	3 conditions – Neutral, laterally wedged ‘supported’ insole 5°, laterally wedged ‘unsupported’ insole 5°	<ul style="list-style-type: none"> - Both supported ($p = 0.025$) and unsupported ($p = 0.022$) lateral wedges increased ankle/STJ complex eversion moments, compared to the control condition. No significant change was found between supported and unsupported ($p = 1.00$) - The unsupported lateral wedge increased maximum ankle/STJ eversion angle by more than both the supported lateral wedge ($p = 0.002$) and the control condition ($p = 0.004$). No significant change between supported and control ($p = 1.00$) - The supported lateral wedge increased lateral COP excursion during early ($p < 0.001$), mid ($p < 0.001$) and late stance ($p = 0.016$), compared to a control condition. The unsupported lateral wedge increased lateral COP excursion during early ($p < 0.001$) and midstance ($p < 0.001$), however not during late stance
Rabiei, Eslami and Movaghar (21)	3 conditions – barefoot, shod and shod including a 6° laterally wedged insole	<ul style="list-style-type: none"> - The lateral wedge significantly increased foot pronation when compared with unwedged conditions, between 5 and 35% of stance phase ($p = 0.012$)
Schmalz et al. (185)	7 conditions – control (unwedged shoe), shoes with either a medial or lateral wedge (10mm, approx. 14°) built into the midsole. Both shoes tested with no additional bracing, an ankle brace or an AFO	<ul style="list-style-type: none"> - No significant change in plantarflexion moment immediately after weight acceptance (p-value not reported) - No significant change in the dorsiflexion moment during toe-off (p-value not reported) - Vertical component of GRF shifted laterally in laterally wedged conditions ($p < 0.05$) - Lateral wedging significantly increased the valgus moment at the ankle ($p < 0.01$)

COP, centre of pressure; STJ, subtalar joint; °, degrees; AFO, ankle foot orthotic; GRF, ground reaction force

8.5 Appendix 5: Clinician Survey administered in Chapter 5

The use of lateral wedges in clinical practice: A survey of New Zealand Podiatrists

Q1 The use of lateral wedges in clinical practice: A survey of New Zealand Podiatrists

Thank you for considering this invitation to participate in our research. My name is Aaron Jackson and I am a PhD candidate at Auckland University of Technology (AUT). This survey will form the beginning of my PhD thesis and data will influence the design of subsequent stages. On this project, I am working alongside my primary supervisor, Associate Professor Matthew Carroll, secondary supervisor's Dr Kelly Sheerin, and Professor Duncan Reid. The survey is split into three sections. The first section will ask you about your practice (location, specialty and experience). The second section asks about your thought process behind orthotic prescriptions. The third section asks how you make lateral wedges (what material you use and where you place them).

What is the purpose of this research? This will be the first time that NZ podiatrists have been surveyed about their use and manufacture of orthotics and lateral wedges. Findings will provide an insight into typical prescriptions specifically in the NZ context. This information will be carried through into the experimental stage of my project that will investigate how these modifications work, using 3D gait analysis. The findings of this research may be used for academic publications or presentations and will be included in my PhD thesis.

How was I identified and why am I being invited to participate in this research? Your details are held by Podiatry New Zealand. They sent you an invite to participate in this research and you are reading this participant information sheet because you have followed the link to take the survey that was included in the introductory email.

How do I agree to participate in this research? Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. At the bottom of this page you will be asked if you agree to participate or not. After considering this information, please make your selection. You can withdraw at any time by exiting the survey before clicking the submit button.

What will happen in this research? If you choose to participate, you will be taken to the first page of the survey. In total, there are 32 questions to complete. Please complete all the questions. The survey takes approximately 10-15 minutes to complete. On completion you will be asked to submit the survey, the answers will then be submitted to me. The submitted answers anonymous, meaning I will not know who they have come from.

What are the discomforts and risks? There are no anticipated discomforts or risks with completing this survey.

What are the benefits? Findings from this survey will give NZ podiatrists an understanding 'typical' prescriptions and clinical reasoning used by colleagues. You will also be able to claim the time you invest in completing this survey toward your 2020-2022 CPD evidence portfolio.

How will my privacy be protected? All collected data will be anonymous therefore it will not be possible to link your responses back to you. All data will be stored securely for 6 years.

What are the costs of participating in this research? Other than your time, there is no cost to participate in this research.

What opportunity do I have to consider this invitation? The survey link will remain open for eight weeks.

Will I receive feedback on the results of this research? As the survey is anonymous you will not be given feedback on the study. However, the final results of the study will be published in a peer-reviewed journal. If

you're interested in seeing these results, you are welcome to contact me at a later date and I can send you a link to the paper.

What do I do if I have concerns about this research? Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Associate Professor Matthew Carroll, matthew.carroll@aut.ac.nz, (+649) 921 9999 ext 7305

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEK, ethics@aut.ac.nz , (+649) 921 9999 ext 6038.

Researcher Contact Details: Aaron Jackson aaron.jackson@aut.ac.nz or (+649) 921 9999 ext 9004

Project Supervisor Contact Details: Associate Professor Matthew Carroll matthew.carroll@aut.ac.nz or (+649) 921 9999 ext 7305

Approved by the Auckland University of Technology Ethics Committee on 12th May 2021, AUTEK Reference number 21/118

Q2 Do you consent to participate in this research?

- Yes, I do
- No, I do not

Q3 How many years have you been a qualified podiatrist for?

- 0-3
- 4-6
- 7-10
- 11-15
- 16+

Q4 Which age bracket do you fit into?

- 20-29
- 30-39
- 40-49
- 50-59
- 60+

Q5 Which region do you practice in (mostly)?

- Northland (Te Tai Tokerau)
- Auckland (Tāmaki Makaurau)
- Waikato
- Bay of Plenty (Te Moana-a-Toi)
- Gisborne (Tūranganui-a-Kiwa)
- Hawkes Bay (Te Matau a Māui)
- Taranaki
- Manawatū-Whanganui
- Wellington (Te Whanganui-a-Tara)

- Tasman (Te Tai o Aorere)
- Nelson (Whakatū)
- Marlborough (Te Taihū-o-te-waka)
- West Coast (Te Tai Poutini)
- Canterbury (Waitaha)
- Otago (Otagou)
- Southland (Murihiku)

Q6 What is your highest form of qualification relevant to podiatry?

- Diploma of Podiatry
- Bachelors degree
- Post graduate qualification (diploma or certificate)
- Masters degree
- Doctoral degree

Q7 Where did you attain your undergraduate podiatry qualification?

- AUT University
- CIT Wellington
- An Australian university (please specify which)
- Other (please specify)

Q8 Which statement best describes the work that you do?

- I predominantly work in general podiatric care
- I work with a mixed patient load
- I predominantly work in high risk foot care
- I predominantly work in sports/biomechanical/musculoskeletal podiatry
- I predominantly work in another field of Podiatry (please specify)

Q9 Approximately how many prefabricated orthotics, custom orthotics or modified insoles do you prescribe in an average week?

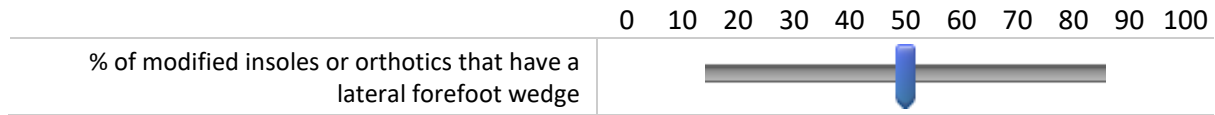
- 0-10
- 11-25
- 26+

Q10 Which of the following forefoot modifications do you routinely use? (select all that apply)

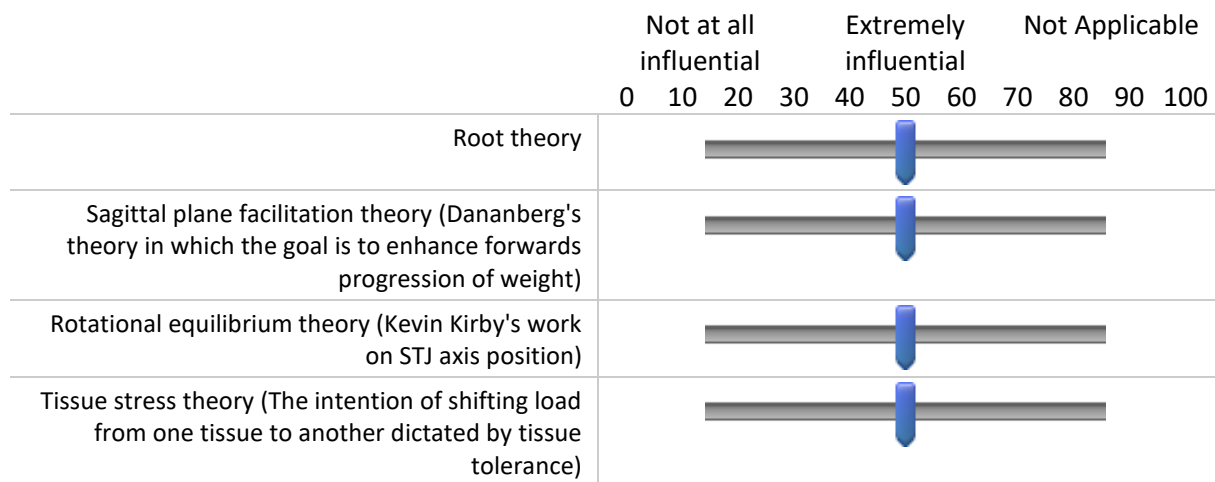
- Reverse mortons extension (2-5 pad)
- Sagittal plane wedge (K wedge of Kinetic wedge)
- Winged plantar cover
- Lateral forefoot wedge
- Medial forefoot wedge
- Metatarsal dome
- Plantar metatarsal pad (PMP)
- Metatarsal bar
- Mortons extension

- Cluffy extension
- Plantar cover with U cutout

Q11 You previously said that you prescribe X orthotics or modified insoles per week. Of these, approximately what percentage include a lateral forefoot wedge? Note: A lateral forefoot wedge here is defined as material placed under the forefoot which is thicker on the lateral side compared to the medial side.



Q12 How influential do you think each of the following podiatric theories/paradigms are in your orthotic prescription?



Q13 Which of the following statements do you believe are true? (select all that apply)

- Lateral forefoot wedging shifts the centre of pressure medially
- Lateral forefoot wedging balances the rearfoot and forefoot alignment
- Lateral forefoot wedging reduces time spent on the forefoot during gait
- Lateral forefoot wedging increases time spent on the forefoot during gait
- Lateral forefoot wedging increases plantar pressure under the lateral aspect of the foot
- Lateral forefoot wedging increases plantar pressure under the medial aspect of the foot
- Lateral forefoot wedging increases utilised range of motion in the 1st MPJ during gait
- Lateral forefoot wedging decreases utilised range of motion in the 1st MPJ during gait
- Lateral forefoot wedging causes 1st MPJ extension to begin earlier in the gait cycle
- Lateral forefoot wedging delays the onset of 1st MPJ extension during the gait cycle
- Lateral forefoot wedging effects movement of the ankle
- None of the above
- Other (please specify)

Q14 Which is the MOST COMMON reason that you use lateral forefoot wedging in your practice? (select only one)

- to shift the centre of pressure medially
- to balance the forefoot to rearfoot alignment
- to reduce time spent on the forefoot during gait
- to increase time spent on the forefoot during gait
- to increase plantar pressure under the lateral aspect of the foot
- to increase plantar pressure under the medial aspect of the foot
- to increase range of motion of the 1st MPJ during gait
- to decrease range of motion of the 1st MPJ during gait
- to initiate 1st MPJ extension earlier in the gait cycle
- to delay the onset of 1st MPJ extension during the gait cycle
- None of the above/Other (please specify)

Q15 When managing patients with the following conditions, how likely are you to prescribe a lateral forefoot wedge?

Respondents were asked to provide answers on a 5-point Likert scale relating to each of the diagnoses listed below. The 5 points were very unlikely; unlikely; neutral; likely; very likely

- Achilles tendinopathy
- Adult acquired flatfoot
- Calf strain
- Chronic ankle instability
- First MPJ joint sprain
- Iliotibial band syndrome
- Medial ankle osteoarthritis
- Medial knee osteoarthritis
- Medial tibial stress syndrome
- Morton's neuroma
- Patellofemoral pain
- Peroneal tendon issues
- Plantar heel pain

- Plantar plate injury
- Posterior tibial tendon dysfunction
- Stress fracture (metatarsal)
- Stress fracture (tibial)

Q16 How important do you think it is to consider the following, when using a lateral forefoot wedge?

Respondents were asked to provide answers on a 3-point Likert scale relating to each of the considerations listed below. The 3 points were not important; neutral; important

- Activity level of the patient
- Foot posture index
- Footwear
- Forefoot position
- Patients bodyweight
- Rearfoot pronation/supination
- Supination resistance test
- Type of activity it will be used for

Q17 Do you think that the biomechanical effect of a lateral forefoot wedge is the same when someone is running, compared to when they are walking?

- Yes
- No

Q18 You said that effect of a lateral forefoot wedge is different for walking vs running gait. Which of these statements do you agree with? (select any/all that apply)

*This question was only shown to respondents who answered 'yes' to Q17

- When I prescribe a lateral wedge for someone to run in, I instruct them not to use it if they are going for a walk.
- The biomechanical effect of a lateral forefoot wedge is enhanced when used in running gait compared to walking gait.
- The biomechanical effect of a lateral forefoot wedge is reduced when used in running gait compared to walking gait.
- My biomechanical objectives when prescribing a lateral forefoot wedge for running gait vs for walking gait, are entirely different.
- I use a different shape and/or different materials if it's being used for running gait rather than walking gait.

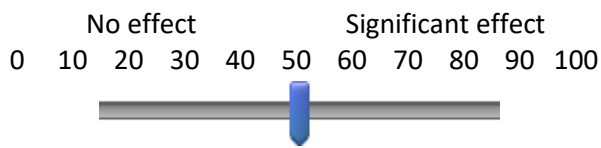
Q19 In walking gait you said that you most commonly prescribe lateral forefoot wedging was X. What is the most common reason you prescribe lateral forefoot wedging in RUNNING GAIT?

*This question was only shown to respondents who answered 'yes' to Q17

- To shift the centre of mass medially
- To balance the forefoot to rearfoot alignment
- To reduce time spent on the forefoot during gait

- To increase time spent on the forefoot during gait
- To increase plantar pressure under the lateral aspect of the foot
- To increase plantar pressure under the medial aspect of the foot
- To increase range of motion of the 1st MPJ during gait
- To decrease range of motion of the 1st MPJ during gait
- To initiate 1st MPJ extension earlier in the gait cycle
- To delay the onset of 1st MPJ extension during the gait cycle
- None of the above/Other (please specify)

Q20 In the case of a runner, how much of an effect do you think foot strike position has on the outcome of lateral forefoot wedging? (Foot strike position is defined as the part of the foot to first strike the ground and typically categorised as rearfoot, midfoot or forefoot strike)



Q21 Lateral forefoot wedges are typically placed in one of the 3 following locations. Please estimate how frequently you use each of the following options (as a percentage of the lateral wedges you use)? (your total should equal 100%)

- On a simple insole or sock liner
- On an orthotic (custom or prefabricated)
- In the midsole of the shoe

Q22 On a prefabricated orthotic, do you typically use a prefabricated wedge (commercially available, premade wedge) or construct your own?

- Prefabricated wedge
- Make my own

Q23 Which brand of prefabricated wedge do you most commonly use?

*This question was only shown to respondents who answered 'prefabricated wedge' to Q22

- FootBionics
- Formthotics
- Other (please specify)

*All remaining questions were only shown to respondents who answered 'make my own' to Q22

Q24 Which of the following most closely reflects the typical length (distally) you use?

- To the end of the insole
- To the sulcus
- Proximal to the Metatarsal heads
- Other (please specify)

Q25 Which of the following most closely reflects where your material typically begins (proximally)?

- At the Styloid process
- At the Calcaneo-cuboid joint
- Full length, from the back of the heel
- Other (please specify)

Q26 Do you always use the same shape when prescribing a lateral forefoot wedge?

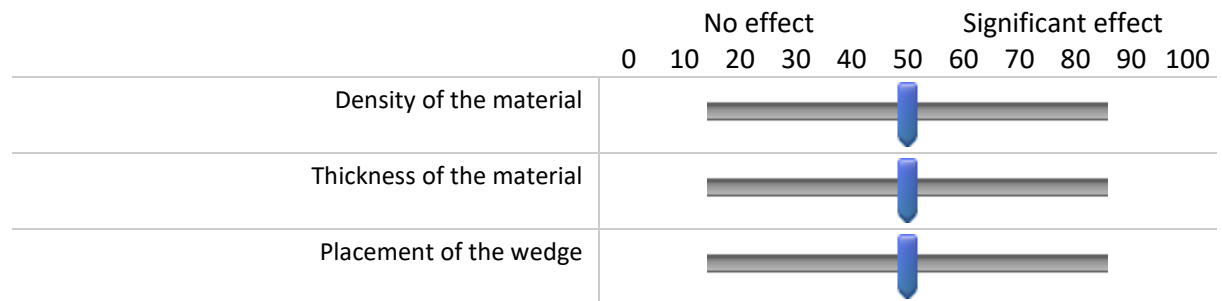
- Yes
- No

Q27 You said that you don't always use the same shape in your lateral forefoot wedges. What factors impact your decision to change the shape from one patient to another? (select all that apply)

*This question was only shown to respondents who answered 'no' to Q26

- The patients symptoms or injury
- Their foot posture index
- The type of activity the patient will be using it for
- Their footwear
- Other (please specify)

Q28 How much of an impact do you think the following have on the effect of the lateral forefoot wedge?



Q29 In the last 12 months, which of the following materials have you used for a lateral forefoot wedge? (select all that apply)

- Low density EVA (soft)
- Medium density EVA
- High density EVA (hard)
- Poron
- Multiform
- Felt
- Spenco
- Other (please list)

Q30 When prescribing a lateral forefoot wedge, which of the following EVA densities do you use most commonly? (select one)

- Don't know - whatever is in the drawer
- Low density (soft)
- Medium density
- High density (hard)

Q31 Please select all EVA thicknesses that you have used in the last 12 months when making or ordering a lateral forefoot wedge. (select all that apply)

- 3mm
- 4mm
- 5mm
- 6mm
- 8mm
- 10mm
- Other (please specify)

Q32 When prescribing a lateral forefoot wedge, which thickness of EVA are you MOST LIKELY to use? (select one)

- 3mm
- 4mm
- 5mm
- 6mm
- 8mm
- 10mm
- Other (please specify)

8.6 Appendix 6: Checklist for Reporting Results of Internet E-Surveys (CHERRIES) relating to Chapter 5

All survey data relating to Chapter 5 were reported in accordance with the Checklist for Reporting Results of Internet E-Surveys (200). Details of where in this thesis each checklist item appears is outlined below.

Checklist Item	Explanation	Page Number
Describe survey design	Describe target population, sample frame. Is the sample a convenience sample? (In “open” surveys this is most likely.)	72-73
IRB approval	Mention whether the study has been approved by an IRB.	NA
Informed consent	Describe the informed consent process. Where were the participants told the length of time of the survey, which data were stored and where and for how long, who the investigator was, and the purpose of the study?	72-73
Data protection	If any personal information was collected or stored, describe what mechanisms were used to protect unauthorized access.	73
Development and testing	State how the survey was developed, including whether the usability and technical functionality of the electronic questionnaire had been tested before fielding the questionnaire.	73
Open survey versus closed survey	An “open survey” is a survey open for each visitor of a site, while a closed survey is only open to a sample which the investigator knows (password-protected survey).	73
Contact mode	Indicate whether or not the initial contact with the potential participants was made on the Internet. (Investigators may also send out questionnaires by mail and allow for Web-based data entry.)	73
Advertising the survey	How/where was the survey announced or advertised? Some examples are offline media (newspapers), or online (mailing lists – If yes, which ones?) or banner ads (Where were these banner ads posted and what did they look like?). It is important to know the wording of the announcement as it will heavily influence who chooses to participate. Ideally the survey announcement should be published as an appendix.	72
Web/E-mail	State the type of e-survey (eg, one posted on a Web site, or one sent out through e-mail). If it is an e-mail survey, were the responses entered manually into a database, or was there an automatic method for capturing responses?	72
Context	Describe the Web site (for mailing list/newsgroup) in which the survey was posted. What is the Web site about, who is visiting it, what are visitors normally looking for? Discuss to what degree the content of the Web site could pre-select the sample or influence the results. For example, a survey about vaccination on a anti-immunization Web site will have different results from a Web survey conducted on a government Web site	72
Mandatory/voluntary	Was it a mandatory survey to be filled in by every visitor who wanted to enter the Web site, or was it a voluntary survey?	NA
Incentives	Were any incentives offered (eg, monetary, prizes, or non-monetary incentives such as an offer to provide the survey results)?	72
Time/Date	In what timeframe were the data collected?	72

Randomization of items or questionnaires	To prevent biases items can be randomized or alternated.	NA
Adaptive questioning	Use adaptive questioning (certain items, or only conditionally displayed based on responses to other items) to reduce number and complexity of the questions.	73
Number of Items	What was the number of questionnaire items per page? The number of items is an important factor for the completion rate.	NA
Number of screens (pages)	Over how many pages was the questionnaire distributed? The number of items is an important factor for the completion rate.	NA
Completeness check	It is technically possible to do consistency or completeness checks before the questionnaire is submitted. Was this done, and if “yes”, how (usually JavaScript)? An alternative is to check for completeness after the questionnaire has been submitted (and highlight mandatory items). If this has been done, it should be reported. All items should provide a non-response option such as “not applicable” or “rather not say”, and selection of one response option should be enforced.	NA
Review step	State whether respondents were able to review and change their answers (eg, through a Back button or a Review step which displays a summary of the responses and asks the respondents if they are correct).	73
Unique site visitor	If you provide view rates or participation rates, you need to define how you determined a unique visitor. There are different techniques available, based on IP addresses or cookies or both.	NA
View rate (Ratio of unique survey visitors/unique site visitors)	Requires counting unique visitors to the first page of the survey, divided by the number of unique site visitors (not page views!). It is not unusual to have view rates of less than 0.1 % if the survey is voluntary.	NA
Participation rate (Ratio of unique visitors who agreed to participate/unique first survey page visitors)	Count the unique number of people who filled in the first survey page (or agreed to participate, for example by checking a checkbox), divided by visitors who visit the first page of the survey (or the informed consents page, if present). This can also be called “recruitment” rate.	NA
Completion rate (Ratio of users who finished the survey/users who	The number of people submitting the last questionnaire page, divided by the number of people who agreed to participate (or submitted the first survey page). This is only relevant if there is a separate “informed consent” page or if the survey goes over several pages. This is a measure for attrition. Note that “completion” can involve leaving questionnaire items blank. This is not a measure for how completely questionnaires were filled in. (If you need a measure for this, use the word “completeness rate”.)	74

agreed to participate)		
Cookies used	Indicate whether cookies were used to assign a unique user identifier to each client computer. If so, mention the page on which the cookie was set and read, and how long the cookie was valid. Were duplicate entries avoided by preventing users access to the survey twice; or were duplicate database entries having the same user ID eliminated before analysis? In the latter case, which entries were kept for analysis (eg, the first entry or the most recent)?	NA
IP check	Indicate whether the IP address of the client computer was used to identify potential duplicate entries from the same user. If so, mention the period of time for which no two entries from the same IP address were allowed (eg, 24 hours). Were duplicate entries avoided by preventing users with the same IP address access to the survey twice; or were duplicate database entries having the same IP address within a given period of time eliminated before analysis? If the latter, which entries were kept for analysis (eg, the first entry or the most recent)?	NA
Log file analysis	Indicate whether other techniques to analyze the log file for identification of multiple entries were used. If so, please describe.	NA
Registration	In “closed” (non-open) surveys, users need to login first and it is easier to prevent duplicate entries from the same user. Describe how this was done. For example, was the survey never displayed a second time once the user had filled it in, or was the username stored together with the survey results and later eliminated? If the latter, which entries were kept for analysis (eg, the first entry or the most recent)?	NA
Handling of incomplete questionnaires	Were only completed questionnaires analyzed? Were questionnaires which terminated early (where, for example, users did not go through all questionnaire pages) also analyzed?	74
Questionnaires submitted with an atypical timestamp	Some investigators may measure the time people needed to fill in a questionnaire and exclude questionnaires that were submitted too soon. Specify the timeframe that was used as a cut-off point, and describe how this point was determined.	NA
Statistical correction	Indicate whether any methods such as weighting of items or propensity scores have been used to adjust for the non-representative sample; if so, please describe the methods.	NA

This checklist has been modified from Eysenbach G. Improving the quality of Web surveys: the Checklist for Reporting Results of Internet E-Surveys (CHERRIES). J Med Internet Res. 2004 Sep 29;6(3):e34 [erratum in J Med Internet Res. 2012; 14(1): e8.]. Article available at <https://www.jmir.org/2004/3/e34/>; erratum available <https://www.jmir.org/2012/1/e8/>. Copyright ©Gunther Eysenbach. Originally published in the [Journal of Medical Internet Research](#), 29.9.2004 and 04.01.2012.

This is an open-access article distributed under the terms of the Creative Commons Attribution License (<https://creativecommons.org/licenses/by/2.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work, first published in the Journal of Medical Internet Research, is properly cited.

8.7 Appendix 7: Ethical Approval for Chapter 5

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology

D-88, Private Bag 92006, Auckland 1142, NZ

T: +64 9 921 9999 ext. 8316

E: ethics@aut.ac.nz

www.aut.ac.nz/researchethics

12 May 2021

Matthew Carroll
Faculty of Health and Environmental Sciences

Dear Matthew

Ethics Application: 21/118 **The use of lateral wedges in clinical practice: A survey of New Zealand podiatrists**

We advise you that a subcommittee of the Auckland University of Technology Ethics Committee (AUTEC) has **approved** your ethics application.

This approval is for three years, expiring 11 May 2024.

Non-Standard Conditions of Approval

1. Inclusion of the following in the Information Sheet at the beginning of the survey:
 - a. Include AUT logo on the survey.
 - b. Ensure that the 'how was identified section' in the Participant Information Sheet at the beginning of the survey states 'your details are held by PBNZ. You were sent an email by them, inviting
 - c. Include a statement something like 'you can withdraw at any time by exiting the survey and before clicking the submit button'.

The committee observes that this is Health Research (section A.7.2 of the EA1).

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

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 in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research 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.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through <http://www.aut.ac.nz/research/researchethics>

(This is a computer-generated letter for which no signature is required)

The AUTEK Secretariat

Auckland University of Technology Ethics Committee

Cc: hff3400@aut.ac.nz; duncan.reid@aut.ac.nz; ksheerin@aut.ac.nz

8.8 Appendix 8: Participant information sheet relating to Chapter 6

Participant Information Sheet

Date Information Sheet Produced:

4th of May 2022

Project Title

The influence of lateral wedge inclination and placement on centre of pressure and first metatarsophalangeal joint function, in walking and running gait.

An Invitation

My name is Aaron Jackson, I am a PhD student from Auckland University of Technology. Along with my supervisors Associate Professor Matt Carroll, Dr Kelly Sheerin and Professor Duncan Reid, I would like to invite you to participate in this research. This project aims to understand how your gait changes when wedges are placed inside your shoe.

Project team

In addition to the individuals previously mentioned, Dr. Hannah Wyatt and Ivan Jukic form part of the project team.

What is the purpose of this research?

The purpose of this research is to understand how lateral wedges (insoles inside your shoe) affect the way that your foot moves when you walk and run. These wedges are commonly used by podiatrists in clinical practice, however there is limited evidence examining the way they work. We are interested to see if the design (shape of the wedge), material, and where the wedge is placed makes a difference. Additionally, no previous research has compared function of lateral wedges between walking and running gait, yet people often wear these in their shoes during both activities. This research forms the final stage of my PhD thesis and may be used for academic publications and presentations.

As an additional part of this study, we are also looking to establish the accuracy of some new technology (developed at Stanford University) that captures movement information using the video function on four synchronised iPads. More information about the technology can be found here: <https://www.opencap.ai/>

How was I identified and why am I being invited to participate in this research?

You have received this participant information sheet as a result of completing our expression of interest survey and meeting the inclusion criteria. Specifically, you have stated that you run more than 10km per week, have not sustained an injury in the previous 6 months which has prevented you from running (for more than 2 weeks), and you do not have any medical conditions that affect the joints of your feet and legs.

Please note, if you are a current Podiatry student at AUT, or a student of any supervisor of this project, you will not be able to participate in this research.

How do I agree to participate in this research?

Once you have had the chance to learn more about the study, and have decided that you're keen to participate, we will book you in for the session.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as

belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

If you choose to participate in this research, you will make an appointment with me at AUT Millennium (17 Antares Place, Rosedale). Upon arrival you will be given an opportunity to ask any questions that you may have about the study and/or the data collection process. Once you are happy to proceed you will be asked to sign a consent form.

At this stage we will measure your foot and complete several clinical assessments (including your weight, height, and foot type). You will then be provided with shoes to use for the duration of the assessment, these will have one of the insoles that we are studying fitted inside them already. We will place a number of reflective markers on your legs and shoes before asking you to stand on the treadmill. The system will be calibrated and then we will be ready to begin collecting data.

You will then walk on the treadmill (at 5km/h), you will be given some time to familiarise yourself with this before we capture data for 30 seconds. Wearing the same shoe/insole, we will increase the speed of the treadmill to a running speed (10km/h) and once again you will be given time to familiarise yourself before we record 30 seconds of data, the treadmill will then be stopped.

You will then be asked to remove your shoes, researchers will change the insole and give it back to you to put on again. The same process will be repeated for all 10 insoles and will be done so in a predetermined, random order. In total this appointment is likely to take approximately 2 a half hours.

If you consent to it, the video will be simultaneously recorded on four iPads positioned behind the treadmill. Unlike the data from the marker-based system, you will be identifiable in the iPad video (albeit only from behind). The video footage will only be used for the purpose of comparison to the marker-based system, to enable us to develop cheaper, more portable recording methods for future research.

Note: the video footage will be captured at the same time, and you will not be required to do anything additional. If you do not wish to have video taken, it will not affect your involvement in the remainder of the study.

What are the discomforts and risks?

There should be no significant risk to you during the study. Given the short duration of running it is not expected that you will experience any muscle soreness or fatigue that would affect any of your training.

Note: All equipment that is either touched by, or attached to, participants will either be disposed of or cleaned with a medical-grade cleaning disinfecting product.

How will these discomforts and risks be alleviated?

If you are experiencing discomfort at any stage, you are encouraged to inform the researcher with you at the time in order that they can best address the problem. If you have any questions regarding and risk or comfort that you anticipate, please feel free to address these concerns to the researcher so that you feel comfortable at all times throughout the process.

What are the benefits?

One of the key benefits of this research will be an improvement in our understanding of how this common intervention works. We are particularly interested to see if certain designs change the outcome and additionally, if people with different foot types and foot strike patterns, respond differently. Ultimately the goal is to improve the accuracy and efficacy for clinicians using these wedges in practice.

While it is not necessarily the goal of this study to identify subject-specific risk of injury, you may experience benefit via your participation by learning about your biomechanics, and how your running technique aligns with what is considered ideal running technique. You will also receive a \$50 Prezzy card as koha.

Lastly, I (Aaron Jackson) will benefit from this research as it will contribute towards my doctoral thesis.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The only people who will have access to any of the data collected will be myself, Associate Professor Matt Carroll, Dr Kelly Sheerin, and Professor Duncan Reid. If any of your data are published you will be un-identifiable. Your name will be coded so that all of your data will be stored under the code name. Your privacy will be of primary concern when handling the data.

Any videos captured on iPads will be removed from local storage on these devices and stored on the secure cloud-based (<https://www.opencap.ai>) platform. The video footage will only be accessible to the project team.

All data will be stored on password-protected computers or in locked files.

What are the costs of participating in this research?

There are no monetary costs associated with participating in this research, the only cost being your time. It is anticipated the data collection session will last for 2 and a half hours.

What opportunity do I have to consider this invitation?

We would appreciate it if you could let us know within two weeks whether you would be available to take part in the study or not.

Will I receive feedback on the results of this research?

We are more than happy to provide you with a summary of the research findings at the conclusion of the study. If you would like to receive this summary, please identify this on your consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Associate Professor Matt Carroll, matthew.carroll@aut.ac.nz, (09) 921 9999 ext 7305.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEK, ethics@aut.ac.nz, (09) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Aaron Jackson

Phone: (09) 921 9999 ext 9004

Email: aaron.jackson@aut.ac.nz

Project Supervisor Contact Details:

Associate Professor Matt Carroll

Phone: (09) 921 9999 ext 7305

Email: matthew.carroll@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 3rd of June 2022, AUTEK Reference number 22/121.

8.9 Appendix 9: Ethical Approval for Chapter 6

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology

D-88, Private Bag 92006, Auckland 1142, NZ

T: +64 9 921 9999 ext. 8316

E: ethics@aut.ac.nz

www.aut.ac.nz/researchethics

3 June 2022

Matthew Carroll

Faculty of Health and Environmental Sciences

Dear Matthew

Re Ethics Application: **22/121 The influence of lateral wedge inclination and placement on centre of pressure and 1st metatarsophalangeal joint function, in walking and running gait.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 3 June 2025.

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 in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research 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.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through <http://www.aut.ac.nz/research/researchethics>

(This is a computer-generated letter for which no signature is required)

The AUTEK Secretariat

Auckland University of Technology Ethics Committee

Cc: aaron.jackson@aut.ac.nz; kelly.sheerin@aut.ac.nz; duncan.reid@aut.ac.nz

8.10 Appendix 10: Participant Consent form used in Chapter 6

Consent Form

Project title: *The influence of lateral wedge inclination and placement on centre of pressure and first metatarsophalangeal joint function, in walking and running gait.*

Project Supervisor: *Associate Professor Matt Carroll*

Researcher: *Aaron Jackson*

- I have read and understood the information provided about this research project in the Information Sheet dated 4th of May 2022.
- I have had an opportunity to ask questions and to have them answered.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data or tissue that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- I am not suffering from any injury which influences my ability to run, and I do not have any medical conditions that affect the joints in my legs and feet.
- I agree to videos being recorded of my walking and running from iPads placed behind me and understand that this footage will not be shared outside of the research team. Yes No
- I agree to take part in this research.
- I wish to receive a copy of my individual results (please tick one): Yes No
- I wish to receive a summary of the research findings (please tick one): Yes No

Participant's signature:

Participant's name:

Participant's Contact Details (if appropriate):

.....

.....

.....

.....