Plantar Pressure Parameters Associated with Ankle Osteoarthritis During Walking and the Immediate Effects of an Ankle Brace

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Declaration

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This Thesis/Dissertation/Research Project entitled: **Plantar Pressure Parameters Associated with Ankle Osteoarthritis During Walking and the Immediate Effects of An Ankle Brace**

is submitted in partial fulfilment for the requirements for the Unitec degree of the Master of Osteopathy

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**CANDIDATE’S DECLARATION**

I confirm that:

- This Thesis/Dissertation/Research Project represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the
Unitec Research Ethics Committee.

Research Ethics Committee Approval Number: 2016-1080

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Abstract:

**Background:** Little is known about plantar pressure changes in the limb affected by OA compared to the unininvolved limb or healthy controls. The immediate effects of ankle braces on plantar pressure measures and ankle pain, perceived stability and comfort levels during gait in those with ankle osteoarthritis is also not known. This thesis aims to address these unknowns. **Methods:** Thirty-two participants were included: 16 with ankle osteoarthritis and 16 healthy controls of a similar age and gender. A Novel pressure system was used to compare plantar pressures between the involved limb, unininvolved limb and the dominant limb of a healthy control group. An ankle brace was tested to assess its effect on plantar pressure measures in the involved limb. Perceived pain, stability and comfort levels related to walking with the brace, were measured through questionnaires. SPSS software (Version 25.0) was used for statistical analysis. Pearson correlations coefficients showed no association between body mass and plantar pressure measures. Single-factor repeated measures ANOVA with planned contrasts and independent t-tests were also performed. For all analyses the alpha level was set at 0.05.

**Results:** Contact times varied significantly across all comparisons. The control group had significantly lower pressure-time integrals than the unininvolved side of the ankle osteoarthritis group. Significant results were not seen in the remaining plantar pressure comparisons. The ankle brace increases contact time and provides comfort and stability for most of those with ankle osteoarthritis, but did not seem to affect pain. **Conclusion:** No definitive conclusions can be made about differences in plantar pressures assessed between those with ankle osteoarthritis and those without, or about the effect of an ankle brace on these measures.
Subjective reports of the participants affected by ankle OA suggest that ankle braces can be used as a conservative, cost-effective way of improving stability and comfort in most of those with ankle osteoarthritis.
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Chapter 1: Introduction

Background

Arthritis is a debilitating condition and one of the leading causes of disability in New Zealand (Ministry of Health, 2015; Queen, Carter, Adams, Easley, DeOrio, & Nunley, 2011). The most recent economic review has shown that the cost of arthritis in New Zealand was approximately $3.2 billion in 2010 (1.7% GDP) with the burden of the disease equating to an additional $3.8 billion per annum in disability-adjusted life years and premature death (Borman, Harrison, Kirby, MacGibbon, Miles, Valentino et al., 2010).

Osteoarthritis (OA) is the most common form of arthritis and it affects up to 80% of those over the age of 65 (Wright, Cook, Flynn, Baxter, & Abbott, 2011). In OA, the articular cartilage covering the joint surfaces progressively degenerates until there is bone-on-bone contact at the joint (Queen et al., 2011). This results in decreased congruency and surface area of the joint, inducing inflammation, pain, stiffness and decreased range of motion, (Bhatia, 2014; von Tscharner & Valderrabano, 2010). OA is a dynamic, degenerative disease leading to decreased quality of life and difficulties with activities of daily living (Bernad-Pineda, de las Heras-Sotos, & Garcés-Puentes, 2014; McKean, Landry, Hubley-Kozey, Dunbar, Stanish, Deluzio, 2007).

Symptomatic ankle OA makes up about 11% of people undergoing treatment for arthritis and has been shown to be as distressing and physically disabling as severe OA affecting other joints such as the hip or knee (Jomha, Scharfenberger, Goplen, & Pedersen, 2013; Queen et al., 2011).
Although ankle OA is less common than knee or hip OA, it is important to note that 70 to 78% of ankle OA is post-traumatic in nature (Jomha et al., 2013; Valderrabano, Horisberger, Russell, Dougall, & Hintermann, 2009). For this reason, younger populations who have longer projected lifespans are affected, resulting in increased overall disease burden (Claessen, Meijer, van den Bekerom, Gevers, Mallee, Doornberg et al., 2016; Lobet, Hermans, Bastien, Massaad, & Detrembleur, 2012; Queen et al., 2011; Valderrabano et al., 2009).

The prevalence and overall burden of ankle OA in New Zealand is likely to increase in the coming decades due to an increase in the aging population and an increase in the number of ankle injuries (Borman et al., 2010). There has been a 10.3% increase in the number of new ankle injury claims made to Accident Compensation Corporation (ACC) over the last five years from 117,710 in 2013 to 129,824 in 2017 (See Appendix A) (Accident Compensation Corporation, 2016). Furthermore, the total cost of rehabilitation has increased from around $26,500,000 in 2013 to over $41,000,000 in 2017 (see Appendix B) (Accident Compensation Corporation, 2016). The figures in New Zealand are comparable to international statistics, which indicate that 40 to 70% of ankle injuries lead to chronic ankle instability (Accident Compensation Corporation, 2009; Golditz, Steib, Pfeifer, Uder, Gelse, Janka, et al., 2014). In turn, it has been shown that 66% to 78% of chronic ankle instability cases go on to develop ankle OA (Hubbard, Hicks-Little, & Cordova, 2009).

Pain due to ankle OA tends to be aggravated by weight-bearing activities such as walking, climbing stairs and jogging (Valderrabano et al., 2007; Wang & Brown, 2016). Limitations in
these areas decrease one's ability to undertake activities of daily life easily and reduces participation in common recreational and sporting activities (McKean et al., 2007). In addition to joint pain, ankle OA has been associated with neuromuscular problems such as decreased muscle strength, decreased joint range of motion and altered gait patterns, all of which may contribute to a patient’s overall level of disability (Hubbard et al., 2009; Lobet et al., 2012). Characteristically, those who have ankle OA spend a greater portion of the gait cycle in stance phase resulting in decreased stride length, reduced ankle range of motion, reduced cadence and an average decrease of 67% in walking speed (Khazzam, Long, Marks, & Harris, 2006). Given that the ankle joint experiences loading of up to five times body weight (Brockett & Chapman, 2016; Egloff, Hügle, & Valderrabano, 2012), it is not surprising that those with ankle OA experience so much pain with walking (Huang, Harbst, Kotajarvi, Hansen, Koff, Kitaoka et al., 2006).

Individuals with foot pain have been shown to have altered plantar pressure measures compared to those without foot pain (Mickle, Munro, Lord, Menz, & Steele, 2010). Plantar pressure measures provide a sophisticated way of assessing gait adaptations in those with foot and ankle pathologies (Lobet et al., 2012; McKay, Baldwin, Ferreira, Simic, Burns, Vanicek et al., 2017). Plantar pressure measures can identify differences in loading patterns and the distribution of pressure acting on the foot during walking (McKay et al., 2017). Platform systems used to measure plantar pressures provide high spatial resolution due to the large number of sensors arranged in matrix formation in the pressure pad, thereby providing accurate pressure maps of the foot during walking (Ingrosso, Benedetti, Leardini, Casanelli, Sforza, Giannini, 2009).
Plantar pressure analysis is thought to provide a reliable method of diagnosing foot and ankle pathologies, including OA (Wafai, Zayegh, Woulfe, Aziz, & Begg, 2015). Additionally, plantar pressure measures have been shown to identify differences across patient groups and those who are frequent fallers or at higher risk of falling (Gray, Ivanova, & Garland, 2014; Moghadam Ashayeri, Salavati, Sarafzadeh, Taghipoor, Saeedi et al., 2011; Rouhani, Crevoisier, Favre, & Aminian, 2011). Not only do plantar pressure analyses provide a way of assessing differences in gait between individuals with ankle OA and healthy controls, they also provide a way of assessing the effect of interventions, thus extending existing research.

The Problem

OA of the ankle joint is a major problem that negatively affects quality of life. There is limited research that has examined plantar pressures during gait in people with OA of the ankle joint. Furthermore, there is a need to explore the potential of a low-cost intervention on individuals with ankle OA. This research aims to address fundamental questions that will ultimately help in the understanding of how plantar pressure measures differ in people with ankle OA, as well as how an ankle brace affects pain, stability, comfort and plantar pressures during gait, with the aim of decreasing functional limitations.

To date, treatment of end-stage ankle OA often involves surgery. Recently the tendency has been to move away from ankle fusions in favour of total ankle arthroplasties (Jomha et al., 2013). However, there are still numerous contraindications and potential complications
associated with total ankle arthroplasties including their relatively short life-span and limited
efficacy in comparison to other types of arthroplasty (de Kruijf, Verlinden, Huygen, Hofman,
van der Geest, Uitterlinden et al., 2015; Hintermann & Ruiz, 2014; Hosman, Mason, Hobbs, &
Rothwell, 2007; Jomha et al., 2013; Rao, Riskowski, & Hannan, 2012). This highlights the
need to explore conservative management strategies for those suffering with ankle OA. Due to
the younger population being affected by the disease, it is important to have an effective, low-
cost management plan in place (Queen et al., 2011). In this regard, the use of an ankle brace
has potential in the management of ankle OA (Hadadi, Mousavi, Fardipour, Vameghi, &
Mazaheri, 2014). It has been suggested that ankle braces may work to decrease pain by
restoring alignment of the ankle joint, redistributing plantar loads and subsequently, reducing
the loads acting on the damaged ankle joint (Rao et al., 2012). Surprisingly, no studies have
investigated the effect of ankle braces on plantar pressure measures in patients with ankle OA.

Research Aim and Objectives

Primary

(1) To investigate the differences in selected plantar pressure measures during gait between
the involved and uninvolved limb in individuals with ankle joint OA.

(2) To determine the short-term effects of an ankle brace on gait-related pain, perceived ankle
stability and comfort, as well as selected plantar pressure measures during gait.
Secondary

(1) To investigate whether selected plantar pressure measurements are different across individuals with and without OA of the ankle joint.

Research Questions

(1) Are there differences in hindfoot peak pressure, the pressure-time integral and contact time during stance phase across involved and uninvolved limbs of individuals with OA of the ankle joint?
(2) Are the above-mentioned differences altered by wearing an elastic support brace?
(3) Are there differences in hindfoot peak pressure, pressure-time integral and stance contact time across of the uninvolved limb of the OA group compared to a control group limb without OA of the ankle.

Practical Application

This study aims to inform its readers, providing insight into plantar pressure differences during walking between those with ankle OA and those without. It also aims to examine the effects of an inexpensive, commercially available ankle brace on these parameters. This may be of
benefit to health professionals involved in the management of ankle OA. Their understanding of altered patterns of foot and ankle loading could be enhanced by providing evidence (or otherwise) for the use of braces in the management of ankle OA. Ultimately, this may help those with ankle OA receive improved treatment and decrease the socioeconomic burden of this long-term degenerative disorder.
Chapter 2: Literature Review

The objective of this chapter is to provide the reader with a deeper understanding of ankle OA, plantar pressure measures and the potential utility of ankle bracing. The first section of this chapter will outline search strategies for the literature reviewed. Following this, a brief discussion of the ankle joint and the epidemiology of ankle osteoarthritis is provided. Plantar pressure measures will then be reviewed. Thereafter, ankle bracing is examined and its potential effect on ankle OA and plantar pressure measures is discussed.

Search Methods

Initially, the search for literature was undertaken using a range of sources including textbooks, reports and systematic reviews from published literature. Following this, an extensive list of keywords was generated covering terms specific to ankle OA and interventions as well as plantar pressure measurers.

Keywords

Ankle, arthritis, osteoarthritis, gait analysis, pressure pad(s), centre of pressure, orthoses, brace(s)(ing), foot posture index, plantar pressure(s), chronic ankle instability, weight bearing,
aging population, quality of life, pressure-time integral, contact time, instant of peak pressure, force-time integral mean pressure, peak pressure, lower limb task questionnaires, validity, reliability, pain, stability, comfort, brief pain inventory.

The keyword list and all combinations of keywords were used uniformly to ensure a standardised approach to the search procedure. Keywords were searched for using the following databases: Academic Onefile (Gale), Cochrane Library Databases, EBSCO Health databases, Google Scholar, PEDro, PubMed, ScienceDirect, ProQuest 5000 and Scopus. Articles were identified and collected by using keywords, subject terms and hand-searching reference lists through previously attained articles. The searches were restricted to English publications and only articles between 1990 and 2017 were included. Papers reviewed included experimental designs and reviews, as well as book chapters related to the topic area. Article selection was based on the relevance of the title and abstract.

The Ankle Joint

The ankle joint bears more load per unit of surface area than any other joint in the body (Morrison & Kaminski, 2007). It also has a thinner layer of cartilage (1.0 - 2 mm) covering the joint surfaces when compared to the hip and knee (1.7-3 mm) (Bhatia, 2014; P. McNair & Rice, 2015; Saltzman, Salamon, Blanchard, Huff, Hayes, Buckwalter et al., 2005; Weatherall, Mroczek, Mclaurin, Ding, & Tejwani, 2013). This is thought to be due to the ankle joint being more congruent than the hip or knee, where thicker cartilage is needed to increase the surface
area of the joints (Hendren & Beeson, 2009). Thinner cartilage may also indicate more even
distribution of forces within the joint, whereas with greater variation, forces are more able to be
concentrated to the thicker regions as needed (Hendren & Beeson, 2009).

Ligaments provide support at joints by restricting certain movements, as determined by their
attachment points (Bruening, Crewe, & Buczek, 2008). At the ankle joint, the ligaments
supporting the ankle are found on the medial and lateral sides of the joint (Brockett &
Chapman, 2016). The medial aspect of the ankle joint is supported by the deltoid ligaments
and can be damaged in eversion injuries (Brockett & Chapman, 2016). The lateral side of the
ankle joint is supported by the lateral collateral ligaments consisting of the anterior and
posterior talofibular ligaments and these are frequently damaged during inversion injuries
(Jastifer & Gustafson, 2014).

Aetiology of Ankle Osteoarthritis

Compression of the healthy ankle results in fluid movement within the cartilage, resulting in
even weight distribution and decreasing forces applied to the subchondral bone (Hendren &
Beeson, 2009). Hendren and Beeson (2009) found that cartilage at the ankle responds
differently to slowly applied loads compared to rapid loading. When the ankle joint undergoes
sudden loading, such as during acute joint trauma, the fluid does not have time to move
(Hendren & Beeson, 2009). This damages the matrix, mechanically stressing the chondrocytes
leading to chondral damage associated with ankle OA (Hendren & Beeson, 2009). Ankle OA
may be primary, secondary or post-traumatic in nature. Primary OA refers to the idiopathic
degeneration of the articular cartilage without a history of trauma and normally occurs bilaterally (McNair & Rice, 2015; Valderrabano et al., 2009). Secondary OA occurs when the cartilage at the ankle joint is affected because of other pathologies, for example, rheumatoid arthritis (Valderrabano et al., 2009). Post-traumatic ankle OA refers to OA that develops after a traumatic injury and is normally unilateral (Bhatia, 2014; Hubbard et al., 2009; Koshino, Yamanaka, Ezawa, Ishida, Kobayashi, Samukawa et al., 2014; Valderrabano et al., 2009).

Primary Osteoarthritis

Studying the epidemiology of ankle OA; Valderrabano, Horisberger, Russell and Hintermann, (2009) found that around 9% of ankle OA cases occur insidiously. Primary OA at the ankle develops with gradual wearing down of the cartilage covering the joint and rarely affects those under 40 years of age (Saltzman et al., 2005). The ankle joint is thought to adapt well to slowly applied forces, such as gradual loading with weight gain (Hendren & Beeson, 2009). This is because cartilage at the ankle joint preserves its fracture stress and tensile stiffness with age and gradual degeneration, making primary osteoarthritis less common than posttraumatic ankle OA (Saltzman et al., 2005). The tensile stiffness of the ankle cartilage is thought to be due to its higher proteoglycan density, lower matrix degradation and higher compressive stiffness when compared to cartilage at the hip or knee (Aurich, Squires, Reiner, Mollenhauer, Kuettner, Pool et al., 2006; Egloff et al., 2012).

Secondary Osteoarthritis
Secondary OA of the ankle makes up around 13% of those with ankle OA (Valderrabano et al., 2009). It results from pathologies such as rheumatoid arthritis, haemophilia, hemochromatosis, avascular necrosis of the talus, clubfoot deformity osteochondritis dissecans and post-infection arthritis (Barg, Wimmer, Wiewiorski, Wirtz, Pagenstert, Valderrabano, 2015; Valderrabano et al., 2009). The mechanism behind the development of secondary OA is like that of primary OA, where alterations that occur within the joint can lead to disruptions within the cartilaginous structures causing degeneration and thereby resulting in OA (Valderrabano et al., 2009). There are also changes seen in the synovial fluid of the joint with increased levels of inflammatory and catabolic mediators including neuropeptides, nitric oxide, prostaglandin E2 and inflammatory cytokines (Sellam & Berenbaum, 2010). This promotes degradation of the cartilage matrix by hindering repair and results in an increase in proteolytic enzymes causing cartilage degeneration (Sellam & Berenbaum, 2010).

Post-traumatic Osteoarthritis

Approximately 70% to 78% of ankle OA cases are post-traumatic (Lobet et al., 2012; Valderrabano et al., 2009). Given that a much higher percentage of ankle OA cases are caused by trauma, it has been found that a large proportion of those with OA of the ankle joint are in younger populations (Queen et al., 2011). This differs from those with primary ankle OA, who tend to be much older (Valderrabano et al., 2009). Post-traumatic OA commonly results from ankle or malleolar fractures, as well as ligament sprains or ruptures caused by inversion or eversion injuries (Valderrabano et al., 2009). Fractures with posterior malleolar injuries are
more likely to result in ankle osteoarthritis when the posterior malleolus has not been surgically reduced, where screws are used to pin the joint together (Khazzam et al., 2006). Another study looking at the epidemiology of ankle arthritis, from a sample of 639 cases, found that the majority of post-traumatic ankle OA cases had a history of rotational ankle fractures (Saltzman et al., 2005). This is supported by another study that has found that the three most common causes of posttraumatic ankle OA are rotational ankle fractures (37%), recurrent ankle instability (14.6%) followed by a single sprain associated with continuing pain and symptoms (13.7%) (Weatherall et al., 2013).

A large percentage of those with posttraumatic ankle OA have an underlying history of chronic ankle instability, which affects 40 to 70% of people after an ankle sprain injury (Golditz et al., 2014). Inversion sprains make up 85% of all ankle sprains with eversion sprains making up the remainder (Morrison & Kaminski, 2007). These injuries are common in sports involving running, jumping or twisting quickly such as soccer, basketball and gymnastics (Attenborough, Hiller, Smith, Stuelcken, Greene, Sinclair, 2014). Chronic ankle instability has been described as an insufficiency of the ankle joint complex associated with perceived and mechanical instability, recurrent sprains and persisting symptoms (Attenborough et al., 2014). It has been shown that 66% to 78% of chronic ankle instability cases go on to develop ankle OA (Hubbard et al., 2009; Valderrabano et al., 2009). The mechanism behind this is thought to be increased laxity at the joint, which if uncontrolled by muscle action compromises the stability of the joint (Hintermann & Ruiz, 2014) and changes ankle joint loading (Valderrabano et al., 2009).

Specifically, decreased stability changes the load distribution and overall contact of the ankle joint surfaces during gait and other activities, leading to articular cartilage degeneration
Another study using T2-mapping found that cartilaginous changes occur with uneven loading of the ankle joint in cases of ankle instability (Golditz et al., 2014).

Regardless of its aetiology, all forms of ankle OA result in irreversible damage to the tibiotalar articular cartilage with chronic, aberrant loading of the cartilage resulting in destruction of the joint space (Khazzam et al., 2006). The resulting pain and structural changes in the joint may lead to altered plantar pressures during gait (Valderrabano et al., 2009), which may in turn, affect the way the damaged ankle joint is loaded and the subsequent progression of the disease.

**Plantar Pressure Measurements: Methodological Considerations**

Measuring plantar pressure distribution in those with ankle OA is a dynamic way of assessing loading in different parts of the foot during various weight-bearing tasks, including gait (Rao et al., 2012). Pressure distribution is measured by an instrumented pad containing force sensors (4 sensors/cm2) which participants walk over (Novel, 2014). Peak pressure, pressure-time integral, and contact time are plantar pressure measures that are commonly assessed during gait (Keijsers, Stolwijk, & Pataky, 2010).

Peak Pressure (PP) is the single most commonly reported measure and represents the maximum load in the plantar surface of the foot or given area of the foot during gait (Bus & Waaijman, 2013; Keijsers et al., 2010; Melai, IJzerman, Schaper, de Lange, Willems, Meijer et al., 2011).
This is clinically important because the magnitude of the peak pressure can be localised when walking (Melai et al., 2011).

Pressure-time integral (PTI) is defined as the area under the pressure-time curve within each mask and expressed in kilopascals multiplied by seconds (kPa.sec) (Rao, Baumhauer, & Nawoczenski, 2011a; Redmond, Crane, & Menz, 2008). The PTI describes the total effect of pressure over time in a given area of the foot, providing a value for the total load exposure of the sole of the foot area with each step (Melai et al., 2011). It has been found that those with forefoot pain had significantly higher levels of PTI compared to healthy controls (Keijzers, Stolwijk, Louwerens, & Duysens, 2013).

Contact time (CT) is also a clinically relevant measure as it indicates the time in milliseconds (ms) each area of the foot is in contact with the pressure pad during stance phase (Putti, Arnold, Cochrane, & Abboud, 2008). This can aid in understanding loading patterns and can identify compensations or fear-avoidance associated with loading the painful area (Rao et al., 2012).

Walking speed has been shown to affect plantar pressure measures (Taylor, Menz, & Keenan, 2004). Taylor et al. (2004) analysed the changes of walking speed on plantar pressure parameters in young, healthy participants. It was found that walking at a slower speed did not affect maximum force and PP but slower walking speeds are needed to accurately assess the force- and time-integrals at most regions of the foot (Taylor et al., 2004). This is supported by other studies that have found that having participants walk at relaxed, self- selected speeds produces the most appropriate normative data for the given individual (Akins, Keenan, Sell,
Masking is a process which divides the sole of the foot into 6 to 11 areas that are used to easily assess plantar pressure parameters. Normally, the plantar pressure images collected on the plantar pressure software (e.g.: Novel GmbH Inc., Munich, Germany) undergo an automatic masking process dividing the foot into an average and maximum of 6 to 11 anatomical regions of interest to calculate the plantar pressure parameters (Keijsers, Stolwijk, Nienhuis, & Duysens, 2009; Keijsers et al., 2010). The variation in the masks used makes study comparisons difficult (Keijsers et al., 2009). However, the masks selected are determined by what the researchers are wanting to assess.

The masking used in this study is a 6-segment model with each of the following being divided into medial and lateral sides: (1) forefoot and toes, (2) midfoot, and (3) hindfoot. Due to the resource constraints of this study, only plantar pressure measures in the medial and lateral hindfoot were analysed (Horisberger, Hintermann, & Valderrabano, 2009). The medial and lateral divisions were chosen to allow an assessment of the medial to lateral (or vice versa) ratio in the PP and PTI, which has yet to be studied in this population. It was thought that this measure would allow an appreciation of the distribution of loading at a time when high levels of load are placed on the foot, that being at the time of foot strike (Khazzam et al., 2006).
Reliability of Plantar Pressure Platforms

The reliability of plantar pressure platforms/pads has been established. Gurney et al. (2008) examined the reliability of plantar pressure parameters during normal gait of 9 healthy adults (5 men and 4 women, age 26 ± 8.4 years) across 5 separate days at roughly the same time of day (Gurney et al., 2008). Gurney et al. (2008) used a capacitive pressure distribution platform (EMED AT, Novel GmbH, Munich, Germany), with the sampling set at 50 Hz to record the plantar pressure parameters during walking at self-selected speeds. In addition to measuring the PP and CT, Gurney et al. (2008) also investigated maximum force and impulse. They used the Novel auto-mask which divides the foot into 10 areas of interest (Gurney et al., 2008). The participants in the study by Gurney et al. (2008) had 5 trials on each foot and the resulting correlation coefficients (ICC) and coefficients of variation (CoV) for the individual means of the plantar pressure parameters were analysed accordingly for each of the whole foot and the 10 areas of the foot individually. Results from this study suggest that areas of the foot that have high levels of loading have a higher level of reliability in the ICC’s such as the central forefoot (>0.9) and the medial and lateral hindfoot (>0.8) when compared to areas that are loaded less, such as the medial midfoot (<0.8) (Gurney et al., 2008). These authors found no statistically significant difference between the day-to-day measuring of the above plantar pressure parameters, that they can be used in comparative evaluations and that the measures of repeatability are satisfactory for the use in clinical populations (Gurney et al., 2008).

Another study that assessed the reliability of plantar pressure measurements, found that the mean result of three or more trials on the Novel emed F system provided excellent reliability (Hughes, Pratt, Linge, Clark, & Kleenerman, 1991). The right feet of ten healthy participants
were tested at three speeds: slow, medium and fast. The speeds were guided by a metronome, where slow speeds were set at 84 steps min, equating to a stance phase of 0.9 seconds, medium speeds were set at 112 steps per minute, with a stance phase of 0.7 seconds and fast speeds were set at 144 steps per minute with a stance phase of 0.5 seconds (Hughes et al., 1991). In addition to measuring the FTI, PP and CT, other plantar pressure parameters assessed in the study by Hughes et al. (1991) were total force, pressure-time integral, area, beginning of contact (% stance phase), end of contact (% stance phase), instant of peak force and instant of peak pressure (Hughes et al., 1991). Coefficients of reliability ranged from 0.75 to 0.9 and were generally indicative of excellent reliability (Hughes et al., 1991).

Asymmetry in Plantar Pressure Measures

Asymmetries in plantar pressure distributions during gait have been widely studied in populations with lower limb pathologies such as knee OA, diabetic ulcers and toe deformities (Bennetts, Owings, Erdemir, Botek, & Cavanagh, 2013; Mickle, Munro, Lord, Menz, & Steele, 2011; Shiozawa, Hirata, & Graven-Nielsen, 2015; Waaijman & Bus, 2012; Wafai et al., 2015). These asymmetries are thought to be a representation of a number of factors such as the intra-articular biomechanical changes, compensation patterns to relieve pain, bony deformities and changes in muscular activation (Fukaya, Mutsuzaki, Okubo, Mori, & Wadano, 2016; Hintermann & Ruiz, 2014). Plantar pressure asymmetries have been argued to affect foot function during the gait cycle by inflicting high pressure onto new locations within the foot (Wafai et al., 2015). Significant asymmetry of the plantar pressure between the symptomatic and asymptomatic foot during walking may also increase the risk of falling
(Mickle et al., 2010; Wafai et al., 2015) which is known to be elevated in people with foot and ankle pain (Rao et al., 2012). Another study looked at the ground reaction forces in 20 participants with ankle OA compared to six healthy controls (Shih, Wu, & Lo, 1993). This study found that the magnitude of the vertical ground reaction force during toe-off was decreased in the ankle OA (involved) side compared to the contralateral or uninvolved side, as well as when compared to the control participants (Shih et al., 1993). While differences were seen in ground reaction forces no plantar pressure parameters were measured.

It appears that only one study has assessed the plantar pressure measures in an ankle OA population. A study by Horisberger et al (2009) explored the plantar pressure distribution in 120 patients with post-traumatic end-stage ankle OA. The plantar pressure parameters which were assessed included maximum force, CT, PP, contact area, and centre of pressure measures (Horisberger et al., 2009). Five trials were recorded on the pressure pad (EMED, Novel GmbH, Munich, Germany, 4 sensors/cm2) for each foot in the study (Horisberger et al., 2009). Significant decreases in maximum force and contact area in the whole foot of the affected limb during gait were found. PP in the hindfoot and toes area was also decreased. The authors suggested that this may be due to compensation patterns in which the participant attempts to reduce weight-bearing on the pathological and painful ankle (Horisberger et al., 2009). It has also been suggested that plantar pressure changes may be due to bony deformities, or ankle malalignment due to either the initial injury or the degeneration associated with ankle OA (Hintermann & Ruiz, 2014). Yet another explanation is that atrophy and/or inhibition of the muscles acting on the ankle contribute to these changes in plantar pressures (Horisberger et al., 2009; Valderrabano et al., 2007). Muscle atrophy
associated with ankle OA might be expected to increase loading on the affected side (Valderrabano et al., 2006). Alternatively, muscle atrophy may alter the neuromuscular control strategies, which may contribute to a change in loading patterns observed (Nüesch, Huber, Pagenstert, von Tscharner, & Valderrabano, 2012). Overall, given the numerous factors that might influence loading and limb asymmetry, it is difficult to assess their relative contribution to changes in loading.

The study conducted by Horisberger et al (2009) assessed a large cohort, of post-traumatic OA subjects. As posttraumatic ankle OA is usually unilateral, the asymptomatic limb was used as the control (Horisberger et al., 2009). These authors noted the following changes across limbs: maximum force and contact area were decreased in the whole involved foot and PP in the hindfoot and toes area was also decreased in the involved side compared to the uninvolved side. These findings provided a foundation upon which to develop further research. An important plantar pressure measure not considered by Horisberger et al (2009) was the PTI. The importance of the PTI is that it provides additional information about how load is distributed over time, rather than simply an instantaneous measure of peak pressure (Keijsers et al., 2013). It may be that pressure levels maintained over time during gait are more influential in progressing joint damage. Additionally, given the different factors that influence the loading asymmetries mentioned above, Horisberger et al (2009) thought that participants might alter the positioning of the subtalar joint at the time of foot strike to reduce or alter the normal pattern of loading upon the ankle joint. Utilising a ratio of medial to lateral pressure measures at the hindfoot at the time of foot strike could allow an appreciation of such changes.
It is also possible that gait patterns may be altered in the contralateral limb in an attempt to maintain bilateral symmetry in the motion of lower limb joints (McNair et al., 2018; Queen et al., 2011). In addition, bilateral neuromuscular deficits are common even in individuals with unilateral joint pathology (Redmond, 1998). Given these possibilities, it seemed of merit to examine pressure measures of the uninvolved side in OA patients and determine if they might be different from those of a control group without OA.

**Intervention Options**

The definitive treatment of end-stage ankle OA is surgery, and recently this has changed from ankle fusions to total ankle arthroplasties (Hintermann & Ruiz, 2014; Jomha et al., 2013). However, there are still numerous contraindications to surgery, including but not limited to osteoporosis and severe ligamentous laxity and malalignment (Hintermann & Ruiz, 2014; Jomha et al., 2013). For those who do undergo total ankle arthroplasties, there are high risks of serious complications including, but not limited to aseptic loosening, which occurs in 8.7% of patients, intraoperative fractures, which has an occurrence rate of 8.1%, wound healing problems, which happen in 6.6% of cases on top of high technical failure rate (6%) and implant failure (6%) (de Kruijf et al., 2015; Hintermann & Ruiz, 2014; Hosman et al., 2007; Jomha et al., 2013; Rao et al., 2012). Even without complications, ankle arthroplasties continue to have a relatively short life-span; in New Zealand, the failure rate after 5 years is 14% (Hosman et al., 2007). Pharmaceutical management options for ankle OA exist, such as simple analgesics, nonsteroidal anti-inflammatory medications and injections such as corticosteroid injections, hyaluronic acid or platelet-rich plasma injections (Huang et al.,
However, these treatments may also have adverse effects, only provide short-term relief, and are not advised to be taken long-term (Bhatia, 2014; Hirsch, Kitas, & Klocke, 2013; S. F. Sun et al., 2009). These problems reveal the crucial need to explore alternative conservative management strategies.

Due to the younger population being affected by ankle OA, it is important to have an effective, low cost management plan in place that minimises adverse reactions (Queen et al., 2011; Rao et al., 2012; Thompson, Jennings, Hodge, 1992). Within such a plan, the use of an ankle brace intervention has potential (Hadadi et al., 2014; Shine & Bongiovanni, 2009). In those with unstable ankles, this intervention has been shown to improve postural control and balance (Bhatia, 2014). Improved stability and control is thought to occur via a number of potential mechanisms including neutralising ankle malalignment, stabilising the joint, and improving ankle proprioception (Hadadi et al., 2011). Clinically, this means bracing of the arthritic ankle might delay the need for surgical intervention and offer a management plan for those who either cannot have surgery due to contraindications or who do not want to solely rely on pharmaceutical interventions (Jomha et al., 2013; Shine & Bongiovanni, 2009).

Studies have assessed the impact of bracing on OA, but mainly in relation to knee OA while literature covering bracing for ankle OA remains scarce. A review of 41 pieces of literature assessing the effects of knee braces on the loading patterns within the knee in those with osteoarthritis, found that while there is debate around the biomechanical changes caused by bracing, braces seem to decrease pain, and increase stability and quality of life measures (Steadman, Briggs, Pomeroy, & Wijdicks, 2016). This is supported by another review.
assessing the use of bracing in the management of knee OA (Phillips, Li, Phillips, Bischoff, Ali, Chahal et al., 2016). Phillips et al., (2016) found that 92% of the articles reported positive effects of bracing on pain and instability related to knee OA. Six percent of the articles noted no change, with the final 2% reporting a negative effect (Phillips et al., 2016). The articles that noted no change in pain or stability may have used braces that did not unload the knee joint enough for participants to perceive a difference. The braces may have worked well on some participants but not on others, thereby making it seem that there was no change overall. For the study that reported a negative effect, it may be that the researchers had selected the wrong type of brace for their given participants, for example, it may have further loaded the part of the joint most affected by the OA, thereby increasing pain (Ornetti, Fortunet, Morisset, Gremeaux, Maillefert, Casillas et al., 2015). The review by Phillips et al. (2016) noted that most studies failed to specify which braces were used. This is a limitation, as it is not known which braces are the best and whether multiple studies tested the same brace. If two studies assessed the same brace but got different results, researchers would not be able to identify the factors that may have led to differences seen. While there has been literature describing the unloading effect of knee braces on OA (Otto, 2012) there has been no research undertaken on the effects of braces on plantar pressure loading in those with ankle OA.

Braces and Stability

It has been shown that ankle bracing decreases the incidence of acute ankle sprains by 70% in those with a history of ankle injuries (McGuine, Brooks, & Hetzel, 2012). Ankle braces are thought to improve joint stability by providing mechanical support and improving ankle
proprioception (Kaminski & Gerlach, 2001). The exact mechanism of this is still debated. Some studies suggest that this is due to the increased stimulation of the cutaneous mechanoreceptors (Kaminski & Gerlach, 2001; Pavailler, Forestier, Hintzy, Horvais, & Lapole, 2016) whereas others suggest that bracing helps to re-align the ankle joint (Bhatia, 2014; Shine & Bongiovanni, 2009).

In a randomised-crossover study of 15 participants with chronic ankle instability, surface electromyography showed that ankle bracing increased the neuromuscular activity of the muscles acting on the ankle during walking thereby stabilising the ankle with muscular control which may, in turn, decrease the risk of future sprains (Barlow, Donovan, Hart, & Hertel, 2015). Another study has assessed the effects of braces on the postural stability of those with unilateral functional ankle instability (Hadadi et al., 2011). Those with functional ankle instability had greater postural sway when balancing on both legs compared to healthy controls (Hadadi et al., 2011). It was also found that those with functional ankle instability had significantly lower centre of pressure parameters when wearing either a soft or semi-rigid ankle brace, with the soft brace being more effective (Hadadi et al., 2011).

Bracing compliance is an important factor in the effect bracing has on the ankle. Factors that increase compliance include having a low-profile brace that is comfortable, provides adequate support, and decreases pain associated with the OA (Shine & Bongiovanni, 2009). Several studies have noted the importance of having a comfortable brace, particularly as it has a direct influence on compliance and should be an outcome measure (Accident Compensation Corporation, 2009; Fantini Pagani, Willwacher, Benker, Brüggemann, & Bruggemann, 2013; Hadadi et al., 2011).
The following three articles looked specifically at the use of ankle orthoses in the management of ankle OA. The first study examined the effects of orthoses in the long-term management of foot and ankle OA (Thompson et al., 1992). The 64 participants in this study were divided into three groups, orthoses were used as the sole therapeutic intervention in one group, the second group received an orthosis in conjunction with nonsteroidal anti-inflammatory drugs while the final group just received nonsteroidal anti-inflammatory drugs (Thompson et al., 1992).

Results show that all participants who had the orthoses as the sole intervention had significantly longer periods of pain relief compared to the group receiving just the nonsteroidal anti-inflammatory drugs. Most participants (55%) in the group receiving both the orthoses and the nonsteroidal anti-inflammatory drugs also experienced statistically significant longer periods of time that they had pain relief for compared to the group who just had the nonsteroidal anti-inflammatory drug intervention (Thompson et al., 1992).

The second study assessed the use of three different braces on the range of motion at the hindfoot (calcaneus relative to the tibia and forefoot metatarsal relative to the calcaneus) in 13 participants with ankle OA (Huang et al., 2006). Range of motion of the forefoot and hindfoot was measured using an 8-camera motion analysis system as the participants walked on level, ascending, descending and side-sloping surfaces (Huang et al., 2006). The results suggested that the rigid hindfoot orthoses provided the best support for the ankle joint as it restricted ankle-hindfoot motion while allowing for sufficient forefoot motion when compared to the other orthoses (Huang et al., 2006). The authors concluded that the rigid hindfoot orthosis could be used to treat those with ankle OA who experience pain as a result of ankle movement (Huang et al., 2006). The rigid hindfoot orthosis described in the study by Huang et al., (2006) has a fairly high profile which is a factor that can decrease compliance, as patients generally
do not want a brace that draws attention to their chronic injury or condition (Shine & Bongiovanni, 2009).

The third study looked at combining orthotics with a rehabilitation programme (Return to Run clinical pathway) in 16 participants with posttraumatic ankle OA (Patzkowski, Owens, Blank, Kirk, & Hsu, 2012). The participants in this study were all military personnel who had sustained high-energy trauma during combat (Patzkowski et al., 2012). Outcome measures for this study were functional, occupational and recreational capabilities. Results found improvements in the functional, recreational and occupational capabilities of the participants (Patzkowski et al., 2012). Before participating in this study, six of the 16 participants had wanted to undergo late amputation, however, following this study, only one participant wanted to still undergo amputation (Patzkowski et al., 2012).

Together, these studies suggest that providing ankle support may be a viable option for those suffering with ankle OA. Surprisingly, no studies have assessed braces in ankle OA populations with the aim of improving joint pain and stability while using objective plantar pressure measures to determine differences in plantar loading.

**Research Rationale**

Overall, compared to the knee or hip joint, there has been little research exploring ankle OA patterns of loading during gait. The current study builds on Horisberger et al’s work. It will
examine a previously unassessed plantar pressure variable (pressure-time integral) in an OA cohort, and additionally will examine a ratio of medial to lateral pressure variables to ascertain whether there is a pattern of change in the distribution of pressures across these areas of the hindfoot at the time of loading during gait. Additionally, a secondary aim of the work that is also novel is whether there are differences in pressure variables in the uninvolved side of an ankle OA cohort compared to a cohort without OA. Finally, while bracing has demonstrated benefits in knee OA, and is known to improve postural stability at the ankle, no studies have assessed the effect of ankle bracing on plantar pressure measures, pain, stability and comfort in people with ankle OA.
Chapter 3: Methodology

Study Design

Cross sectional comparison across limbs of those with ankle OA and healthy controls; and a single cohort, randomized cross-over design comparing a brace and non-braced condition within a single session in those with ankle OA. All testing procedures were completed at the Motion Analysis Laboratory AA113 located at the Auckland University of Technology, Akoranga Campus, Gate 2/90 Akoranga Drive, Northcote, Auckland.

Recruitment

Participants were recruited through newspaper and Facebook advertisements, community noticeboards, contacts with local orthopaedic surgeons and healthcare clinics, sport groups and word-of-mouth. All participants were sent an information sheet before consenting to participating (Appendix C). The inclusion criteria were symptomatic post-traumatic ankle OA as diagnosed by their doctor or specialist, including frequent or constant joint pain, perennial swelling and stiffness following a history of trauma (e.g. fracture, multiple sprains) to the affected ankle joint. Radiographs were used to confirm the presence of ankle OA using the Kellgren and Lawrence Scale (Kellgren & Lawrence, 1957) (see Appendix D) to assess severity.
The exclusion criteria were a history of surgical intervention for the ankle OA, rheumatoid arthritis affecting the ankle, other inflammatory arthritic conditions, neuropathies, bilateral ankle injuries or pain, a recent injury (<6 months) to their ankle joint and patients with gait afflictions related to other conditions. In addition to not suffering from any of the conditions mentioned in the exclusion criteria, the control group criteria were that participants did not have any current or recent ankle injuries (<6 months) and no history of major ankle trauma where there were ongoing issues with pain and instability following the injury (Attenborough et al., 2014). To aid in homogeneity across the groups, the control group participants were matched 1-to-1 with the ankle OA group regarding gender and age (within five years).

Sample Size Calculation

Data from Horisberger et al. (2009) and pilot testing utilising a Novel foot pressure pad allowed the calculation of sample sizes, which was undertaken in the software program G-Power (Faul, Erdfelder, Buchner, & Lang, 2009). The dependent variable of most interest was the pressure-time integral at the hindfoot. The alpha level was set to 0.05 and power at 0.80 to identify a medium effect size (0.75 Standard deviations) across the involved and uninvolved limbs for this variable. This analysis showed that a sample size of 17 participants was required.

Study Protocol
This study was granted ethical approval by both the Unitec Research Ethics Committee (Ref No: 2016-1080) (see Appendix E) and the Auckland University of Technology Ethics Committee (Ref No 17/16) (see Appendix F).

Participants attended a single session of data collection. It was required of them to refrain from taking pain medication on the day of testing to ensure no interference with the pain levels. All participants provided written consent to participate in the study (see Appendix G). This involved the attainment of demographic data as well as the completion of questionnaires related to pain and function. Walking tests were conducted on a Novel Pressure Pad at baseline for both groups. This was to allow for between group comparisons in plantar pressure measures. The ankle OA group then repeated the walking tests in an unbraced and braced condition to allow for comparison in plantar pressure measurements between the unbraced and braced conditions. In the latter; ratings of pain, comfort and stability were recorded when utilising a brace while walking.

**Questionnaires**

**Foot Function Index**

The Foot Posture Index (FPI 6) is a practitioner-reported classification scheme using six criteria to classify feet into one of three groups, neutral, pronated or supinated (Sánchez-
Rodríguez, Martínez-Nova, Escamilla-Martínez, & Pedrera-Zamorano, 2012) (See Appendix H). The FPI 6 has been found to be a valid tool for the classification of the neutral, standing posture of the ankle (Redmond et al., 2008). High inter-rater and moderate inter-rater reliability has been established by Cornwall, McPoil, Lebec, Vicenzino and Wilson (2008) who showed it to have an intra class correlation coefficient of 0.566.

Participants stood in a relaxed position with double limb stance. The researcher, who had been trained to use the FPI 6 and had practiced on 25 other individuals before the study, then evaluated each of the following bilaterally in those with ankle OA. First the talar head was palpated and scored, then the supra and infra lateral malleolar curvature was examined followed by the calcaneal frontal plane position, the prominence in the region of the talonavicular joint, congruence of the medial longitudinal arch, and finally the abduction/adduction of the forefoot on the rearfoot (Redmond, 2005). Each of these criteria were scored on a 5-point scale from -2 to +2. Negative 2 indicates clear signs of supination and +2 denotes clear signs of pronation (Redmond, 2005). The total score for each foot was then calculated.

Lower Limb Tasks Questionnaire

The Lower Limb Task Questionnaire (LLTQ) has two sections, the Activities of Daily Living (ADL) section and the Recreational Activities section and these can be measured separately. It has a high level of reliability and responsiveness while relating well with other measures of function (McNair et al., 2007). The ADL section of this questionnaire was selected as it
seemed unlikely that those with ankle OA (who are generally aged over 60 years) would be engaging in many of the physical activities presented in the recreational section (e.g. kicking a ball or sidestepping) (see Appendix I).

The LLTQ is a self-reported measure with each section having ten questions. Each question is rated in terms of difficulty. Difficulty is scored on a scale of 0 to 4, with 0 indicating the participant is unable to perform the task and four indicating no difficulty. Thus, an overall score is calculated out of 40 for the Brief Pain Inventory Short Form.

The Brief Pain Inventory Short Form (SF-BPI) is a reliable and validated, self-reported questionnaire that describes the participants pain at its worst and at its least in the previous 24 hours, as well as average pain and the pain that they are in right that moment (Keller et al., 2004; Mendoza, Mayne, Rublee, & Cleeland, 2006). While previous experience with a soft brace has not been assessed, the SF-BPI is commonly used in studies involving participants with arthritis (Mendoza et al., 2006). In this study, the SF-BPI was used to provide an average pain level for individuals in the ankle OA group (see Appendix J).

Plantar Pressure Measurements

A Novel pressure system (EMED, Novel GmbH, Munich, Germany 4 sensors/cm2) was used to record the plantar pressure measures. The Novel pressure system has shown to be an accurate and reliable way of assessing plantar pressures (Hafer et al., 2013). The Novel
pressure pad has capacitive sensors that are individually calibrated, providing accurate plantar pressure parameters during loading of the foot (Giacomozzi, 2010; Seitz & Kalpen, 2006). Data were collected using a sampling rate of 50 Hz, a sampling rate appropriate for the analysis of walking gait (Taylor et al., 2004).

Specific plantar pressures measured were the CT, PTI and PP. The CT provides the time over which the whole foot was in contact with the pressure pad and was measured in milliseconds. The PTI is defined as the product of change in time and change in pressure, and can be observed as the area under a curve within a pressure-time graph. As such, it is measured in kilopascals/seconds (kPa.s). The PP is measured in kilopascals (kPa), and as the name suggests, is the maximum pressure observed within a region of interest (exempli gratia: medial hindfoot). The Novel System records pedographs mapping the pressures (Figure 1). The Novel System software was utilised to provide the above dependent variables.

Subdivision of areas of the foot were obtained through the selection of an appropriate masking system from within the Novel software. The masking system utilised in the current study was a 6-section automask (see Figure 1). These sections were medial hindfoot, lateral hindfoot, medial midfoot, lateral midfoot and medial forefoot + toes and lateral forefoot + toes. The medial and lateral boundaries are delineated by a line from the centre of the heel to the centre of the second toe (“Novel Scientific Medical Manual,” 2012). The horizontal boundaries separate the hind- from the mid- and forefoot. The horizontal boundary separating the hindfoot from the midfoot is placed at 73% of the foot length from the top of the foot while the line separating the midfoot from the forefoot is placed at 45% of the foot length from the top of the foot (“Novel Scientific Medical Manual,” 2012). Both horizontal lines are perpendicular to the
line dividing the foot into medial and lateral boundaries.

McNair and Rice (2015) have commented that loading on the OA ankle joint is associated with heel strike during gait activities, and can lead to progressive degeneration of articular cartilage. Hence the focus of the data analyses was on the hindfoot as this area generally makes first contact with the ground surface, and relatively large impact forces are generated (Valderrabano et al., 2007). In the mask utilised, the hindfoot was subdivided into medial and lateral aspects to examine possible changes in loading across these regions in the early loading period of stance phase. Hence a ratio of medial to lateral PTI and PP was calculated. Medial and lateral ratios of PTI and PP have not been assessed to date but doing so provides valuable information about loading patterns while walking. When considering the total area of the hindfoot, for the PP and PTI variables, the mean values were calculated from the medial and lateral sections.

*Figure 1: Novel Pedograph Results Ankle OA divided into medial and lateral hindfoot, midfoot*
and forefoot and toes. Pink indicates highest levels of pressure and black the lowest pressure. The curved line follows the centre of pressure during the given step.

The figure above is the average of five trials taken during baseline testing of a participant with OA in the left ankle.

In the lab, the participants were instructed to walk from a mark 2.5 metres from the pressure pad to another mark on the floor 2.5 metres past the pressure pad. It has been shown that walking at fast speeds can significantly affect the magnitude and timing of plantar pressure measures while slower walking speeds provide more accurate measurements (Taylor et al., 2004). Therefore, participants were instructed to walk at a self-selected pace, as if strolling through a park (Mündermann, Dyrby, & Andriacchi, 2005). They were also asked to place only one foot on the pressure pad during each trial. The participants were given practice trials before the baseline data were collected.

Once the participants were familiar with the requirements, they performed five trials for each foot, although for the control participants, only the recordings for the dominant foot were assessed in the data analysis. This is a novel approach and was used to determine a baseline for what is considered normal in the dominant limb of healthy controls. The dominant limb was selected due to the fact that the participants in this study had injured what used to be their dominant limb prior to the injury. It has been found that at least 3 trials are needed for each foot
to provide sufficient reliability when measuring plantar pressures (Hughes et al., 1991).

Once baseline testing had been done, the participants with OA repeated the same walking tasks in the following conditions: wearing an ankle brace and not wearing an ankle brace. These conditions were randomised utilising a computer-generated number sequence. The researcher was blinded to this process as follows: Firstly, the researcher left the room between each testing condition. Secondly, the participants wore long socks and long pants to fully conceal their legs. This ensured that the researcher did not know when the brace was worn. A research assistant put the ankle braces on when needed. Prior to pressure pad trials, OA participants walked for a 10-minute period during which they assessed the comfort, stability and pain of the brace. For control participants, only the baseline testing was conducted and no braces were worn. An alpha numeric code was utilised when saving trial data to maintain the blinding of the researcher when undertaking data analysis.

Following the collection of PP measures, participants completed a Likert scale to determine their pain levels. There is a high correlation between results from Likert scales compared to the visual analogue scales, however, the Likert scale is easier to administer and interpret, making it preferable to the visual analogue scale when assessing those with OA (Bolognese, Schnitzer, & Ehrich, 2003). For this reason, 7-point Likert scales were used to assess ankle joint pain, perceived stability and comfort comparing the braced to the unbraced conditions of the ankle OA group.

**Braces**
The brace utilised was an elastic ankle support manufactured for Whiteley Allcare (AOA51 Allcare Ortho Elastic Ankle Support Auckland, NZ) and is available across New Zealand and Australia (see Figure 2). In addition to providing hindfoot support, it was chosen for its ease of application, positive anecdotal comments from patients with unstable ankles who had tried the brace, and the cost ($15). The elastic straps that wrap about the foot and ankle were tightened to a level that the participants believed was ‘firm’ but not painful.

Figure 2: Allcare Ortho Elastic Ankle Support

[AOA51 Allcare Ortho Elastic Ankle Support] Retrieved April 14, 2018 from
Statistical Analyses

Statistical analysis was conducted using SPSS software (IBM Corp. Released 2018. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.). Data were checked for issues related to undertaking parametric statistics and no violations were found. This involved Kolmogorov-Smirnov, Shapiro-Wilk and Grubbs tests. Pearson correlations coefficients were also calculated to establish whether mass of participants was associated with PTI and PP variables; and whether PTI, PP and contact time variables were correlated with one another. Thereafter, inferential testing involved the following procedures. For the foot function index, a dependent t-test was utilised to compare involved and uninvolved limbs. For the pressure measurements, to compare across involved limb, involved limb and brace, and uninvolved limb, a single factor repeated measures ANOVA with planned contrasts was performed. A comparison of the uninvolved limb and the control group limb was undertaken with an independent t-test.

Separate analyses were undertaken for each dependent variable. The variables of interest were (1) the ratio of the medial to lateral hindfoot for variables PTI and PP, (2) the average pressure across medial and lateral PTI and PP in the hindfoot, (3) the total contact time during total stance phase. For all analyses the alpha level was set at 0.05.
Chapter 4: Results

This section is divided into two sections. Section one provides a description of the participant demographics and the results from the Lower Limb Task Questionnaires, Foot Posture Index and the Brief Pain Inventory. Section two is where the plantar pressure measure results are found.

Participant Demographics, Pain and Function

The results reported in this chapter refer to data that was collected from 16 participants with ankle OA and 16 control participants. All participants who started the testing process also completed the testing.

There was no significant difference (p>0.05) in the ages, height, body weight or BMI between the ankle OA group and the control group. The LLTQ and BPI scores were only assessed in those with ankle OA, as the control participants did not have any ankle pain that would warrant doing these questionnaires. The mean LLTQ score seen in these results shows that the ankle OA participants found it mildly to moderately difficult to perform the activities of daily living. The SF-BPI scores seen in this study represent the average of the four pain ratings in the SF-BPI (see Table 1).
Table 1: Participant Demographics, Lower Limb Task Questionnaire and Average Pain Rating

<table>
<thead>
<tr>
<th></th>
<th>OA (n=16)</th>
<th>Control (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>68 ± 12</td>
<td>66 ± 12</td>
</tr>
<tr>
<td>Male: Female</td>
<td>11: 5</td>
<td>11: 5</td>
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<tr>
<td>Mass (kg)</td>
<td>81 ± 18</td>
<td>76 ± 14</td>
</tr>
<tr>
<td>Height (cm)</td>
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<td>BMI (kg/m²)</td>
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<td>27 ± 4</td>
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<tr>
<td>LLTQ (/40)</td>
<td>27 ± 6</td>
<td>N/A</td>
</tr>
<tr>
<td>SF-BPI Score (/10)</td>
<td>3.1 ± 1.3</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Values are group means and ± SD. Ratio of males to females are given. BMI = body mass index. LLTQ = lower limb task questionnaire. BPI = Brief Pain Inventory.

Foot Posture Index

The mean (SD) of the involved and uninvolved limbs were 4 (±4) and 2 (±4) respectively. Positive scores in this index are indicative of increased pronation, while negative scores indicate increased supination (Redmond, 1998). There was no significant difference (p>0.05) in the foot posture index (FPI) between the involved and uninvolved feet of those with ankle OA.
Plantar Pressure Measures in the Involved, Versus Uninvolved Side of the Ankle Osteoarthritis Participants

There was no significant difference (p>0.05) in the mean hindfoot PTI values between the involved, and the uninvolved limbs of the ankle OA participants (see Figure 3).

Figure 3: Medial and Lateral Hindfoot Pressure-Time Integrals Across Four Conditions
There was no significant difference (p>0.05) in the ratio of medial to lateral hindfoot PTI values between the involved, and the uninvolved limbs of the ankle OA participants (see Figure 4).

Figure 4: Ratio of Medial to Lateral Pressure-Time Integral in the Hindfoot Across Four Conditions
There was no significant difference (p>0.05) in the mean hindfoot PP between the involved, and the uninvolved limbs of the ankle OA participants (see Figure 5).

*Figure 5: Medial and Lateral Hindfoot Peak Pressure Across Four Conditions*
There was no significant difference (p>0.05) in the ratio of medial to lateral hindfoot PP between the involved, and the uninvolved limbs of the ankle OA participants (see Figure 6).

*Figure 6: Ratio of Medial to Lateral Peak Pressure in the Hindfoot Across Four Conditions*
There was a significant difference (p<0.05) in the contact time during stance phase between the involved and the uninvolved limbs in the ankle OA group. The contact time seen in the uninvolved limbs (mean: 837 ms), was significantly (p<0.05) longer than that of the involved limb (mean: 806 ms) (see Figure 7).

Figure 7: Contact Time of the Whole Foot During Stance Phase Across Four Conditions

Plantar pressure measures in the uninvolved side of ankle osteoarthritis participants versus healthy control participants
There was a significant difference (p<0.05) in the mean hindfoot PTI values between the uninvolved limb of the ankle OA group and the control group limb. The control group had a significantly lower PTI (mean: 75.5 kPa.sec) than the uninvolved side of the ankle OA group (mean: 104.1 kPa.sec) (see Figure 3). There was no significant difference (p>0.05) in the ratio of medial to lateral hindfoot PTI between the uninvolved limb of the ankle OA group and the control group limb (see Figure 4). There was no significant difference (p>0.05) seen in the mean hindfoot PP between the uninvolved limb of the ankle OA group and the control group limb (see Figure 5). There was no significant difference (p>0.05) in the ratio of medial to lateral hindfoot PP in the between the uninvolved limb of the ankle OA group and the control group limb (see Figure 6). There was a significant difference (p<0.05) in the contact time during stance phase between the uninvolved limb of the ankle OA group and the control group limb. Participants in the control group spent less time in stance phase (mean: 731 ms) than the uninvolved limbs of the ankle OA participants (mean: 837 ms) (see Figure 7).

Associations between plantar pressure measures and in relation to body mass

Pearson correlation coefficients showed that there were no significant associations (p>0.05) between peak pressure and body mass and the PTI and body mass. Additionally, there were no significant correlations (p>0.05) between PP and the PTI. Finally, there were no significant correlations between contact time and PP and PTI in the OA group.

The effects of bracing on plantar pressure measures in ankle OA participants
There was no significant difference (p>0.05) in the mean hindfoot PTI between the involved, and the involved braced conditions of the ankle OA group (see Figure 3). There was no significant difference (p>0.05) in the ratio of medial to lateral hindfoot PTI between the involved and the involved braced conditions of the ankle OA group (see Figure 4). There was no significant difference (p>0.05) in the mean hindfoot PP between the involved and involved braced conditions in the ankle OA group (see Figure 5). There was no significant difference (p>0.05) in the ratio of medial to lateral hindfoot PP between the involved and involved braced conditions in the ankle OA group (see Figure 6). There was a significant difference (p<0.05) in the contact time during stance phase between the involved braced and the uninvolved conditions of the participants with ankle OA. The contact time during stance phase of the involved braced condition (mean: 827 ms) was significantly (p<0.05) longer than that of the involved limb without the brace on (mean: 806 ms) (see Figure 7).

The effects of bracing on joint pain, perceived stability and comfort during walking in ankle osteoarthritis participants

When participants with ankle OA were asked how painful their ankle was during gait in the braced vs the unbraced condition, 43.8% reported no change, 31.3% reported some improvement and 25.1% reported some worsening with the brace (see Table 2). The participants who did not find the brace to increase stability, normally wore specialised orthotics.
Table 2: Perceived ankle pain during walking in the braced compared to the unbraced condition

<table>
<thead>
<tr>
<th>Scoring Category</th>
<th>Much Worse</th>
<th>Worse</th>
<th>Slightly Worse</th>
<th>No Change</th>
<th>Slightly Better</th>
<th>Better</th>
<th>Much Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Ankle</td>
<td>6.3%</td>
<td>0%</td>
<td>18.8%</td>
<td>43.8%</td>
<td>25%</td>
<td>0%</td>
<td>6.3%</td>
</tr>
</tbody>
</table>

When participants with ankle OA were asked how stable it was to wear the ankle brace during walking compared to not wearing it, 37.5% of participants found it to provide slightly better support, 25% found it to provide much better support, 12.5% found it to be better, another 12.5% found no change, 6.3% found the stability to be worse and the final 6.3% found the stability to be much worse (see Table 3).

Table 3: Perceived ankle stability during walking in the braced compared to the unbraced condition

<table>
<thead>
<tr>
<th>Scoring Category</th>
<th>Much Worse</th>
<th>Worse</th>
<th>Slightly Worse</th>
<th>No Change</th>
<th>Slightly Better</th>
<th>Better</th>
<th>Much Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Ankle</td>
<td>6.3%</td>
<td>6.3%</td>
<td>0%</td>
<td>12.5%</td>
<td>37.5%</td>
<td>12.5%</td>
<td>25%</td>
</tr>
</tbody>
</table>
When participants with ankle OA were asked how comfortable it was to wear the ankle brace during walking compared to not wearing it, 31% found their comfort levels to be slightly better, another 31.5% found their comfort levels to be slightly worse, 18.8% found the brace to provide better comfort, 12.5% found their comfort levels to be much better and 6.3% found their comfort levels to be much worse when wearing the brace (see Table 4).

*Table 4: Perceived ankle comfort during walking in the braced compared to the unbraced condition*

<table>
<thead>
<tr>
<th>Scoring Category</th>
<th>Much Worse</th>
<th>Worse</th>
<th>Slightly Worse</th>
<th>No Change</th>
<th>Slightly Better</th>
<th>Better</th>
<th>Much Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Ankle</td>
<td>6.3%</td>
<td>0%</td>
<td>31.3%</td>
<td>0%</td>
<td>31.3%</td>
<td>18.8%</td>
<td>12.5%</td>
</tr>
</tbody>
</table>
Chapter 5: Discussion and Conclusion

The results of the study are discussed in this chapter. First, the participant demographics, function, pain and FPI are explored. Next, the plantar pressures that are commonly measured between limbs in the ankle OA group are discussed and compared to studies that have undertaken research in this area. Although not commonly assessed, the PTI is included here for flow. This is followed by between-group comparisons. Associations between plantar pressure measures and how they relate to body mass are then explored. The novel measurements of this study are then discussed, namely, the ratios of medial to lateral PTI and PP the as well the effects of bracing on plantar pressure in those with ankle OA. Following this is an exploration of the effects bracing has on joint pain, perceived stability and comfort during walking. Included within this chapter are the limitations, practical applications of this research, as well as future directions and conclusion. Supporting, as well as contrasting literature is used throughout this discussion. From this, the ramifications of the results of this study are explored.

Participant Demographics, Function and Pain

The mean age of the ankle OA participants in this study was 67.63 years and the control participants was 66.38 years. This is slightly higher than other studies, where the typical age range for those with end-stage ankle OA is 52.9 years to 59.5 years (Horisberger et al., 2009; Valderrabano et al., 2006, 2007). The mean pain ratings of the average scores for all four
pain ratings in the SF-BPI for those with ankle OA was 3.1. The pain rating of the present population was markedly lower than those recorded in other studies, where ankle OA participants had pain scores of 6.6 to 6.8 out of 10 on the visual analogue scale at the time of examination (Horisberger et al., 2009; Valderrabano et al., 2006). Even averaging of the average pain rating from the SF-BPI gives the participants of this study a pain rating of 3.5, which is still markedly lower than what the other studies mentioned. The examinations undertaken by Horisberger et al. (2009) and Valderrabano et al. (2006) involved range of motion testing of the ankle joint such as dorsiflexion, plantarflexion, inversion and eversion. It is unclear if the visual analogue scores in the studies by Horisberger et al. (2009) and Valderrabano et al. (2006) were taken before or after these examinations. If they were taken after the range of motion testing, the ankle movements could have caused sufficient pain to increase the scores of the participants. The lower pain ratings seen in this study may be due to an age-related decrease in activity compared to the younger populations in the studies by Valderrabano et al. (2006) and Horisberger et al. (2009). A systematic review has noted that those over the age of 60 are less likely to be physically active than adults under the age of 60 years (Sun, Norman, & While, 2013). Decreasing the physical activity and therefore decreasing the amount of time the ankle joint is loaded for may explain the decreased pain levels of the participants in the current study.

Alternatively, the lower pain ratings seen in this study may be because most of the participants were recruited through newspapers as opposed to people seeking medical care. Most individuals actively seeking medical care for OA do so because they are in pain (Vallerand, 2003). The present population descriptively scores lower on pain levels compared to the study by Horisberger et al. (2009) which may explain the difference in
plantar pressure measures seen between the studies. Previously, high levels of pain in the foot and ankle region have been associated with increased plantar pressure measurements (Mickle et al., 2010).

While pain medications were recorded for participants with ankle OA, the analysis of these medications and how they affected the pain levels of this sample were beyond the scope of this study. However, it has been noted that long-term (<180 days) use of non-steroidal anti-inflammatory use in those with OA decreases the overall pain (Girbes, Nijs, Torres-Cueco, & Cubas, 2013; Reijman et al., 2005). Further examination of the medications taken by the current sample may help to explain the low pain ratings seen in the current sample.

Foot Posture Index

There was no trend in the types of foot posture seen in the ankle OA participants of this study. This differs from the study by Horisberger et al. (2009), where radiographical tibiotalar alignment and the resulting foot posture, showed that 60.9% of their ankle OA participants to have varus alignment, resulting in supination of the foot, with 30% showing a normal alignment and the final 9.1% a valgus alignment, resulting in pronation of the foot. While the parameters of the current study did not allow for the assessment of the radiographical findings of those with ankle OA, the FPI does identify pronated, supinated and the neutral feet (Cornwall, McPoil, Lebec, Vicenzino, & Wilson, 2008; Redmond et al., 2008). Aging processes have been noted to cause biomechanical changes within the foot, altering the FPI of the individuals (Said, Justine, & Manaf, 2016) and could be a factor in this study. Horisberger
et al. (2009) identifies the malalignment seen in their ankle OA population as being a factor that affected their plantar pressure measures. If this is indeed a factor, it is not surprising that few significant results were seen in the current study.

Plantar Pressure Measures in the Involved, Versus Uninvolved Side of the Ankle Osteoarthritis Participants

Hindfoot Peak Pressure in the Involved, Versus Uninvolved Side of the Ankle Osteoarthritis Participants

While the difference did not reach significance, the involved limb demonstrated a higher hindfoot PP (395.39 kPa), compared to the uninvolved limb (357.44 kPa). In contrast, a previous study found that the uninvolved limb had an average of 311 kPa in the hindfoot while the involved limb had an average of 279.6 kPa (Horisberger et al., 2009). This was interpreted as indicating an attempt by the participant to reduce load through the ankle, and subsequently decrease pain during walking (Horisberger et al., 2009). Even though the difference seen in the current study is not significant, the higher PP values may be due to the older population (mean age 67.63 years) compared to the study by Horisberger et al. (2009) (mean age 59.5 years) as it has previously been established that older populations have higher PP (Redmond et al., 2008). However, these comparisons cannot be interpreted meaningfully as the difference in hindfoot PP did not differ significantly between the involved and uninvolved limbs of those with ankle OA. Increased walking speed, which has been found to increase hindfoot PP (Taylor et al., 2004), is another factor that may account for the results seen in this study.
The lack of significant difference in PP between the involved and uninvolved limbs is suggestive of a bilateral gait adaptation that may be related to more advanced ankle OA, or differing pain levels compared to the participants in the study by Horisberger et. al (2009). If indeed, bilateral gait adaptations exist in older individuals with ankle OA, it may explain the PP results of this study. More studies looking at the changes in the PP during different stages of ankle OA and at different ages are needed to further test this hypothesis.

Whole Foot Contact Time in the Involved, Versus Uninvolved Side of the Ankle Osteoarthritis Participants

The contact time of the uninvolved limb was significantly longer (mean: 837 ms) than that of the involved limb without a brace (mean: 806 ms). The difference seen in the current study is in line with the study by Horisberger et al. (2009), where the contact time of the involved limb is significantly shorter (mean: 991.5 ms) than the uninvolved limb (mean: 1019 ms). The differences seen between the limbs in both studies suggest that those with ankle OA alter their gait, potentially to decrease pain levels. Even though the trend of the contact time is similar between the studies, the current study suggests a shorter CT overall compared to the study by Horisberger et al. (2009). This may be because the participants in this study were walking at a faster walking speed than the participants in the study by Horisberger et al. (2009), as increased gait speeds result in shorter contact times (Taylor et al., 2004).

Another explanation for the decreased CT seen in the involved limb compared to the
uninvolved limbs is the decrease in plantar flexion characteristically seen in those with ankle OA (Schmitt, Vap, & Queen, 2015). This limitation in movement means that those with ankle OA have decreased stride length, thereby decreasing the CT of the involved limb (Jomha et al., 2013; Leardini, O'Connor, & Giannini, 2014).

Hindfoot Pressure-Time Integral in the Involved, Versus Uninvolved Side of the Ankle Osteoarthritis Participants

Measuring the PTI value is a novel variable to be tested in those with ankle OA. Since PTI is suggested by some to correlate with PP (Keijzers et al., 2010), it is not surprising that there are no significant differences in the PTI values between limbs in the ankle OA group of this study. The lack of difference in the PTI between the limbs may suggest bilateral changes in the loading pattern of both the affected and unaffected limbs of those with ankle OA. An additional explanation may be due to minimal pain levels seen in the involved limb. Elevated foot pain has been shown to increase the PTI values of those over the age of 65 years (Mickle et al., 2010) meaning that the level of pain experienced by the participants in this study may not be enough to influence the PTI measures.

Plantar Pressure Measures in the Uninvolved Side of Ankle Osteoarthritis Participants Versus Healthy Control Participants

Hindfoot Pressure-Time Integral in the Uninvolved Side of Ankle Osteoarthritis Participants
Versus Healthy Control Participants

The control participants in this study had a mean PTI value of 75.5 kPa.sec in the hindfoot, which is significantly lower than the uninvolved limbs of the ankle OA participants (104.1 kPa.sec). It may be that the different PTI values seen in those with ankle OA indicate a gait adaptation that may predispose them to developing contralateral foot and ankle problems (Schmitt, Vap, & Queen, 2015). Alternatively, these changes could reflect an inherent bilateral difference in the gait pattern that increases the loading of the hindfoot and ankle which may be a risk factor for these individuals developing ankle OA in the first place (Schmitt, Vap, & Queen, 2015; Valderrabano et al., 2007).

It has been shown that healthy individuals over the age of 60 years demonstrate a higher PTI value in the hindfoot (101.7 kPa.s. for males and 93.0 kPa.s. for females) compared to younger populations of 20-59 years, where males on average have an average PTI value of 93.8 kPa.s. and females 85.2 kPa.s. in the hindfoot (McKay et al., 2017). This means that the healthy control participants in the current study demonstrated much lower PTI values in the hindfoot than either the younger or older adult group in the study by McKay et al. (2017). This may indicate a variety of factors, such as a difference between populations in differing countries, differing activity levels or everyday fitness or genetic variabilities.

Ankle OA participants in this study had more comparable results to the healthy participants in the study by McKay et al. (2017). This may be related to gait speed, as the participants in the current study were asked to walk at a relaxed pace, which may have been slower than the participants in the study by McKay et al. (2017). Faster walking speeds have been shown to
increase PTI values in older participants (Keijsers et al., 2010). However, as noted previously, slower walking speeds have been shown to be necessary for accurate measurements of PTI to be made (Taylor et al., 2004). Ankle OA was not specifically noted to be an exclusion criterion for participants in the study conducted by McKay et al. (2017). Instead, anyone who was healthy by self-report, able to participate in age-appropriate activities, did not have health conditions such as diabetes mellitus, neurological disorders or infectious or inflammatory arthropathies and a BMI $\geq 40$ kg/m$^2$ was able to participate (McKay et al., 2017). This means that some of these participants may have been suffering from degenerative conditions such as OA that influenced the PTI values and may help to explain the differences seen between the studies.

**Hindfoot Peak Pressure in the Uninvolved Side of Ankle Osteoarthritis Participants Versus Healthy Control Participants**

There was no evidence of significant changes in the mean hindfoot PP measures in the uninvolved limb of the ankle OA group (357.44 kPa) compared to the control limb (332 kPa). The hindfoot PP seen in the control participants of this study (332 kPa) are like the results of the healthy participants in the study by McKay et al. (2017), where males had mean hindfoot PP of 356.7 kPa and females 319.9 kPa. This does not support the hypothesis that there is a difference in the loading patterns between those with ankle OA and those without. However, it does show that there is added value to reporting both the PTI and PP measures, which is a topic that has been widely debated (Bus & Waaijman, 2013; Keijsers et al., 2010).
Whole Foot Contact Time in the Uninvolved Side of Ankle Osteoarthritis Participants Versus Healthy Control Participants

The control group limb spent less time in stance phase (mean: 731 ms) compared to the uninvolved limb (mean: 837 ms). This could mean that the control participants were walking faster than those with ankle OA. Walking speed was not analysed in this study, however, it was previously noted that those with ankle OA have reduced walking speeds compared to those without ankle OA (Horisberger et al., 2009; Valderrabano et al., 2007). Increased ankle range of motion, as seen in those without ankle OA, may result in the ability to offload the hindfoot faster than those with ankle OA (Valderrabano et al., 2006).

Altered neuromuscular control, decreased strength and atrophy of the muscles acting on the ankle joint is commonly seen in those with ankle OA (Hubbard et al., 2009; Valderrabano et al., 2006). These factors may result in the ankle OA group feeling unstable when loading their involved limb, and may cause them to want to step off their involved limb faster than the healthy controls.

Associations Between Plantar Pressure Measures and in Relation to Body Mass

The results suggest that there is no association between body mass and either PP or PTI or
between PP and the PTI. The implication of these results is that there is not a strong relationship between body mass and PP or PTI and that differences observed in PTI between the uninvolved limb of the ankle OA participants and healthy controls is unlikely to be related to differences in body mass. This finding is supported by results from the study by Horisberger et al. (2009), who did not find a correlation between BMI and either PP or PTI in the hindfoot. Having no association between PP and PTI adds further evidence that there is value in reporting both measures, particularly when studying ankle OA.

The Effects of Bracing on Plantar Pressure Measures in Ankle Osteoarthritis

Participants

The Effects of Bracing on Hindfoot Pressure-Time Integral

Results suggest that wearing an ankle brace for a short period of time and/or over short walking distances does not affect the PTI in the hindfoot. It may take longer than 10 minutes of walking for the pressure to change within the foot and/or for the foot to adapt to the brace enough to alter the PTI. As the PTI is the area under the peak pressure in a given mask over time (“Novel Scientific Medical Manual,” 2012), it can be deduced that the variables needing to change in order for a difference to be seen would be the pressure and contact time of the given mask. It would be possible for both factors to change slightly without changing the overall value. For instance, if the pressure were slightly decreased and the contact time slightly increased when wearing the brace, the result may be like the value generated before
wearing the brace and may be likely since contact time was increased. No studies have assessed the effects of ankle braces on the PTI measures. Given the size of this topic and the multiple variables which still need exploring, conclusions cannot be made at this early stage of development.

The Effects of Bracing on Hindfoot Peak Pressure

The lack of change in PP when wearing the ankle brace may also indicate different adaptation strategies to the brace, making it difficult to generalise either across the small population, or with the short timeframe and distance walked. It has been suggested that mechanical and neuromuscular adaptation times to external structures acting on the foot and ankle (such as braces) are highly individualised (McLaughlin, Chowdary, Woledge, McCarthy, & Mayagoitia, 2013). This may explain the results of this study. Novelty of wearing the brace may have also been a factor at play here. It may be that because participants were not previously familiar with the brace used or the research setting, that they were more acutely aware of their involved limb and the brace when walking, thereby influencing the way they load their foot. Future studies that wish to assess change in PP with bracing may want to increase the length of time spent wearing the brace, as well as the distance walked.

The Effects of Bracing on Contact Time
The CT of the involved braced condition (mean: 827 ms) was significantly longer than the unbraced condition of the involved limb (mean: 806 ms). This may be clinically important, as it shows that there is an immediate effect of ankle braces on contact time, which trend towards individual normalisation compared to the uninvolved side. These results suggest that without the brace, those with ankle OA compensate when walking by reducing their contact time compared to the uninvolved limb. This may be due to a protective mechanism, where those with ankle OA are wanting to protect the involved limb by loading it for less time, and may be an attempt to decrease pain (Horisberger et al., 2009).

The increase in contact time when wearing the ankle brace may also mean that there was an overall increase in the load of the ankle and foot. This is potentially detrimental, despite the increases in perceived stability as it could be further damaging the ankle cartilage and causing more impingement where there are osteophytes present (Bhatia, 2014). Similar effects have been seen with the use of nonsteroidal anti-inflammatory drugs in OA management, where pain relief is suggested to result in an increase in activity and subsequent loading of the OA joint, leading to further degeneration and a quickening of the disease process (Reijman et al., 2005).

**Ratio of Medial to Lateral Pressure-Time Integral in the Hindfoot**

The current study found no significant difference in the medial to lateral ratio of the hindfoot PTI between the involved limb of those with ankle OA and the control group limb. This is interesting, as the ratio of medial to lateral PTI is normally used to determine the medial to
lateral load changes in structural and functional conditions, and is an indicator for dynamic balance issues (Deschamps, Roosen, Bruyninckx, Desloover, Kaat, Deleu et al., 2013). There are no studies looking at the ratio of medial to lateral PTI in those with ankle OA. What these results indicate however, is that there may be no change in the medial to lateral loading during walking in those with ankle OA.

This may be due to differences in the exact joint surface location of the ankle OA between participants. If some participants had more damage to the medial aspect of the joint, their loading pattern may be different to other participants, who may have more damage to the central or lateral aspects of the joint. There is currently no research that has assessed this possibility.

**Ratio of Medial to Lateral Peak Pressure in the Hindfoot**

This study showed no significant difference in the ratio of medial to lateral PP between the involved, involved braced and the uninvolved conditions or between the uninvolved limb and the control group limb. This means that there was no change or no significant change in the medial to lateral peak pressure distribution when walking. As mentioned above, this may relate to heterogeneity in foot posture and the distribution of structural changes in the OA joint. There are currently no other studies that have assessed the ratio of medial to lateral PP in those with ankle OA, so further research is needed in this area to better understand the changes in loading patterns. Changes in ankle alignment may be a factor that affects the ratio of medial to lateral loading within the joint. An increase in eversion has been shown to shift
the contact within the ankle joint laterally, and vice versa for inversion (Kura, Kitaoka, Luo, & An, 1998). These changes might explain why there is no difference between the uninvolved limb of those with ankle OA and the control participants. It is not known if there is a difference between the medial to lateral PTI ratio in the whole foot. The hindfoot was chosen specifically for this study, as it was thought to present the greatest change due to the closest proximity to the joint affected. Since there was no significant difference seen in the FPI measures within the ankle OA group tested, there was no true foot posture pattern identified for the ankle OA group, which may help explain the lack of differences in the ratios of medial to lateral PTI or PP.

The Effects of Bracing on Perceived Joint Pain, Stability and Comfort During Walking in Ankle Osteoarthritis Participants

Perceived Pain

To the author’s knowledge, this is the first study to assess the effects of an ankle brace on pain. When asked how painful their ankle was when walking with the brace on compared to walking without the brace, many people found no difference in their ankle pain while some improved and some worsened. The lack of change in many of the participants may be due to the short nature of the intervention and these participants may require longer to notice an effect. The reasons some people felt a decrease in pain while others felt an increase in pain may come down to the effect of the brace on loading. Individual differences in the structural damage of the joint and differences in walking patterns are factors that determine changes in
pain levels (Weatherall et al., 2013). Joint pain would have been likely to worsen in the second 10-minute block of walking compared to the first 10-minute block due to the cumulative loading of the joint. If so, this could help to explain the heterogenous effects of the bracing, where those randomised to wear the brace in the second block of walking may find their joint pain worse. This may be largely due to the order they received the intervention in and cumulative loading, rather than the effects of the brace. The OA pain associated with repetitive loading of the ankle joint is thought to be due to stretching of the joint capsule, increased pressure on the subchondral bone and the presence of osteophytes causing impingement (Huang et al., 2006).

Perceived Stability

Most participants (75%) said that to some extent, the brace provided them with improved stability when walking compared to the unbraced condition. This may be due to a combination of factors such as the ankle brace restricting excessive movement at the joint and improving neuromuscular control (Pavailler et al., 2016; Shine & Bongiovanni, 2009). However, the exact reason for the increased support is not known due to joint range of motion or neuromuscular control being beyond the parameters of this study. Having said this, it has been found that ankle braces further reduce the plantarflexion and dorsiflexion motion of the ankle joint in those with ankle OA (Distefano, Padua, Brown, Atc, & Guskiewicz, 2008; Huang et al., 2006). However, if the braces used in the studies by Distefano et al. (2008) and Huang et al. (2006) resulted in decreased range of motion, it is plausible to deduce that the
brace used in this study might also reduce the range of motion at the ankle joint.

Another way in which the ankle brace is thought to provide stability is by enhancing the cutaneous and joint mechanoreceptors, thereby influencing neuromuscular control (Barlow et al., 2015), which could increase stability as subjectively perceived by participants.

The participants who normally wore specialised orthotics might have found the brace to decrease or not improve stability because the transition from wearing supportive shoes to just wearing an elastic brace with a wrap-around strap with socks was a downgrade in stability for some. This may help to explain why one of the participants did not think the ankle brace provided any support.

Perceived Comfort

Most of the ankle OA group (62.6%) found some level of comfort with wearing the brace, compared to not wearing it. One of the factors that influenced the selection of this brace was that it is soft and is not bulky. Factors such as comfort and having a low profile, as already noted, help to increase the compliance rates of patients (Shine & Bongiovanni, 2009). One limitation however, is that the sizing of the brace was quite small. This meant that the extra-large braces were used in most cases. Those who found the brace to be uncomfortable had larger feet or there was oedema present. In these cases, even the largest braces were a little too tight. This was reflected in the comfort as well as the pain levels experienced by these participants.
Limitations

Limitations of this study include the small sample size (n=16), which was close to providing sufficient power for significant results to be observed (if there were differences), particularly in the plantar pressure measures across limbs in those with ankle OA. Due to unforeseen absences and exhaustive use of recruitment processes, the target sample size (n=17) was not able to be achieved in the allocated timeframe. The study was not sufficiently powered to assess differences between the ankle OA participants and healthy controls. Despite this, the current data provides valuable information showing that larger sample sizes are needed in future research to more accurately assess such a comparison.

This study’s ankle OA sample was around ten years older than the average end-stage ankle OA population (Horisberger et al., 2009; Valderrabano et al., 2006, 2007). This may be due to the recruitment strategy behind the study. The most success was recruiting through retirement villages and newspapers, with a few participants being recruited through specialists. The retirement villages and newspapers naturally mean that the participants are slightly older. The social media platforms used (Facebook) was less successful in the recruitment process. This, in addition to reasons already discussed, may be why the participants in this current study are slightly older than that of other studies. However, this study does support the other literature claiming that age may be an important factor influencing PP and PTI measures (McKay et al., 2017; Mickle et al., 2010).
Another limitation of this study is that only two plantar pressure measures were assessed, with other measures such as mean pressure, instant of peak pressure and contact area not being analysed due to size constraints of the study and the need to limit the number of statistical tests undertaken. Contact time of the hindfoot was not measured in the current study. This was due to equipment limitations, where the highest sampling rate of 50 Hz was unable to provide accurate estimates of the parameter.

Ankle range of motion was not assessed. This could aid in the understanding of CT in all comparisons and the effect of the ankle brace on perceived stability. There was no room in the study to allow for the assessment of radiological findings to identify hindfoot alignment in those with ankle OA.

The order effect of the bracing intervention was not analysed in this study. This would have provided a better appreciation of the effect bracing had on the ankle, as well as determine if putting the brace on immediately before walking provides any benefit. Future studies should consider this when testing braces in this population.

**Future Directions**

Larger sample sizes are needed for between limb comparisons in the ankle OA population (n≥17) and even more when making between group assessments, such as ankle OA groups to healthy controls. Future studies should be done where the ankle braces are assessed over a
longer period of time and over longer distances, to see if they affect the plantar pressure measures of those with ankle OA. To better assess the long-term influence of ankle braces on the pain, stability, comfort and plantar pressure measures in those with ankle OA, future studies should compare the use of an ankle brace in an ankle OA intervention group compared to an ankle OA control group. There is a need for further research to assess the influence of ankle braces on healthy control participants compared to those with ankle OA, with the aim of assessing the degree of change within the plantar pressure measures.

Hindfoot alignment should be assessed radiographically to be able to better compare the plantar pressure measures and ratios of those measures in those with ankle OA. Future studies should also aim to match the medial to lateral ratios to individual areas of joint damage to better understand the specific loading patterns in those with ankle OA when specific areas of the joint are affected. Medial to lateral ratios could also be assessed when the participants walk on uneven surfaces, such as up and down slopes and across slopes.

More plantar pressure measures including, but not limited to mean pressure, instant of peak pressure and contact area should be studied comparing brace to unbraced condition within the ankle OA population as well as between those with ankle OA and healthy individuals. The plantar pressure measures should be assessed in the whole foot, to determine if there are loading changes associated with ankle OA in older populations with ankle OA as well as when testing ankle braces. Gait analysis should be undertaken in older individuals with ankle OA compared to younger individuals with ankle OA to see if gait related changes occur with disease progression.
Practical Application

Ankle braces can be used clinically to provide a conservative way of managing some cases of ankle osteoarthritis. This study demonstrates that an inexpensive, commercially available soft ankle brace can be used to improve perceived ankle stability when walking and significantly increases the contact time of the involved foot during stance phase. It may also improve ankle pain during walking in some, but not all patients, compared to walking without a brace and is often perceived as more comfortable to wear than walking without a brace. However, as with any intervention or management plan, the degree of success is dependent on the individual and should be considered on a case-by-case basis.
Conclusion

More studies are needed to provide conclusive results about the difference in plantar pressure measures between limbs in those with ankle OA, between those with ankle OA and healthy individuals and to determine the effect of a brace on plantar pressures. The use of an ankle brace has potential to provide an affordable management option for individuals suffering from ankle OA, with fewer side effects than medication commonly used in the management of OA. Although not an aim of this research, the study does suggest there is value in reporting both the PTI and PP values when studying plantar pressure changes in those with ankle OA. The results of this study suggest that older individuals with ankle OA may represent bilateral gait adaptation, although further investigation is needed.
References


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6. Retrieved from

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http://doi.org/10.1016/j.gaitpost.2015.07.005


http://doi.org/10.1038/nrrheum.2010.159


Shiozawa, S., Hirata, R. P., & Graven-Nielsen, T. (2015). Center of pressure displacement of standing posture during rapid movements is reorganised due to experimental lower
http://doi.org/10.1371/journal.pone.0144933


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http://doi.org/10.1016/j.foot.2003.09.004


Valderrabano, V., Tscharner, V. von, Nigg, B. M., Hintermann, B., Goepfert, B., Fung, T. S.,


Appendix A

Results

Your selections

Claim type: All claims
Account type: All
Age when injured: All
Gender: All
Body part that was injured: Ankle
Cause of the injury: All
Diagnosis of the injury: All
Show sport-related injuries only: No
Scene of the injury: All
Region of New Zealand: All

Claims and total costs

<table>
<thead>
<tr>
<th>Financial year</th>
<th>New claims</th>
<th>Active claims</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul 2012 - Jun 2013</td>
<td>117,710</td>
<td>144,306</td>
<td>$105,848,481</td>
</tr>
<tr>
<td>Jul 2015 - Jun 2016</td>
<td>128,724</td>
<td>158,796</td>
<td>$141,015,391</td>
</tr>
</tbody>
</table>

This data is current as of 29 April 2017.
Appendix B

Results

Your selections

- Claim type: All claims
- Account type: All
- Age when injured: All
- Gender: All

<table>
<thead>
<tr>
<th>Body part that was injured: Ankle</th>
<th>Cause of the injury: Folding/Collapse, Lifting/Carrying/Strain, Object Coming, Locomotion/Shift, Pushed or Pulled, Skid, Struck by Person/Animal, Twisting/Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show sport-related injuries only: No</td>
<td>Diagnosis of the injury: Fracture / Dislocation, Gradual Onset, Soft Tissue Injury</td>
</tr>
<tr>
<td>Scene of the injury: All</td>
<td>Region of New Zealand: All</td>
</tr>
</tbody>
</table>

Claims and total costs

<table>
<thead>
<tr>
<th>Financial year</th>
<th>New claims</th>
<th>Active claims</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul 2012 - Jun 2013</td>
<td>38,922</td>
<td>46,506</td>
<td>$26,630,584</td>
</tr>
<tr>
<td>Jul 2013 - Jun 2014</td>
<td>38,139</td>
<td>47,532</td>
<td>$28,605,086</td>
</tr>
<tr>
<td>Jul 2014 - Jun 2015</td>
<td>43,648</td>
<td>52,290</td>
<td>$33,566,701</td>
</tr>
<tr>
<td>Jul 2015 - Jun 2016</td>
<td>44,247</td>
<td>63,616</td>
<td>$38,662,732</td>
</tr>
<tr>
<td>Jul 2016 - Jun 2017</td>
<td>47,796</td>
<td>51,010</td>
<td>$41,122,931</td>
</tr>
</tbody>
</table>

This data is current as of 29 April 2017.

Notes:

- These statistics are approximate. If you need data for research or analysis, contact:
  Email: statistics@bnc.co.nz
- ≤ 3 means that the cell contains less than or equal to three claims. We’ve removed this data to protect the privacy of our clients.
My name is Kendyl Roodt. I am currently enrolled in the Master of Osteopathy degree in the Department of Osteopathy at Unitec New Zealand and seek your help in meeting the requirements of research for a Thesis course which forms a substantial part of this degree.

**Research Project Title**

Plantar pressure parameters associated with ankle osteoarthritis during balance tasks and the immediate effects of an ankle brace.

**Synopsis of project**

Osteoarthritis of the ankle is a major problem affecting quality of life and balance in those who suffer from the condition. Osteoarthritis of the ankle normally affects those who have a history of ankle trauma and the number of people who suffer from the condition is rising and is expected to continue rising over the coming years. By participating in this research project, you are helping researchers figure out the differences between the way pressure is distributed through the feet of those who suffer from the condition and those who don’t. This provides valuable information that will help shape the way osteoarthritis of the ankle is managed in the future.
The primary aim of this project is to assess the difference in plantar pressure measures (the way in which pressure is distributed in the soles of the feet) between participants with ankle osteoarthritis and those without. The secondary aim is to determine the extent to which an external brace effects these same plantar pressure measures as well as perceived pain and support in people with osteoarthritis of the ankle.

**What we are doing**

This project will be run by a student researcher (Kendyl Roodt) and a research assistant who will work under the guidance of three supervisors.

In this project, the researcher and research assistant will gather data related to the pressure distribution through the soles of the feet with the aim of assessing the difference between participants with osteoarthritis of the ankle joint and those without. The pressure distribution will be measured on a pressure pad. In addition, we aim to determine the effects of an ankle brace on the same pressure distribution as measured above as well as on the perceived support and comfort ratings.

**What it will mean for you**

Participation in this study requires you to provide informed consent to undertake a simple set of walking and balance tasks and participate in the study as it is detailed below.

If you are in the osteoarthritis group, you will be asked to fill out a few questionnaires relating to ankle function, stability and pain. The researchers will measure the amount of movement that you have at your ankle joints. Your height and weight will also be recorded.

You will then be asked to undertake a series of walking and balance tasks on a pressure pad, which is where the pressure distribution is going to be measured, once with a soft ankle brace on, and once without a brace on. The whole process will be done in a single session.
and will take approximately one to one and a half hours to complete.

If you agree to participate, you will be asked to sign a consent form. This does not stop you from changing your mind if you wish to withdraw your results from the project while you are being tested. However, because of our schedule, any withdrawals must be done either before or immediately after the completion of data collection.

Your name and information that may identify you will be kept completely confidential. All information collected from you will be stored on a password protected file and only the two researchers and our supervisors will have access to this information. Neither you nor your organisation will be identified in the Thesis. The results of the research activity will not be seen by any other person in your organisation without the prior agreement of everyone involved.

I hope that you find this invitation to be of interest. If you would like more information on this research project, then please contact the student researcher or supervisor:

Student researcher:

Kendyl Roodt

Phone +64 27 9511494 or

Email: kenkat@netz.co.nz

Supervisor:

Dr Peter McNair

Phone +64 9 921 9999 ext 7143 or

Email: peter.mcnair@aut.ac.nz
UREC REGISTRATION NUMBER: 2016-1080 This study has been approved by the UNITEC Research Ethics Committee from 8.12.16 to 8.12.17. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 8551). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Appendix D

Kellgren-Lawrence Grading Scale

Grade 1: doubtful narrowing of joint space and possible osteophytic lipping

Grade 2: definite osteophytes, definite narrowing of joint space

Grade 3: moderate multiple osteophytes, definite narrowing of joints space, some sclerosis and possible deformity of bone contour

Grade 4: large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone contour
Appendix E

Kendyl Roostt
25 Mollusc Road
Hobsonville
Auckland, 0618
8.12.16

Kia ora Kendyl,

Your file number for this application: 2016-1080
Title: Plantar pressure parameters associated with ankle osteoarthritis during balance tasks and the immediate effects of an ankle brace

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 8.12.16
Finish date: 8.12.17

Please note that:
1. The above dates must be referred to on the information AND consent forms given to all participants.
2. You must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.

You may now commence your research according to the protocols approved by UREC.
We wish you every success with your project.

Yours sincerely,

[Signature]
Nigel Adams
Deputy Chair, UREC

cc: Megan McEwan
Cynthia Almeida
Appendix F

23 February 2017

David Rice

Faculty of Health and Environmental Sciences

Dear David

Ethics Application: 17/16  **Plantar pressure parameters associated with ankle osteoarthritis during balance tasks and the immediate effects of an ankle brace.**

Thank you for submitting your application for ethical review. I am pleased to confirm that the Auckland University of Technology Ethics Committee (AUTEC) has approved your ethics application for three years until 20 February 2020.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through [http://www.aut.ac.nz/researchethics](http://www.aut.ac.nz/researchethics). When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 20 February 2020;

- A brief report on the status of the project using form EA3, which is available online through [http://www.aut.ac.nz/researchethics](http://www.aut.ac.nz/researchethics). This report is to be submitted either when the approval expires on 20 February 2020 or on completion of the project;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the
parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O’Connor

Executive Secretary

Auckland University of Technology Ethics Committee

Cc:  mmcewen2@unitec.ac.nz; kenkat@netz.co.nz; Peter McNair
Participant Consent Form

**Research Project Title:**

Plantar pressure parameters associated with ankle osteoarthritis during balance tasks and the immediate effects of an ankle brace

*I have had the research project explained to me and I have read and understand the information sheet given to me.*

I understand that I do not have to be part of this research project should I chose not to participate and that I may withdraw at any time prior to the completion of the data collection.

I understand that:

- Everything I say is confidential
- I consent to provide the researchers with honest and accurate information and will continue to throughout the study.
- I will be required to undergo a balance test, taking one leg off the ground and completing a 10 – 15 minute walk which may cause me some discomfort.
• That none of the information I give will identify me.

• I consent to the researchers contacting my orthopaedic surgeon/GP to obtain x-ray results.

• The only persons who will have access to the information I provide will be the researchers and their supervisor as well as potentially other participants if they undertake the testing at the same time as me.

• All the information that I give will be stored securely on a computer at Unitec for a period of ten years.

• I consent to the research being published and the results of this research project being used for future investigations.

For participants with ankle osteoarthritis:

• In addition to the above, I consent to the researchers contacting my orthopaedic surgeon/GP to obtain copies of my x-rays and their results.

I understand that I am able to request a copy of the finished research document if I wish to see it.

I have had time to consider everything and I give my consent to be a part of this project.

Participant Name: ……………………………………………………………………....
UREC REGISTRATION NUMBER: 2016-1080

This study has been approved by the UNITEC Research Ethics Committee from 8.12.16 to 8.12.17. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 8551). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
## Foot Posture Index Datasheet

**Patient name**

**ID number**

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>PLANE</th>
<th>SCORE 1</th>
<th>SCORE 2</th>
<th>SCORE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Date</td>
<td>Date</td>
<td>Date</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comment</td>
<td>Comment</td>
<td>Comment</td>
</tr>
<tr>
<td>Tuberous pyramidal</td>
<td>Transverse</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Curves above and below the lateral malleolar</td>
<td>Frontal/</td>
<td>-2 to +2</td>
<td>-2 to +2</td>
<td>-2 to +2</td>
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<tr>
<td>Transverse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inversion/eversion of the calcaneus</td>
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<td>Left</td>
<td>Right</td>
<td>Left</td>
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<tr>
<td>Transverse</td>
<td></td>
<td>-2 to +2</td>
<td>-2 to +2</td>
<td>-2 to +2</td>
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<tr>
<td>Prominence in the region of the TNG</td>
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<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Transverse</td>
<td></td>
<td>-2 to +2</td>
<td>-2 to +2</td>
<td>-2 to +2</td>
</tr>
<tr>
<td>Congruence of the medial longitudinal arch</td>
<td>Sagittal</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Transverse</td>
<td></td>
<td>-2 to +2</td>
<td>-2 to +2</td>
<td>-2 to +2</td>
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<tr>
<td>Adduction foot on rearfoot</td>
<td>Transverse</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Transverse</td>
<td></td>
<td>-2 to +2</td>
<td>-2 to +2</td>
<td>-2 to +2</td>
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<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Reference values**

- Normal = 0 to ±5
- Pronated = +6 to +9, Highly pronated ≥10
- Supination = −6 to −9, Highly supinated −10 to −12

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www.bode.ac.uk/education/FOOT/FP

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# Appendix I

## LOWER LIMB TASKS QUESTIONNAIRE

**ACTIVITIES OF DAILY LIVING SECTION**

### INSTRUCTIONS

Please rate your ability to do the following activities in the past 24 hours by circling the number below the appropriate response.

If you did not have the opportunity to perform an activity in the past 24 hours, please make your best estimate on which response would be the most accurate.

Please also rate how important each task is to you in your daily life according to the following scale:

1. = Not important  
2. = Mildly Important  
3. = Moderately Important  
4. = Very Important

Please answer all questions.

<table>
<thead>
<tr>
<th></th>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULTY</th>
<th>UNABLE</th>
<th>IMPORTANCE OF TASK</th>
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<tr>
<td>1.</td>
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<tr>
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<tr>
<td>10.</td>
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<td></td>
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<td></td>
<td>2</td>
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</table>

**TOTAL (140)***

*Enquiries concerning this questionnaire: Peter J. McNaught PhD, Health and Rehabilitation Research Centre, Auckland University of Technology, Private Bag 92006, Auckland, New Zealand. Email: peter.mcnaught@aut.ac.nz Phone: 921-9999 Ext 7148*

![AUT Logo]
Appendix J

Brief Pain Inventory (Short Form)

1. Throughout our lives, most of us have had pain from time to time (such as minor headaches, sprains, and toothaches). Have you had pain other than these everyday kinds of pain today?
   □ Yes  □ No

2. On the diagram, shade in the areas where you feel pain. Put an X on the area that hurts the most.

   Front
   Back
   Right  Left  Right  Left

3. Please rate your pain by marking the box beside the number that best describes your pain at its worst in the last 24 hours.

   □ 0  □ 1  □ 2  □ 3  □ 4  □ 5  □ 6  □ 7  □ 8  □ 9  □ 10
   □ No Pain
   □ Pain as bad as you can imagine

4. Please rate your pain by marking the box beside the number that best describes your pain at its least in the last 24 hours.

   □ 0  □ 1  □ 2  □ 3  □ 4  □ 5  □ 6  □ 7  □ 8  □ 9  □ 10
   □ No Pain
   □ Pain as bad as you can imagine

5. Please rate your pain by marking the box beside the number that best describes your pain on the average.

   □ 0  □ 1  □ 2  □ 3  □ 4  □ 5  □ 6  □ 7  □ 8  □ 9  □ 10
   □ No Pain
   □ Pain as bad as you can imagine

6. Please rate your pain by marking the box beside the number that tells how much pain you have right now.

   □ 0  □ 1  □ 2  □ 3  □ 4  □ 5  □ 6  □ 7  □ 8  □ 9  □ 10
   □ No Pain
   □ Pain as bad as you can imagine
Full name of author: Kendyl Kathleen Roodt

ORCID number (Optional): ........................................

Full title of thesis/dissertation/research project ('the work'):
Plantar Pressure Parameters Associated with Ankle Osteoarthritis During Walking and the Immediate Effects of An Ankle Brace

Practice Pathway: Health Care
Degree: Master of Osteopathy
Year of presentation: 2018

Principal Supervisor: Megan McEwen

Associate Supervisors: Dr Peter McNair (Auckland University of Technology) and Dr David Rice (Auckland University of Technology)

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AND

Copyright Compliance:
I confirm that I either used no substantial portions of third party copyright material, including charts, diagrams, graphs, photographs or maps in my thesis/work or I have obtained permission for such material to be made accessible worldwide via the Internet.

Signature of author: ............................................
Date: 20/04/2018
Declaration

Name of candidate: Kendyl Kathleen Roodt

This Thesis/Dissertation/Research Project entitled: Plantar Pressure Parameters Associated with Ankle Osteoarthritis During Walking and the Immediate Effects of An Ankle Brace

is submitted in partial fulfillment for the requirements for the Unitec degree of Master of Osteopathy

Principal Supervisor: Megan McEwen

Associate Supervisor/s: Dr Peter McNair (Auckland University of Technology) and Dr David Rice (Auckland University of Technology)

CANDIDATE'S DECLARATION

I confirm that:

- This Thesis/Dissertation/Research Project represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee. Research Ethics Committee Approval Number: 2016-1080

Candidate Signature: ___________________________ Date: 20/4/18

Student number: 1410162