Aboriginal and Torres Strait Islander readers are warned that this thesis may contain images of deceased people.

Theme: In Kaurna language "Paiendi Kokotinna Tidna" means "Seeking Healthy Feet".

Title: An investigation into ankle joint dorsiflexion, musculoskeletal injury, arch height, foot pressure and diabetes in association with poor foot health outcomes in an Aboriginal population.

James Charles M Pod

The Wollotuka Institute

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Declarations

Statement of Originality

I hereby certify that to the best of my knowledge and belief this thesis is my own work and contains no material previously published or written by another person except where due references and acknowledgements are made. It contains no material which has been previously submitted by me for the award of any other degree or diploma in any university or other tertiary institution.

James Charles

Thesis by Publication

*I hereby certify that this thesis is in the form of a series of *papers. I have included as part of the thesis a written statement from each co-author, endorsed in writing by the Faculty Assistant Dean (Research Training), attesting to my contribution to any jointly authored papers. (*Refer to clause 39.2 of the Rules Governing Research Higher Degrees for acceptable papers).*

Candidate

James Charles

Director of Wollotuka

John Lester

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I would like to give a very special, heartfelt thankyou to my wife Sharyn Charles, and my five sons Jordan, Jacob, James, Jonathon, and Jaxon for their support and acknowledge the many sacrifices they have made to allow me to focus my time and energy to conducting this research project.

I would like to acknowledge A/Prof Shelia Scutter, A/Prof Adrain Esterman, A/Prof Jonathon Buckley, Prof Robyn McDermott and Dr Sue Barnett for their support and advice in the development of this research project.

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I would like to acknowledge and thank the representatives on the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and Community Management Council (TSAC and CMC), representing the Paakantji, the Ngiyampaa and the Mutthi Mutthi Peoples for the approval to visit their country and important sites.

I would like to acknowledge my supervisors.
A/Prof Vivienne H. Chuter*:* Head of Discipline & Program Convenor, Podiatry, School of Health Sciences, Faculty of Health and Medicine, University of Newcastle. Priority Research Centre for Physical activity and Nutrition, University of Newcastle.
Dr Andrea Coda: Podiatry Lecturer, School of Health Sciences, Faculty of Health and Medicine, University of Newcastle.
Dr Greg Blyton: Senior Lecturer, Indigenous History, School of Aboriginal Studies, the Wollotuka Institute, University of Newcastle.

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I would like to acknowledge the companies below for their support for this research project.

Companies: Briggate Medical, Axign Shoes, Metcorp Orthotics and Vertical Orthotics.

I would like to acknowledge and thank Mr Terry Johnston (Aboriginal Artist) for providing some fantastic Aboriginal art. Figure 1 and figure 2 were produced specifically to represent this research project and the podiatry service provided to the Aboriginal and Torres Strait Islander communities involved.

I would like to acknowledge several Aboriginal and Torres Strait Islander communities named below for their support and contribution to this PhD.

Aboriginal Communities Involved: The Awabakal, Worimi, Kaurna, Biripi, Darug, Paakantji, Ngiyampaa and the Mutthi Mutthi Aboriginal communities.

Figure 1: Aboriginal Art, Feet Health.

Terry Johnston Painting Story: Middle circle representing practice, people standing around practice, footprints around circle showing people coming and going.

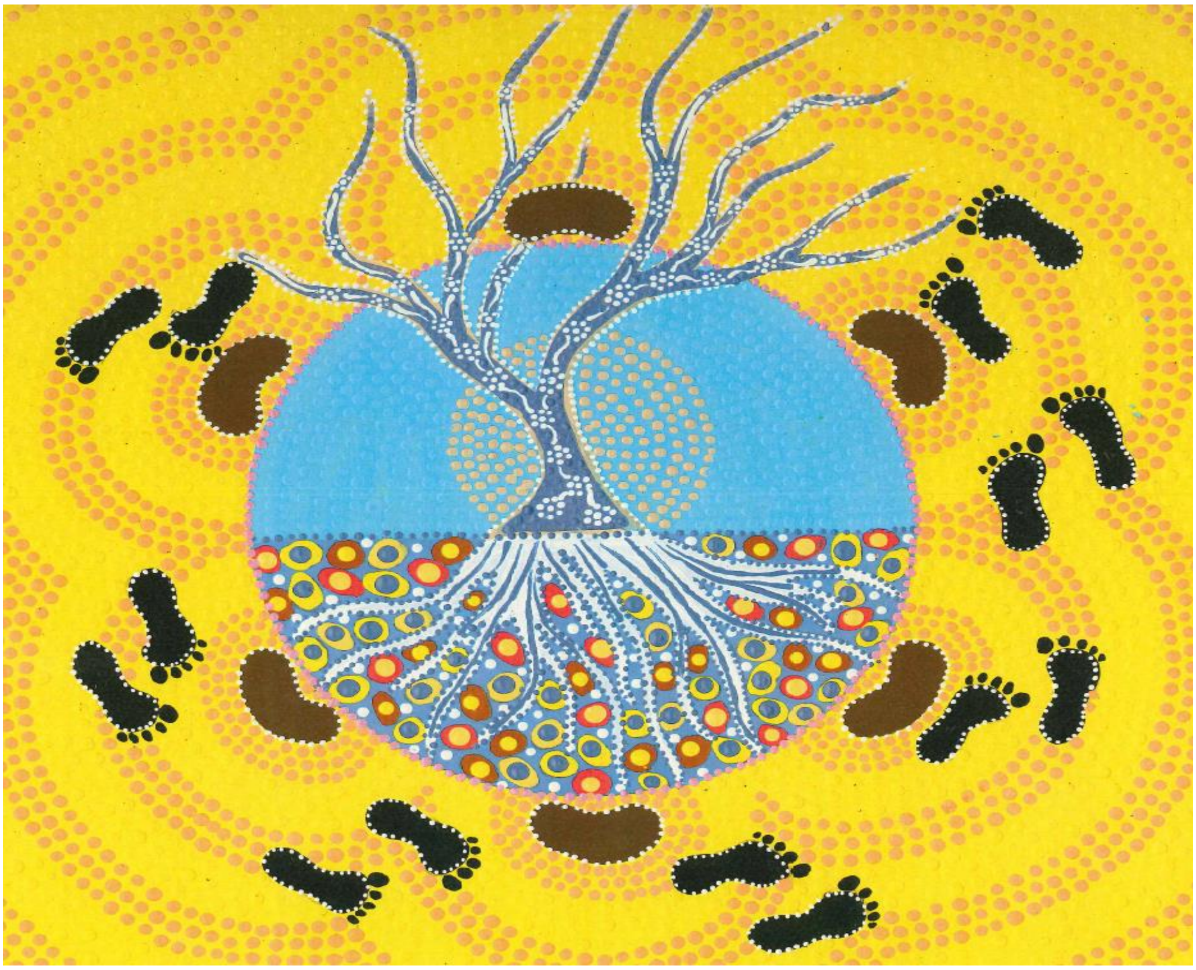

Figure 2: Aboriginal Art, Tree of Medicine

Terry Johnston Painting Story: Showing tree of medicine, knowledge, showing people seated around service, footprints around practice showing people walking more healthily.

List of publications included as part of the thesis

Journal Articles

1. Charles J. (2015) An investigation into the foot health of Aboriginal and Torres Strait Islander peoples: a literature review. *Australian Indigenous HealthBulletin* 15(3). http://healthbulletin.org.au/articles/an-investigati…erature-review/

2. Charles J, Scutter SD, Buckley J. Static Ankle Joint Equinus: Toward a Standard Definition and Diagnosis. *Journal of the American Podiatric Medical Association*. 2010;100(3):195-203. **doi:** http://dx.doi.org/10.7547/1000195

3. Charles J. The design, development, and reliability testing of a new innovative device to measure ankle joint dorsiflexion. *Journal of American Podiatric Medical Association* 2016; (In Press) Manuscript Number 14-051R2 Accepted 01/06/15.

4. Charles J. (2015) An evaluation and comprehensive guide to successful Aboriginal health promotion. *Australian Indigenous HealthBulletin* 16(1). http://healthbulletin.org.au/articles/an-evaluation-and-comprehensive-guide-to-successful-aboriginal-health-promotion

5. Charles J, Coda A, Chuter V. The relationship between ankle joint range of dorsiflexion, arch height and barefoot plantar pressures in Aboriginal Australians. Submitted to *Gait and Posture* 16/06/16.

6. Charles J, Spink M, Chuter V. The relationship between ankle equinus, barefoot plantar pressures and diabetic neuropathy in Aboriginal Australians. Submitted to *Diabetes Research and Clinical Practice* 14/04/16, under review from 02/05/16, Manuscript number DIAB-D-16-00406.

Conference Presentations

Mungabareena Aboriginal Men's Health Summit 19th – 21st Oct 2015, Wodonga Victoria.

- Key Note Speaker. The history and evolution of foot biomechanics and musculoskeletal injury in Aboriginal Australians. Charles J, and Chuter V (Appendix 7).

FIP World Congress of Podiatry Conference 26th – 28th May 2016, Montreal, Quebec Canada.

- The design, development, and reliability testing of a new innovative device to measure ankle joint dorsiflexion. Charles J.
- The relationship between ankle equinus, barefoot plantar pressures and diabetic neuropathy in Aboriginal Australians. Charles J, Spink M, Chuter V.
- The history and evolution of foot biomechanics and musculoskeletal injury in Aboriginal Australians. Charles J, and Chuter V (Appendix 7).

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Thesis Abstract

Aboriginal and Torres Strait Islander Peoples suffer from high rates of chronic disease, including peripheral vascular disease, and diabetes, and the associated increases in morbidity and mortality has an enormous impact on both life span and quality of life. Foot health in Aboriginal and Torres Strait Islander Peoples is widely accepted to be poor. In those with diabetes there is a high incidence of neuropathy, foot ulceration, infection and amputation. However, there is little available literature investigating the nature and extent of foot disease in Aboriginal and Torres Strait Islander Peoples, particularly in those with diabetes, or how this can be effectively managed. Anecdotal evidence suggests high rates of restricted ankle joint dorsiflexion (ankle equinus) may exist in the Aboriginal and Torres Strait Islander population and this may be a significant contributing factor to the development of diabetic foot complications including pressure ulcerations.

This research addresses the hypotheses that.

- Chronic disease and lifestyle factors significantly contribute to foot complications in Aboriginal and Torres Strait Islander Peoples.
- Culturally appropriate inclusive health promotion can improve foot health outcomes and support healthy lifestyle choices in an Aboriginal and Torres Strait Islander community.
- High prevalence of ankle equinus significantly contributes to elevated plantar pressures in Aboriginal and Torres Strait Islander Peoples with and without diabetes, which may be a significant factor contributing to poor foot health.

Firstly, a literature review was conducted to establish current risk factors and risk markers for poor foot health in Aboriginal and Torres Strait Islander Peoples. Little data were found relating specifically to Aboriginal foot health, however high prevalence of chronic disease associated with foot complications including diabetes, neuropathy and peripheral vascular disease were evident. Lifestyle factors associated with increased risk of chronic disease, including smoking and obesity were also found to be highly prevalent, particularly in women. No literature investigating the role of lower limb structure or biomechanical function in development of foot complications was found.

Secondly, a review of the literature to determine a reliable method of measuring ankle joint range of motion was conducted. This review showed significant inconsistency in the literature in relation to the definition and diagnosis of ankle equinus, and a lack of standardised method for clinical assessment. Based on these findings a device for accurately measuring ankle equinus was developed, (the Charles device) which was established to have excellent inter- and intra-tester reliability.

Thirdly, a culturally appropriate health promotion program for improving foot health, reducing injury and increasing healthy lifestyle choices was developed for the local Worimi Aboriginal community in Forster/Tuncurry, New South Wales. Evaluation of this program demonstrated that it was effective in improving healthy lifestyle knowledge, behaviours and reducing risk of lower limb injury. These

findings suggest appropriate health promotion may be successful in reducing risk of foot complications in Aboriginal and Torres Strait Islander People.

Subsequently two cross-sectional cohort studies, one in Aboriginal and Torres Strait Islander People with diabetes and one in those without diabetes, were undertaken to test the hypothesis that restricted ankle joint dorsiflexion increases plantar pressures under the forefoot. High prevalence of isolated gastrocnemius equinus was found in both cohorts. Reducing ankle joint range of dorsiflexion was found to be significantly associated with higher peak pressures under the forefoot, and to be an independent predictor of increasing pressure-time integral under the forefoot in both populations. These results, limited by cross-sectional design, suggest ankle equinus may play a key role in the development of pressure-related forefoot complications in Aboriginal and Torres Strait Islander Peoples.

Finally, as an appendix to this thesis, visual assessment of Aboriginal skeletal remains of the foot, of a small number of Kaurna People and 21,000 years old footprints of the Paakantji, Ngiyampaa and the Mutthi Mutthi Aboriginal People in Lake Mungo was undertaken. These were examined for arch height, indications of biomechanical characteristics of the foot and ankle and overt osseous pathology. Many of the ancient footprint showed signs of a high arch foot type similar to modern day Aboriginal footprints. In addition, bony spurring on the calcanei on a number of specimens was consistent with possible restriction in ankle dorsiflexion, suggesting ankle equinus may be an evolutionary trait in this population (Appendix 7).

Acknowledgement Traditional Owners

Acknowledgement: I would like to acknowledge the traditional owners of all the many Aboriginal and Torres Strait Islander Nations that make up the great continent of Australia. I would like to pay my respects to the Aboriginal and Torres Strait Islander elders past and present, also the young community members, as the next generation of leaders and representatives.

Disclaimer and Warning

Disclaimer: In some instances in this thesis I will be using the term 'Aboriginal' to describe both Aboriginal and Torres Strait Islander Peoples. No disrespect is intended to any individual or group.

Warning: Aboriginal and Torres Strait Islander Peoples: This thesis has images of skeletal remains of deceased Kaurna People.

Preamble

As an Aboriginal podiatrist working in Aboriginal Medical Services in South Australia, anecdotally I noted a trend of reduced range of dorsiflexion at the ankle (ankle equinus) in Aboriginal and Torres Strait Islander Peoples. When considering the potential impact of a high prevalence of ankle equinus on foot function and injury I hypothesised that this may be contributing to gastrocnemius, ankle and Achilles strains, seen in the Aboriginal Medical Services. The reduced dorsiflexion at the ankle joint could also be contributing to increased pressure and time spent on the midfoot and forefoot during gait. This may be a factor in the development of dermatological conditions associated with high plantar pressures including callus and corn, as well as increasing the risk of pressure ulcerations in people with diabetes. Supporting this premise, I found that in many of the ulcerating wounds I treated in the Aboriginal Medical Service podiatry clinics in Adelaide, there was coexisting ankle equinus. Specifically, I was typically finding that the restriction in dorsiflexion was occurring only when the knee was in an extended position, suggesting it was isolated to the gastrocnemius muscle. This has several potential implications as it appeared to be less likely that the equinus was related to diabetes and the associated process of non-enzymatic glycosylation which causes limited joint mobility. In addition it may suggest that this high prevalence of equinus could possibly be specific to Aboriginal and Torres Strait Islander Peoples.

In these Aboriginal Medical Service podiatry clinics, ankle joint dorsiflexion was routinely measured on all patients as part of a new patient assessment. However, the clinical findings described above were limited by the fact that the measurements were being undertaken with a goniometer, which has been shown to have poor reliability. Furthermore, I could not exclude the fact that this finding could be related to the type of individuals attending the podiatry clinics i.e. those attending would be more likely to have pathology and therefore biomechanical abnormalities. However, as a podiatrist volunteering for the Kaurna Eagles Football Club (Aboriginal AFL team) in Adelaide, doing strapping etc. I noticed that nearly all the players also had an ankle equinus. These men were young and fit, did not have diabetes, had never had ulcerations and had never attended the Aboriginal Medical Service podiatry clinics. This supported the hypothesis that in fact, Aboriginality was related to this reduced dorsiflexion at the ankle and this was caused by isolated gastrocnemius tightness. The potential implications of high prevalence of ankle equinus on foot function and foot health, became the central hypotheses underpinning the research conducted as part of my candidature. Specifically this investigated the potential implications of high prevalence of ankle equinus and how this may contribute to poor foot health in Aboriginal and Torres Strait Islander Peoples.

Overview

Introduction

It is well established that Aboriginal and Torres Strait Islander Peoples suffer from high rates of chronic disease and reduced life expectancy. A number of social determinates of health including residential location, low income, low education levels, and high rates of unemployment are proposed to contribute significantly to Aboriginal and Torres Strait Islander health disadvantage (1). Poor health literacy, unhealthy lifestyle and reduced access to affordable, culturally appropriate health care, especially in rural and remote areas, increases the risk and incidence of development of chronic disease, and results in poor long term health outcomes (2). It is likely many of these factors contribute to poor foot health in Aboriginal and Torres Strait Islander communities, however there are little data available investigating the prevalence or severity of chronic foot complications in this population. The paucity of research in this area is preventing accurate quantification of the foot health care problems and development of informed strategies to reduce the burden of disease.

In particular, Aboriginal and Torres Strait Islander Peoples are estimated to suffer from diabetes at a rate three times that of the general Australian population and experience elevated rates of associated morbidity and mortality (3, 4). Despite diabetes-related foot complications being some of the most common complications of diabetes, there has been little investigation into the nature and extent of foot disease in Aboriginal and Torres Strait Islander Peoples. The limited available data demonstrates disproportionately high representation of Aboriginal and Torres Strait Islander Peoples developing foot ulcers, with increased rates of hospitalisation, infection and amputation and associated mortality (5).

A number of factors are known to increase the risk of foot complications in diabetes cohorts (4). These include longer duration of diabetes and poor glycaemic control, which are a shared risk factors for peripheral vascular disease, peripheral neuropathy and increased rates of wound infection (6, 7). Peripheral vascular disease is associated with the development of ischaemic wounds and elevated risk of related cardiovascular mortality, while neuropathy is known to increase the likelihood of undetected foot trauma as well as significantly increased plantar pressures (8, 9). Elevated plantar pressures are associated with the development of pressure-related foot ulceration and are an established risk factor for predicting future foot complications (10, 11). In addition to the known association between neuropathy and high plantar pressures, limited joint mobility has also been suggested to contribute to increasing foot pressure and risk of ulceration in susceptible neuropathic feet (12).

Limited joint mobility in diabetes cohorts is attributed to a process of non-enzymatic glycosylation, often due to chronic hyperglycaemia which causes stiffening of the skin, ligaments and tendons (13). Specifically stiffening of the Achilles tendon is associated with restriction in ankle joint dorsiflexion (ankle equinus) and this has been implicated in the development of increased pressure time integrals under the forefoot in people at risk of diabetic foot complications (13, 14). During gait, ankle equinus is proposed to cause a restriction in forward movement of the tibia over the foot during stance phase. This is suggested to result in compensations which leads to prolonged forefoot loading and contribute to the development of elevated forefoot plantar pressures and, in people with diabetes, may increase the risk of pressure related foot ulceration (15-17).

Current evidence investigating the relationship between ankle equinus and plantar pressures in people with diabetes is inconclusive. A few studies have demonstrated ankle equinus to co-exist with neuropathy in diabetic cohorts with a history of foot ulceration (18, 19). Ankle equinus has also been found to be associated with delayed ulcer healing and increased likelihood of ulcer recurrence, however a consistent relationship between restricted range of ankle joint dorsiflexion and forefoot plantar pressures has not been established (20, 21). Several factors are likely to contribute to this, for example existing literature investigating ankle equinus and foot pressures in people with diabetes uses a range of definitions for equinus, making comparison between studies challenging. The method of range of ankle joint dorsiflexion measurement is also inconsistent, with a number of studies using a goniometer method that has been suggested to be unreliable (22). Nevertheless, there is existing evidence of a relationship between ankle joint range of dorsiflexion and plantar pressures (23). Given the anecdotal evidence of the author of increased incidence of ankle equinus in Aboriginal and Torres Strait Islander Peoples, it is possible that there may be a biomechanical difference specific to this population that may increase the contribution of ankle equinus to plantar pressure distribution and the development of diabetes-related foot complications.

This series of publications was undertaken to address the central hypotheses that a wide range of factors contribute to poor foot health in Aboriginal and Torres Strait Islander Peoples and that improvements in foot health can be achieved with culturally appropriate health promotion. In addition it is hypothesised that a high prevalence of ankle equinus significantly contributes to elevated plantar pressures in Aboriginal and Torres Strait Islander Peoples with, and without diabetes, and this may be a significant factor contributing to poor foot health.

Specifically these publications aimed to:

1. Establish current risk factors and risk markers for poor foot health in Aboriginal and Torres Strait Islander Peoples.

2. Determine a reliable method for measuring ankle joint range of dorsiflexion.

3. Evaluate the effectiveness of a culturally appropriate health promotion package focussed on reducing life-style based risk factors for chronic disease and improving foot health outcomes.

4. Assess the effect of reduced ankle joint range of motion on plantar pressures in Aboriginal and Torres Strait Islander Peoples with and without diabetes.

Although not an aim of this project, a unique opportunity arose to examine skeletal remains of the Kaurna People from Adelaide and fossilised footprints of Paakantji, Ngiyampaa and the Mutthi Mutthi

People from Lake Mungo. This was an investigation to determine if there is historical evidence of biomechanical function, particularly in relation to ankle equinus, and if this was consistent with biomechanical function in modern Aboriginal and Torres Strait Islander Peoples. The investigation looked for possible links in biomechanical foot function between ancient and modern day Aboriginal and Torres Strait Islander Peoples. The skeletal remains (calcaneus and talus) of a small number of Kaurna People and 21,000 years old footprints from the Paakantji, Ngiyampaa and the Mutthi Mutthi People in Lake Mungo were examined for arch height, indications of biomechanical characteristics of the foot and ankle and overt osseous pathology.

Written approval form the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and Community Management Council (TSAC and CMC), representing the Paakantji, the Ngiyampaa and the Mutthi Mutthi Peoples was provided (Appendix 5) to visit their lands and inspect the 21,000 year old fossilised footprints. This permission is not given lightly, the researcher is very thankful to the traditional owners and felt very privileged to stay on their country and look at their sites. The researcher would like to acknowledge the traditional owners contribution to this study and the knowledge gain from my visit to the knowledge of evolution of Aboriginal and Torres Strait Islander Peoples foot structure and function.

Many skeletal remains of Aboriginal and Torres Strait Islander Peoples were removed from their burial sites by the British colonist. Unfortunately some of those burial sites where built on by the colonist, in some cases with large buildings, in one case a football stadium in "Karraundo-ngga" now known as Hindmarsh an inner city suburb of Adelaide, South Australia. This left many skeletal remains of my ancestors in limbo, unable to be repatriated to their Wongayerta (burial site) and unable to rest in peace. Approval from Uncle Lewis O'Brien (Kaurna Elder) was granted to inspect skeletal remains of my ancestors, the Kaurna People from Karraundo-ngga. Very few people have had the opportunity to inspect these bones, again it was a great privilege to be trusted to have this opportunity. The researcher, as a Kaurna man would like to thank Uncle Lewis and the Kaurna community for allowing the inclusion of the knowledge gained from the experience examining these bones contributed to the understanding of Aboriginal and Torres Strait Islander Peoples foot health (Appendix 7).

Many of the ancient footprints examined showed signs of a high arched foot type similar to modern day footprints, suggesting a high arched foot may have been predominant in this population. In addition, bony spurring on the calcaneus and lack of squatting facets on the talus were consistent with possible restriction in ankle dorsiflexion and a sartorial resting posture. These findings may be indicative of a hereditary component to biomechanical characteristics we have found to be more prevalent in modern day Aboriginal and Torres Strait Islander Peoples. However this project examined fossilised footprints and skeletal remains of Aboriginal people for possible links to characteristics of foot and ankle function in modern Aboriginal and Torres Strait Islander Peoples. Collecting the data were not without significant challenges including enabling access of the researcher to the skeletal remains, footprints and associated data and the subsequent examination. Although some of the ancient footprints were preserved very well, many were not preserved well enough to establish arch height. There were footprints of men, women and children however there is no way of knowing if the footprints are a true representation of the Aboriginal population of that time and in that community. The skeletal remains examined were also of very small number and the extent of generalizability of the characteristics of these bones is unknown. Comparison to biomechanical findings in modern day Aboriginal and Torres Strait Islander Peoples to the ancient remains and fossilised footprints required extrapolation to identify possible links between biomechanical structure and function, therefore they are by no means proven. Nevertheless we believe these findings make a valuable contribution to the current limited data in this area (Appendix 7).

Research Design and Results

Aim 1: To establish current risk factors and risk markers for poor foot health in Aboriginal and Torres Strait Islander Peoples.

To determine the risk factors and risk markers for poor foot health in Aboriginal and Torres Strait Islander Peoples a comprehensive review of the literature was undertaken using six health/medical related databases i.e. Cochrane, EMBASE, CINAHL, PUBmed, MEDLINE, and EBSCOhost. The topics investigated were foot health and risk markers i.e. age, gender, area of residence, risk factors i.e. obesity, smoking, chronic conditions (diabetes, neuropathy, peripheral vascular disease) and footwear, for poor foot health. Also an investigation of foot health outcomes i.e. dermatological conditions including corns and callus, ulceration, infection, and amputation was undertaken.

The review of literature highlighted that there has been limited research in Aboriginal and Torres Strait Islander Peoples foot health, and there is a gap in research on foot structure, function and biomechanics. Little data relating to risk markers were identified. There has been no investigation of the impact of age on foot health in Aboriginal and Torres Strait Islander Peoples, although it is known to be a risk factor particularly for dermatological problems. There was limited evidence available relating to foot complications associated with chronic disease such as peripheral vascular disease in the general community. Although residential area was found to be associated with poorer health outcomes and higher rates of chronic disease, this has not been investigated in relation to foot health. Being female was also found to be associated with several risk factors for poor foot health including increased rates of obesity and diabetes in the Aboriginal and Torres Strait Islander population. The review showed rates of smoking are almost double that of the general population. Neuropathy and peripheral vascular disease related to diabetes and smoking were also found to be highly prevalent in Aboriginal and Torres Strait Islander Communities.

This review highlighted the limited amount of research on Aboriginal and Torres Strait Islander foot health with existing research showing foot health is poor and rates of ulcers, infection and amputation are high and exponentially increasing. The outcomes of this review underline the need for more research to inform health policy and support facilitation of more effective care delivery from clinicians.

Aim 2: To determine a reliable method for measuring ankle joint range of dorsiflexion.

To determine a reliable method of measuring ankle joint range of motion. Designed for collecting data across multiple sites, for subsequent studies in this project. A review of the literature relating to the definition, assessment, diagnosis, prevalence, and complications of equinus was conducted. Articles on equinus and assessment of ankle joint range of motion were identified by searching the EMBASE, Medline, PubMed, EBSCOhost, Cinahl, and Cochrane databases and by examining the reference lists of the articles found.

Based on the available data it was found that there is inconsistency regarding the magnitude of reduction in dorsiflexion required to constitute a diagnosis of equinus and there is no standard method for assessment. Therefore the prevalence of equinus in the general population is unknown. Goniometric assessment of ankle joint range of motion was shown to be unreliable, whereas purpose-built tools demonstrated improved reliability.

Reduced dorsiflexion is associated with alterations in gait, increased forefoot pressure, and ankle injury. However, the magnitude of reduction in range of motion required to predispose to foot or lower-limb abnormalities is not known. In the absence of definitive data, we proposed a two-stage definition of equinus: The first stage reflects dorsiflexion of less than 10° and greater than 5° with minor compensation and a minor increase in forefoot pressure, the second stage reflects dorsiflexion of less than 5° with major compensation and a major increase in forefoot pressure. This was proposed to assist with standardizing the diagnosis and will provide a basis for future studies of the prevalence of equinus.

Based on the results of the literature review on ankle equinus, a device (the Charles device) for accurately measuring ankle equinus was developed by the author for use in subsequent cross-sectional cohort studies (Figures 3 & 4, & Appendix 1). Prior to use for data collection an intra-rater and inter-rater reliability study was undertaken. The single measure ICC was 0.998 with a 95% confidence interval of 0.996 to 0.998. The average measures ICC were 0.998 with a 95% confidence interval of 0.995 to 0.999. The 95% limits of agreement (LOA) for average measure were also very narrow: -1.30° to 1.65°, suggesting the device is highly reliable.

Figure 3: Charles Device Prototype made of steel.

Figure 4: Charles Device to measure ankle dorsiflexion, Charles 2016 (24).

Aim 3: To evaluate the effectiveness of a culturally appropriate health promotion package focussed on reducing life-style based risk factors for chronic disease and improving foot health outcomes.

To evaluate the effectiveness of a lower limb assessment and health promotion program for improving foot health, reducing injury and increasing healthy lifestyle choices to reduce risk factors for chronic disease in young Aboriginal and Torres Strait Islander adults, a specific health promotion program was developed for the local Worimi Aboriginal community in Forster/Tuncurry New South Wales (NSW). The unwritten theme for the program was Aboriginal community engagement, consultation and ownership. Changes to lifestyle, self-reported health literacy and development of injury in the four months following the program delivery were measured and qualitative feedback on the program from the participants was collected.

This injury prevention health promotion project was used as an example, in a guide to successful health promotion. As part of the injury prevention strategy for this project, biomechanical assessments, including measuring ankle dorsiflexion and assessment of foot type were undertaken. Prevalence of ankle equinus was high, with all Aboriginal and Torres Strait Islander men having less than 10°of ankle dorsiflexion and 83% (n=10) having less than 5° (stage 2 equinus). In addition 27% (n=4) of women had less than 5° (stage 2 equinus). These findings in a healthy athletic population suggest equinus may be associated with Aboriginality to some extent. A high arched foot type was also highly prevalent occurring in 57% (n=14) of participants, suggesting biomechanical differences from the general Australian population where a lower arch foot type is most common.

From a health promotion perspective, the program was highly successful in that the program had the full capacity of participants (24 people), the participants participated in all aspects of the program, and the messages “cut through”. All participants gave feedback at the 4 month follow-up and reported having more knowledge about the effects of smoking, alcohol, diet and correct training, on their health and performance in sport and activity. The personal feedback about the program from participants and other community members that observed the program was very positive. Most importantly, participants reported they had a better understanding about the musculoskeletal system and how to identify an injury.

Aim 4: To assess the effect of ankle joint range of motion on plantar pressures in Aboriginal and Torres Strait Islander Peoples with and without diabetes.

To determine the effect of ankle equinus, and plantar pressures in Aboriginal and Torres Strait Islander Peoples with and without diabetes, two cross-sectional cohort studies were conducted. The first study, conducted in a population of Aboriginal and Torres Strait Islander People without diabetes, assessed the relationship between biomechanical variables of the foot and ankle with plantar pressures under the midfoot and the forefoot. For all participants, ankle joint range of dorsiflexion was measured using the Charles device, foot type was assessed using a pedograph and plantar pressures were collected using the HR Mat Pressure Measurement System. Peak pressures (PP) and pressure-time integral (PTI) under the medial and lateral forefoot and the midfoot were assessed.

This study demonstrated high rates of reduced ankle joint dorsiflexion in the Aboriginal and Torres Strait Islander participants. By regression analysis we also demonstrated that reduced ankle joint range of dorsiflexion was an independent predictor of increased PTI at the lateral forefoot (beta = -0.258, p=0.01) and a low arch foot type was an independent predictor of increasing midfoot PTI (beta =-0.234, p=0.04). Higher BMI was also a significant predictor of both midfoot and lateral forefoot PTI. Although we did also find a significant correlation between a low arch type and high midfoot PP, and increasing lateral forefoot PP correlated with reducing ankle joint range of dorsiflexion, interestingly these relationships were not as strong. This suggests the biomechanical variables of foot arch type and ankle joint range of dorsiflexion affect duration (PTI) of loading to a greater extent than PP. In relation to ankle joint range of dorsiflexion, this finding is consistent with proposed changes to gait parameters associated with an ankle equinus, where an early heel lift is suggested to increase the time spent on the forefoot with each gait cycle (15, 25).

The second cross-sectional study was performed in a cohort 76 Aboriginal and Torres Strait Islander Peoples with diabetes, recruited from three communities in NSW. Demographic data including age, height, weight, gender, residential area, and self-report medical history (HbA1C and duration of diabetes) were collected from participants. Neuropathy status was determined using a 4 site monofilament test. Ankle joint range of dorsiflexion was measured with the leg flexed and then with leg extended, using the Charles device. Foot arch type was assessed using a pedograph and plantar pressures were collected using the HR Mat Pressure Measurement System.

The sample population had a high prevalence of both neuropathy (50%) and reduced ankle dorsiflexion of 72% (when defined as less than 10° of motion, non-weight bearing). Equinus was also more prevalent among men (90%) compared to women (50%) and generally was only present when the leg was extended, indicating an isolated gastrocnemius equinus. Correlations were performed between PP and PTI for the whole forefoot and midfoot. Consistent with existing research in the general population, we found neuropathy to be most strongly associated with high forefoot PTI ($r=0.42$, $p<0.01$) and high forefoot PP ($r=0.5$, $p<0.05$). Forefoot PTI were moderately and negatively correlated with equinus ($r=-0.38$, $p<0.01$. Being male was also moderately and significantly correlated with equinus ($r= -0.36$, $p<0.01$). By regression analysis we found equinus explained a 9.1% of the variance in forefoot PTI after controlling for demographic variables. We also found the high rates of equinus were largely attributed to a restriction of gastrocnemius range of motion (n=42) and far higher in men. The lack of correlation between neuropathy and ankle joint range of dorsiflexion was surprising and suggests possibly the prevalence of ankle equinus may not have been associated with diabetes. The significant contribution of restriction in ankle joint dorsiflexion made to forefoot PTI in this group does suggest that it may be an important factor in the development of pressure related injury. It also suggests that this may be of great consequence in an Aboriginal and Torres Strait Islander population, particularly in males. This may also in part explain why Aboriginality itself has previously been found to be a risk factor for foot ulceration (26).

Paper 1: An investigation into the foot health of Aboriginal and Torres Strait Islander Peoples: A literature review.

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Acknowledgement: I would like to acknowledge the traditional owners of all the many Aboriginal and Torres Strait Islander Nations that make the great continent of Australia. I would like to pay my respects to the Aboriginal and Torres Strait Islander elders past and present, also the young community members, as the next generation of leaders and representatives.

Disclaimer: In some instances in this paper I will be using the term "Aboriginal" to describe both Aboriginal and Torres Strait Islander Peoples. This is due to word restrictions, and no disrespect is intended to any individual or group.

There is an obligation and desire to publish and present some of the outcomes of this Aboriginal foot health research in free, open access Aboriginal health journals to disseminate the findings more easily to the Aboriginal community. Therefore, the literature review conducted (below) was published in a peer reviewed Aboriginal health journal i.e. Australian Indigenous Health*Bulletin*.

Citation: Charles J (2015) An investigation into the foot health of Aboriginal and Torres Strait Islander peoples: a literature review. Australian Indigenous Health*Bulletin* 15(3).

Author Contribution Statement

As sole author of the paper James Charles was responsible for all aspects of this research and development of the manuscript.

Abstract

Objective: The object of this paper is to review the literature on risk markers, risk factors, and chronic conditions in relation to foot health in the Aboriginal population.

Methods: Basic literature review, databases searched – Cochrane, EMBASE, CINAHL, PUBmed, MEDLINE, and EBSCOhost and references from articles, and not limited by date or language. This search yielded 214 articles, abstracts of these articles were read to identify articles which were directly relevant to the topic, and this strategy provided a total of 55 articles.

Results: Risk markers like age and gender were shown to significantly contribute to poor health and foot health outcomes. Risk factors like obesity and smoking were also shown to be associated with many chronic diseases and poor foot health. Footwear can contribute to poor foot health, for example high heeled shoes have been associated with foot pain, callus and corns.

Conclusions: The search and review revealed that there has been limited research in to risk markers or risk factors for Aboriginal foot health. This review found that risk markers and risk factors for poor foot health outcomes are high and current foot health is poor and under researched.

Implications: The information gained from this study will assist in identifying potential targets for intervention and research to improve foot health in Aboriginal communities.

Introduction

There are approximately 548,000 Aboriginal People, representing 2.5% of the Australian population. Of those, 172,000 live in NSW, comprising 32% of the total Aboriginal population and the highest number of any state or territory (1). Aboriginal People suffer with a high prevalence of chronic conditions which accounts for approximately 60% of the premature morbidity and mortality occurring in this population (2). A number of these chronic conditions including diabetes, neuropathy of various causes and peripheral vascular disease (PVD) are prevalent within Aboriginal communities, and have been shown to be associated with foot pathology (3-5). The little data available on foot health in the Aboriginal population indicate that generally it is poor and the rates of ulceration, infection and amputation are continuing to increase (6, 7). Often the only option to resolve these wounds is to amputate above the affected area. This has led to many more amputations being conducted on the Aboriginal population (8). However, despite evidence of high prevalence of serious foot complications in the Aboriginal community, no research has thoroughly investigated the nature and mechanism of the foot problems affecting Aboriginal communities.

Risk markers for Aboriginal health: Age

Age has been associated with many diseases and chronic conditions which are risk factors for poor foot health (9-11). The ageing process has also been associate directly with impaired foot function which may predispose to poor foot health. Longitudinal research (n=343) has found that age is associated with the development of foot pathology, with the odds of developing a foot pathology increasing by a factor of 1.069 for every year over 65 (5). Older age has also been associated with poor foot health, like calluses and corns, likely due to reduced flexibility and durability of aging skin (12). In summary the literature shows that age is associated with many diseases and chronic conditions associated with poor foot health outcomes but this has not been investigated in the Aboriginal population.

Risk markers for Aboriginal health: Resident Area

An extremely important aspect of Aboriginal health is the different foot health and other health services in different residential areas. Approximately 34% of all Aboriginal People live in cities (233,100 people), and 22% (147,700) Aboriginal People live in inner regional centres, with 21% (146,100) living in outer regional areas, compared to 71%, 18% and 9% respectfully of non-Aboriginal Australians (13). The greatest difference in residence between Aboriginal and other Australians is remote and very remote, with approximately seven times more Aboriginal people living in remote and 26 times more living in very remote areas (13). Location of residence makes a difference to life expectancy at birth for Aboriginal People. Aboriginal men living in cities and inner regional areas live 11.9 years less than non-Aboriginal men, but for Aboriginal women the greatest difference compared with non-Aboriginal women was for those living in remote and very remote areas, living 10.2 years less (14). Although area of residence has been investigated for some areas of health and life expectancy for Aboriginal People, the implications for foot health have not been investigated.

Risk markers for Aboriginal health: Gender

Gender has been associated with many diseases and chronic conditions which are risk factors in Aboriginal health, and which may be associated with changed foot function and poor foot health. Males develop diabetic neuropathic degeneration approximately 4 years earlier than females putting men at greater risk for poor foot health (15). In the total Australian population, males were nearly twice as likely as females to have diseases of the arteries, arterioles and capillaries (16). Some studies have found non-Aboriginal women have a greater prevalence of diabetes than non-Aboriginal men (17, 18). The prevalence of obesity as indicated by waist circumference was higher in women (34.1%) than in men (26.8%) (19). Gender is associated with many of the risk factors and chronic conditions, impacting on foot health, potentially predisposing specific genders to poor foot health outcomes, making gender an important risk marker.

Risk factors for Aboriginal health: Obesity

A study found overweight and obesity results (n=11,247), measured by waist circumference was 39% overweight and 20.8% obese, with BMI the results were 30.5% and 25.5% respectfully (19). Waist circumference was reported to be the most appropriate measure, but with either measure, 56-60% of the Australian population tested were overweight or obese (19). Recent data suggests that obesity is more prevalent in the Aboriginal community than in other Australians. Recent large studies with Aboriginal volunteers (n=10,434) have shown that Aboriginal females have higher waist circumference, waist-hip ratio, waist-height ratio and waist-weight ratio than non-Aboriginal women (19). Aboriginal men had higher weight-height ratio and waist-weight ratio compared with non-Aboriginal men (n=10,434) (19). The proportion of obese Aboriginal women was significantly higher than that of non-Aboriginal women and obesity rates for Aboriginal men are higher than non-Aboriginal men, with the exception of 45-54 years cohort (20). Obesity has been associated with many chronic conditions including diabetes and PVD which are to be investigated in this literature review (21-23). Being overweight or obese has been shown to have a negative impact on foot health, especially due to the associated increase in foot pressure and resulting longitudinal arch collapse (24). Obesity (BMI >30) has been linked to chronic plantar heel pain, and with a flattening of the medial longitudinal arch in an Indian population, using the Arch Index as a measure of flatfeet (25). The literature establishes that obesity is highly prevalent in the Australian population and it is higher for some Aboriginal populations.

Risk factors for Aboriginal health: Smoking

Smoking tobacco in the Aboriginal population is reported to be 45% compared with 22% for non-Aboriginal Australians (26). Smoking is a risk factor for chronic conditions (27) and poor foot health (28). In the general population tobacco smoking is linked to poor healing, research has showed that nicotine was related to non-healing of gastric ulcers in rats (29), possibly as a result of smoking-related reductions in epidermal growth factor (EGF) (30) which may be the same mechanism that prevents healing in human dermal tissue. Cigarette smoking has also been associated with reduced blood circulation, by impairing endothelium-dependent dilatation of vessels (31, 32). Reduced peripheral blood flow, including impaired blood flow to the foot, will put smokers at risk of poor foot health. The literature shows that smoking is a risk factor for chronic conditions and poor foot health for all Australians, but maybe more serious for the Aboriginal population due to far great smoking rates.

Risk factors for Aboriginal health: Footwear

Footwear can contribute to poor foot health, for example high heeled shoes have been associated with foot pain, callus and corn (33). Other studies have also shown wearing shoes is not necessarily related to good foot health. A survey of skeletally mature individuals in India (n=1864) found that those wearing shoes had a higher prevalence of flatfeet (25), especially those that started wearing shoes before they turned 6 years of age (25, 34). Shoes that provide support and cushioning can reduce poor foot health, trauma and falls (35, 36). Wearing of appropriately fitting closed toed shoes can promote foot health in populations at risk of developing foot problems. Podiatrists recommend wearing of such shoes for all diabetics (especially those with peripheral neuropathy), to prevent small traumas that may go unnoticed and become infected and or non-healing. A large unpublished study in South Australia (n=1092) using Aboriginal Health Workers to collect observational data on Aboriginal feet, found that 65% of males and 80% of women with diabetes were wearing slip on shoes e.g. thongs, thus potentially putting their foot health at risk (37). While the wearing of closed toed shoes is advocated, it is important that the shoes fit appropriately. The lack of appropriately fitting closed toed shoes was found to impact on foot health, with 71% of 913 Aboriginal participants wearing closed toed ill-fitting shoes having callus and corn (37). The results of Jones (2001) are supported by early studies showing that people without shoes experienced less pain than those wearing shoes in India, China and Kenya (38). Therefore, although there is evidence for the foot health benefits of wearing shoes, it could be argued that poorly fitting shoes may be worse than slip-on shoes or no shoes.

Chronic conditions related to foot health in the Aboriginal population: Diabetes

There are many important chronic conditions in Aboriginal health that need to be investigated, but diabetes is directly and indirectly related to foot health and other related chronic conditions. Diabetes is a worldwide epidemic and especially prevalent in Western countries. The prevalence of diabetes in Australia (2013) was 4.6% and affecting more males than females (39). In comparison, the prevalence of diabetes in the Aboriginal population is 11% of all adults (2), which is an increase from 8% in 2012-2013 (40). The prevalence of diabetes in the Aboriginal population is 7% in cities and about 12% in very remote regions, which has increased from 6% and 8% in 2001-2012 (40). Diabetes Australia (2007) states Aboriginal adolescents are 6 times more likely to have type 2 diabetes than non-Aboriginal and it is believed that for every person diagnosed there is one undiagnosed (41). Aboriginal men are less likely to have diabetes with only 7% compared to 10% of Aboriginal females (40), which is in contrast with the non-Aboriginal population. In addition about 18% of over 25 year old Aboriginal people have diabetes, and this increases with age, with 39% of over 55's having diabetes (40).

The burden of disease with diabetes in the Aboriginal population occurred 5.1 times non-Aboriginal Australians (42). Diabetes also accounted for 8.9% of the total burden of disease for Aboriginal Peoples, and females carried most of the burden (42). The disability-adjusted life year (DALY) for the total burden for Aboriginal People with diabetes was 8,498 (42). Diabetes is the second leading cause of death of Aboriginal people, accounting for 7.6% of all deaths, which was 6 times higher than non-Aboriginal Australians (43). Diabetes has been found to be a risk factor for other chronic conditions, including PVD and neuropathy (28). It has also been demonstrated to significantly increase risk of foot pathology with increasing age, with a 90 year old person with diabetes having an approximately eight-fold increased risk of developing a foot problem compared to a non-Aboriginal person of the same age (5). A study by Jones (2001) found that in a South Australian Aboriginal population, those with diabetes were twice as likely to have callus and corns as those without diabetes (37). In a random sample of the Australian population, (n=11, 247), Tapp et al (2003) found that 13.1% of those with diabetes had peripheral neuropathy, 13.9% had PVD and 19.6% were at risk of developing a foot ulceration (28).

Diabetes has also been found to modify muscle through oxidation of proteins. Markers of oxidative stress (protein carbonyls) were compared in soleus and plantaris muscles of non-diabetic and diabetic rats, and higher plasma glucose concentrations were associated with greater oxidative stress (44). Human tissue also was found to have a link between higher glucose levels and increased glycation of proteins. Glycation of connective tissue proteins induces structural changes in tendons and muscle, increased density of collagen fibrils, decreased fibrillar diameter and abnormal fibril morphology which leads to decreased stretch and elasticity (3, 45, 46) and may contribute to decreased joint ROM and poor foot health outcomes. Duffin et al (1999) compared foot joints of 302 adolescents with diabetes and 51 non-diabetic controls and found double the prevalence of hammer and claw toe, in the diabetic group, indicating that the changes in the foot are associated with foot pathology (47). Spencer et al (1985) found that 50% of patients with diabetes present with some foot deformity (48) linking diabetic foot changes directly with poor foot health outcomes. A study found 68% of 92 diabetic patients had structural pathology in the foot and this put patients at risk of ulceration and amputation (49). Diabetes increases the risk of ulceration and amputation, with diabetics being 15 times more likely to have an amputation. Diabetic patients that have an amputation will have an increased chance of having a subsequent amputation on the other foot within 2-3 years, and in 2004-5 there were 3400 amputations in Australia (41). The relationship with diabetes and foot health in the Australian Aboriginal population has not been established, which is a gap in the literature.

Chronic conditions related to foot health in the Aboriginal population: Neuropathy

Peripheral neuropathy refers to loss of nerve function in the foot, occurring more frequently in people with diabetes and those who smoke (50). The loss of nerve function in the foot has been found to be a risk factor for foot functional changes and poor foot health, especially amputation (3, 4) Jones (2001) showed that 18% of 94 Aboriginal People with diabetes had peripheral neuropathy in the foot as tested with a 10g monofilament (37). This study may have underestimated neurological function loss, as recent research recommends use of a 6g monofilament for nerve function testing (51). Using a 10g monofilament will give some false positive results because participants with some neurological loss will be able to feel the 10g monofilament. Case studies have shown an association between neurological degeneration and increased risk of foot functional change and poor foot health, due to loss of sensory function of muscle and joints (52). Peripheral neuropathy causes loss of sensation and those individuals without pain will continue their activities, increasing the chance injury and poor foot health.

Chronic conditions related to foot health in the Aboriginal population: Peripheral vascular disease

Risk factors for PVD include diabetes, smoking and age, (28, 37, 53), which have been identified as important variables to foot health in this literature review. The proportion of the Australian population reported as having disease of the arteries, arterioles and capillaries was 1.2%, although Jones (2001) reported a prevalence of 9.4 % of Aboriginal People that volunteered to participated in a study (37). It is likely that PVD often goes undiagnosed, usually secondary to diabetes or smoking. PVD has been associated with poor foot health, including amputation (28, 53). PVD is reportedly very high in the Aboriginal population, with an estimated prevalence of 12%, which is 10 times that for non-Aboriginal population (16). Literature shows that PVD can be associated with poor foot health and risk factors for PVD are high in the Aboriginal population. The very high rates of PVD in the Aboriginal population increases the likelihood of poor foot health outcomes.

Foot health in the Aboriginal population

There are a limited number of studies investigating foot health in Aboriginal communities, but with the high occurrence of risk factors and chronic conditions it is hypothesised that foot health will be poor. A clinical audit at the Alice Springs Hospital found that Aboriginal People accounted for 89% of foot complications and 91% of separations for diabetic foot (6), yet Aboriginal People comprise only 38% of the population in Alice Springs (1). The incidence of diabetic foot complications in Aboriginal People increased nearly 3 fold from 98/100,000 to 285/100,000 people from 1992 to 1997 (6). Half of Aboriginal People with infected diabetic foot wounds were found to be infected with Methicillin Resistant Staphylococcus Aureus (MRSA) (7). Often the only option to resolve these wounds is to amputate above the infected area. Consequently 59% of major amputations in Alice Springs were conducted on Aboriginal People and they accounted for half of all infection cases (n=51) (6). Only 2% of non-Aboriginal people admitted to hospital with diabetes had amputations in Northern Territory from 1993 - 1996 (54) and study on admission data in Alice Springs Hospital showed 7% of Aboriginal People (n=165) with diabetes admitted from 1984 – 1986 with bacterial infection, had amputations, (55). Although no direct comparisons can be made between these studies, it could be used to demonstrate the different amputation outcomes between non-Aboriginal and Aboriginal People.

Conclusion

The literature showed high prevalence of serious foot complications in the Aboriginal community, and no research has thoroughly investigated the nature and mechanism of the foot problems affecting Aboriginal communities. Risk markers like age and gender were shown to be associated with many risk factors and chronic conditions associated with poor foot health outcomes but have not been investigated in the Aboriginal population. Residence has been investigated for many areas of health in the Aboriginal population, but the implications for foot health have not been investigated. Obesity is highly prevalent in the Australian population and it is higher for many Aboriginal cohorts. The literature established it is also associated with poor foot health outcomes but had not been investigated in the Aboriginal community. Smoking is a risk factor for chronic conditions and poor foot health, and the prevalence is extremely high in the Aboriginal population, which increases risk of foot complications. Aboriginal People have been shown to wear a lot of open shoes, and those that were wearing closed shoes perhaps were not an appropriate fit, putting the community at risk of foot complications. The rate of diabetes in the Aboriginal population is extremely high, and has been associated with all aspects of foot health. It is also a risk factor for other foot related chronic conditions (neuropathy and PVD), and directly related to ulceration, infection and amputation. The Aboriginal population is at risk of foot complications, but there is very limited research on foot health. There needs to be research specifically investigating risk markers, risk factors, relevant chronic conditions, foot biomechanics, and poor foot health outcomes.

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Paper 2: Static Ankle Joint Equinus: Toward a Standard Definition and Diagnosis.

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Author Contribution Statement

By signing below I confirm that James Charles contributed to the conception, data acquisition and analysis, preparation of the first draft and editing of the final draft of the publication entitled Static Ankle Joint Equinus: Toward a Standard Definition and Diagnosis.

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Introduction

Equinus is characterized by reduced dorsiflexion of the ankle joint, but there is a lack of consensus regarding criteria for definition and diagnosis. This review examines the literature relating to the definition, assessment, diagnosis, prevalence, and complications of equinus. Articles on equinus and assessment of ankle joint range of motion were identified by searching the EMBASE, Medline, PubMed, EBSCOhost, Cinahl, and Cochrane databases and by examining the reference lists of the articles found. There is inconsistency regarding the magnitude of reduction in dorsiflexion required to constitute a diagnosis of equinus and no standard method for assessment; hence, the prevalence of equinus is unknown. Goniometric assessment of ankle joint range of motion was shown to be unreliable, whereas purpose-built tools demonstrated improved reliability. Reduced dorsiflexion is associated with alterations in gait, increased forefoot pressure, and ankle injury, the magnitude of reduction in range of motion required to predispose to foot or lower-limb abnormalities is not known. In the absence of definitive data, we propose a two-stage definition of equinus: the first stage would reflect dorsiflexion of less than 10° with minor compensation and a minor increase in forefoot pressure, and the second stage would reflect dorsiflexion of less than 5° with major compensation and a major increase in forefoot pressure. This proposed definition of equinus will assist with standardizing the diagnosis and will provide a basis for future studies of the prevalence, causes, and complications of this condition. (J Am Podiatr Med Assoc 100(3): 195–203, 2010)

Search Strategy

This article reviews the literature on ankle joint equinus and devices that measure ankle joint range of motion, identified from searches of the EMBASE, Medline, PubMed, EBSCOhost, Cinahl, and Cochrane electronic databases. The searches were not limited by date or language and used various combinations of the following key words: *equinus contracture, ankle joint, range of motion, measur, apparatus, tool, device,* and *instrument*. This search strategy yielded 214 articles published between January 1, 1988, and October 1, 2008 (inclusive). The abstracts of these articles were read to select articles that were directly relevant to the topic of this review, and the reference lists of these selected articles were examined to identify additional relevant articles that had not been detected by the electronic search. This strategy provided 39 articles for inclusion in this review.

Ankle Joint Motion

The term *ankle joint* refers to the articulation of the talus between the lateral and medial malleoli. The movements of the ankle joint are dorsiflexion and plantarflexion, with the axis of rotation of the joint travelling obliquely downward and laterally, generally in line with the centre of the tips of the lateral and medial malleoli.[1–3] As a result of the position and alignment of the axis of rotation, the movement about the ankle joint was considered to be triplanar with a single degree of freedom[3,4] such that when moving the ankle joint from a neutral position through 25° of dorsiflexion there is a corresponding 4° of supination and 6° of external rotation.[3,4] Mattingly et al[1] used magnetic resonance imaging to examine the rearfoot during nonweightbearing movement of the ankle and found that the movement of the talus was biplanar rather than triplanar. Mattingly et al[1] did not specify which two planes the ankle joint moved through but implied that there was negligible eversion of the talus at the ankle joint.

Definition and Diagnosis of Equinus

Although it is generally accepted that static ankle joint equinus reflects a reduced range of dorsiflexion at the ankle joint, there is no consensus regarding what magnitude of reduction in dorsiflexion is required to constitute this condition. This lack of consensus has resulted in practitioners using a wide range of dorsiflexion limitation for diagnosis.[5] Sobel et al[6] suggested that to have a diagnosis of equinus, patients should have less than 0° of dorsiflexion (ie, no movement beyond plantargrade), whereas Orendurff et al[7] recommended a cutoff value of 5°.

On the other hand, DiGiovanni et al[8] recommended a cutoff value of less than 10° of dorsiflexion, which is in accord with the need for at least 10° of dorsiflexion to achieve normal gait and prevent potential increased loading of the forefoot during locomotion.[7,9,10] This latter suggestion is consistent with the more recent recommendation of Meyer et al[11] that rather than basing a diagnosis of equinus on a particular range of motion for dorsiflexion, a diagnosis should be confirmed when there is a reduction in dorsiflexion of a magnitude that increases tension on the Achilles tendon and loading on the forefoot. Although basing a diagnosis of equinus on a limitation of 10° of dorsiflexion would be expected to increase forefoot pressure during locomotion, there is no evidence that this will lead to the development of foot or lower-leg abnormalities. Furthermore, although a cutoff point of 10° may increase forefoot loading during locomotion, Orendurff et al[7] suggested that a 5° range of dorsiflexion be used for the diagnosis of equinus because they found that forefoot pressure was greater in patients with less than 5° of dorsiflexion compared with patients with more than 5° of dorsiflexion ($P < .05$). Thus, there is support for limiting dorsiflexion to either 5° or 10° as the basis for a diagnosis of equinus, with a 10° cutoff point being based on gait changes, which can increase forefoot loading, and a 5° cutoff point being based on a greater level of forefoot loading. However, although greater limitations in range of motion for dorsiflexion increase forefoot loading, the threshold reduction that leads to an increase in forefoot pressure sufficient to promote the development of foot or lower-leg abnormalities is not known, and a diagnosis of equinus should be based on criteria that will ultimately lead to the development of foot or lower-leg abnormalities.

Therefore, without any prospective studies to determine the effects of different levels of restriction of dorsiflexion on forefoot loading, and the longer-term effects of this loading on foot health, it is difficult to define a particular range of motion below which a definition of equinus can be justified. There is a need for prospective studies to examine the relationships between limitations in range of motion for dorsiflexion and the subsequent development of foot or lower-leg abnormalities. In the absence of definitive data, if using a valid and reliable tool, we propose based on the evidence currently available, a two-stage definition: stage 1 would reflect dorsiflexion of less than 10°, indicating minor compensation and minor increased forefoot pressure, and stage 2 would reflect dorsiflexion of less than 5°, indicating major compensation and major increased forefoot pressure.

Measuring Ankle Joint Range of Motion

Although the lack of a universally accepted definition of equinus poses some difficulty for diagnosis, this is further complicated by the fact that there is no standardized method for measuring dorsiflexion range of motion at the ankle joint. Traditionally, in a clinical setting, ankle joint range of motion is measured by the clinician dorsiflexing the patient's foot passively while aligning one end of a goniometer with the fibula and the other end with the fifth metatarsal bone. However, this method introduces a variety of potential sources of error. The positioning of the knee can affect the range of motion achieved because if the knee is flexed during the assessment it reduces the effect of the gastrocnemius muscle on limiting the range of motion, with the range of motion being limited by tension in the soleus muscle, bony limit, or the end of range of the ligaments. Whether the patient is sitting up or lying down and whether the subtalar joint is maintained in a neutral position can also affect the measurement of dorsiflexion recorded.[12,13] In a sitting position, the range may be limited by the neurovascular bundle,[12,13] and if the midfoot or rearfoot is allowed to move, the measurements will be compromised.[5]

Other major sources of error include the potential to incorrectly align the goniometer with the fibula and the fifth metatarsal and the axis of the goniometer with the axis of movement and the application of nonuniform torque, resulting in a greater or lesser degree of dorsiflexion.[14] Backer[15] compared goniometry measurements of ankle joint range of motion with radiographic measurement and found that clinical goniometer measurement overestimated range of motion, particularly when range of motion was limited. It was suggested that midfoot and rearfoot movement caused the overestimation in goniometric measurements, ie, if the foot is allowed to move at its many joints it will dorsiflex and increase the range of motion measurement without any additional movement of the ankle joint. Martin and McPoil[14] recently reviewed 11 studies that examined the reliability of manual goniometry and found good intrarater reliability for the measurement of ankle joint range of motion (intra-class correlation coefficient [ICC], 0.72–0.99) but poor interrater reliability (ICC, 0.29–0.81). Evans and Scutter[16] found very poor reliability for intrarater and interrater goniometric assessment of ankle joint range of motion. Evans and Scutter[16] reported that the ICC for intrarater reliability ranged from 0.12 to 0.78 with the knee extended and from 0.12 to 0.13 with the knee flexed. Interrater reliability was worse, with ICCs ranging from 0.03 to 0.05. Thus, although manual goniometry may be useful in some clinical contexts, its reliability is questionable, which limits its applicability for use in research.

Recognizing the limitations of manual goniometry, a variety of mechanical devices have been developed in an effort to standardize the assessment of ankle range of motion and improve reliability; 12 such devices were found in this database search.[11,17–26] Although some of these devices may be useful, they are not without their limitations, not the least of which is that they all use static nonweightbearing measurements to predict weightbearing dynamic function, and the validity of this is questionable. Other limitations are discussed herein.

Criteria

Several characteristics should be considered when selecting equipment to assess ankle joint range of motion. An appropriate device would ideally require only a single operator to use, be relatively inexpensive to build or purchase, be portable, align its axis of rotation with the axis of rotation of the ankle joint, reduce or remove any potential for parallax error when reading measurements, facilitate the adoption of standardized body and limb positions, hold the foot securely in a neutral position throughout range of motion, and provide valid and reliable measurements.

Number of Operators

Many clinicians and researchers work independently, making it desirable for any device to be able to be used by a single operator. The publications that describe the devices in the literature have not made it clear whether the devices can be operated by a single user[17,19]; however, it seems that in most devices this is the case, except for those developed by Moseley[18] and by Scharfbillig and Scutter.[25] Moseley's device uses a camera to record range of motion as a second operator applies torque to move the ankle through range of motion. It may be possible to reduce the number of operators required by mounting a camera that automatically records images. The device developed by Scharfbillig and Scutter[25] requires two operators because the inclinometer that records the change in angle of the ankle joint cannot be seen by the operator who has to apply the torque to move the ankle through its range of motion. Again, this tool could be modified by moving the inclinometer to a position where it can be seen by the operator applying the torque or by using an inclinometer that automatically records the change in angle.

Portability

Portability of measurement devices is desirable to allow data collection across a variety of sites and in the field. Many of the existing devices meet this requirement, but some are too large or too heavy to be easily transported.[17,19,20] This lack of portability is a significant disadvantage that considerably reduces the utility of these instruments.

Axis of Rotation

For any device to provide valid measures, its axis of rotation must align with the axis of rotation of the ankle joint. Most devices described in the literature have attempted to achieve this by aligning their axis of rotation with the lateral malleolus, which approximates the axis of rotation of the ankle joint[2,3]; however, they use a coronal axis, which allows for sagittal plane movement only. Moreover, most devices have a fixed axis of rotation that does not accommodate for differences in limb size. Only the device designed by Rao et al[26] has an adjustment that allows for the axis of rotation to be moved to better align with the ankle axis when assessing limbs of different sizes and shapes.

Reliability

It is essential that any device should produce reliable (ie, reproducible) measures. Reliability measures have been reported for most devices, and, for the most part, reliability has been high. This is particularly the case for interrater reliability, which far exceeds the interrater reliability that can be achieved using manual goniometry. Indeed, the device designed by Harvey et al[21] reported the lowest ICC for interrater reliability (ICC = 0.84), whereas that designed by Mayhew et al[20] reported the highest (ICC = 1.00). All of the devices reported good intrarater reliability, with ICC values ranging from 0.77 to 1.00.[17,20] Thus, it seems that most devices described in the literature have good intrarater and interrater reliability and, in particular, provide values that are considerably superior to those that can be achieved using manual goniometry. Furthermore, the variability in measurement with these devices is small, with the standard error of the measurement reported by Scharfbillig and Scutter[25] to be 0.63°, by Orendurff et al[7] to be 0.8°, and by Meyer et al[11] to be 0.60°. This low level of variability allows for precise estimations of differences in range of motion. If the clinician or researcher is using a custom-built tool with a standard error of the measurement less than 1°, this will provide sufficient sensitivity to discriminate between the 5° and 10° cutoff points of the proposed two-stage definition of equinus. This will minimize misdiagnosis and facilitate more accurate evaluation of the effects of any treatment plan on ankle joint range of motion.

Position of Body, Leg, and Foot

Achieving good reliability is, in part, related to the ability to standardize positioning of the body, leg, and foot during assessment to prevent compensatory movement or differences in muscle length, which may affect range of motion. Although standardization of body position can be achieved by having a volunteer sit or lie down, lying down is preferable because sitting up may apply tension on neurovascular tissues.[12,13]

Standardization of the positioning of limbs has been attempted with the assistance of braces or padding, but perhaps the best approach to standardizing the position of the leg being assessed was incorporated into the devices designed by Meyer et al[11] and Weaver et al.[23] Both of these devices attach directly to the leg along the line of the tibia, increasing the likelihood of being able to accurately achieve a neutral (90° to tibia) starting position. The device developed by Weaver et al[23] attaches to the anterior aspect of the tibia, eliminating the effect of muscle and fat. All of the other devices require estimation of the neutral starting point, a potential source of error. The devices designed by Meyer et al[11] and Weaver et al[23] also use heel cups to reduce rearfoot movement during assessment. This assists in ensuring the correct starting position and reducing compensatory movement in the leg and foot during assessments, which should assist in providing valid and reliable results. Indeed, in support of this, the reliability reported by Weaver et al[23] and by Meyer et al[11] was as good as, if not better than, that reported for the other devices. However, although the use of heel cups can reduce rearfoot movement, none of these devices fix the foot securely enough to prevent all compensatory joint movement, and this may potentially lead to some overestimation of ankle joint range of motion.

Torque Application

In addition to standardizing the body, leg, and foot positions during assessment, it is also important that standardized torque be applied to the ankle to achieve valid and reliable estimates of range of motion. All of the devices described in the literature attempted to apply standard torque. The device that seems to be best designed to apply constant, standardized torque is that developed by Meyer et al.[11] This device uses a crank that has an electronic digital display of the torque being applied at the joint axis to dorsiflex the ankle. Use of this digital display would allow for a more consistent application of torque and avoid parallax error, which might occur if a mechanical display were used. Other devices have also attempted to avoid parallax error by using electronic force and angle measurement components,[20–22,24] but many devices do use mechanical readouts and alignments, which are subject to parallax.[11,17–19,23,25,26] However, although there is the potential for parallax to introduce error into the assessment of ankle range of motion, no studies, to our knowledge, have specifically examined the magnitude of this error.

The magnitude of the torque applied is of paramount importance when testing range of motion. The devices identified in this review had a wide range of torques applied (6–25 Nm).[19,26] It is likely that increased torque will result in increased passive range, but it may be argued that the torque applied when measuring functional dorsiflexion should be similar to that experienced in normal gait. The most commonly used torque is 15 to 17 Nm[18,20,24–26]; we believe that this is the torque that best replicates that experienced in gait. It may also be argued that the amount of torque applied should change depending on an individual’s height, weight, and foot length. In an effort to address differences in foot length, some devices have allowed for the application of torque through a footplate, thus negating any effects of differences in foot length. Ideally, an appropriate torque would be applied that replicates an individual’s ground reaction forces during locomotion, but methods for determining such torque require sophisticated and expensive gait analysis equipment and specialized expertise to operate and so is beyond the scope of most clinical practices. In the absence of such equipment and expertise, it is proposed that a standard torque needs to be applied to compare findings from different studies. Because 16 Nm has been used frequently in the past, it is suggested that this be used as a starting point for other studies and for use in clinical practice.

Cost

For any device to be adopted widely, it would be favourable for its cost of purchase or construction to be inexpensive. From the published literature describing the various devices for assessing ankle range of motion, it is difficult to determine how expensive the devices would be to purchase or build, with the only cost of purchase provided by Mayhew et al[20] for a commercial multijoint isokinetic dynamometer that was used to assess ankle joint range of motion ($25,000 US). Thus, sufficient data are not available to comment on the costs associated with the construction of devices for the assessment of ankle range of motion.

Of the devices described in the literature reviewed, that designed by Meyer et al[11] rates highly on most criteria set by the authors and rates best overall compared with the other devices in this evaluation, suggesting that this device is potentially the most appropriate for use in clinical and research applications. Selection of a tool will vary depending on the situation, requirements, and resources of individual clinicians and researchers.

Causes of Equinus

The etiology of equinus is poorly understood, but a variety of potential causes have been identified and discussed in the literature. The reduction in dorsiflexion associated with equinus can be caused by tonic contraction or congenital shortening of the gastrocnemius or soleus muscle, adaptive shortening of these muscles, bony block, or joint stiffness.[10,27,28] A range of neurologic abnormalities can affect the functioning of the ankle (e.g., cerebral palsy and brain injury) and may, therefore, potentially contribute to the development of equinus. However, a discussion of all of these potential neurologic abnormalities is beyond the scope of this review, which instead focuses on the contribution of congenital deformities of the foot and ankle and the roles of aging and type 2 diabetes in the development of equinus.

Congenital Equinus

Sobel et al[6] conducted a prospective study in 60 idiopathic toe walkers aged 1 to 15 years and found that 46% had no dorsiflexion beyond plantargrade and that all had less than 8° of dorsiflexion, thus directly relating reduced ankle joint range of motion to altered dynamic function. Sobel et al[6] found that most toe walking in their sample was caused by a short Achilles tendon and that toe walking resolved with time in most participants. However, despite toe walking resolving with time, the range of dorsiflexion did not increase, indicating that some structural compensation in the foot occurred in some subjects that eventually allowed the heel to touch the ground during walking.

Acquired Equinus

There is evidence to suggest that equinus can develop as part of the aging process because the range of dorsiflexion has been found to be lower in the elderly. Grimston et al[29] compared ankle joint range of motion in young (14–16 years old) and old (70–79 years old) male and female volunteers (n = 120) and found that 14- to 16-year-olds had 29% greater ankle joint range of motion compared with 70- to 79-year-olds, with the greatest difference evident in females. The lesser ankle joint range of motion in older people is most likely due to increased passive resistive torque and passive elastic stiffness. Gajdosik et al[30] measured passive resistive torque and elastic stiffness in a cross-sectional study of 20- to 39-, 40- to 59-, and 60- to 84-year-old women (n = 81) using an isokinetic dynamometer to produce dorsiflexion and found that both of these parameters were reduced with age, as was range of motion for dorsiflexion. The younger women had, on average, 26° of dorsiflexion, the middle-aged women had 23° of dorsiflexion, and the older women had 15° of dorsiflexion. The authors suggested that the reductions in range of motion, passive resistive torque, and elastic stiffness were most likely due to reduced elasticity of ligaments, fascia, and skin. In a similar study in men aged 20 to 35 years and 65 to 80 years (n = 17), Allinger and Engsberg[19] evaluated ankle joint range of motion and reported that both groups had similar range of motion for dorsiflexion but that the older men had reduced plantarflexion, eversion, inversion, abduction, and adduction. However, in this study, skin markers were used to identify landmarks, which were recorded with video cameras, and movement of the skin over the bony landmarks during performance of the ankle movements may have confounded the ability to validly assess range of motion.

Kim et al[31] compared cross-sectional slices of muscle tissue using electron microscopy in young and old rats (n = 344) and found that age-induced sarcopenia was associated with muscle weakness, a reduced muscle fiber number, a reduced muscle fiber cross-sectional area, and increased muscle connective tissue content. The higher connective tissue content in the muscles of older rats exhibited a 3.7-fold greater extramycocyte (ie, connective tissue) area, and this tissue was found to contain more collagen (9.7%) compared with the muscle connective tissue of younger rats (3.7%). The increased connective tissue content in the muscle of older rats, particularly the higher collagen content, would be expected to contribute to greater passive tension and reduced extensibility, which could contribute to reductions in joint range of motion.

Type 2 Diabetes and Equinus

Type 2 diabetes is associated with increased oxidative stress and increased glycation of proteins, and this may contribute to a reduction in joint range of motion.[32,33] Markers of oxidative stress (protein carbonyls) were compared in soleus and plantaris muscles of nondiabetic and diabetic rats, and higher plasma glucose concentrations in diabetic rats were associated with greater oxidative stress and more oxidative damage of muscle proteins.[32]

A study[33] on human tissue has shown that higher glucose levels in patients with diabetes are also associated with increased glycation of proteins. Glycation of connective tissue proteins induces structural changes in tendons, including increased density of collagen fibrils, decreased fibrillar diameter, and abnormal fibril morphological features, which can contribute to the shortening of muscles and reduce their compliance (ie, stretch).[34,35] Connective tissue glycation in patients with type 2 diabetes would be expected to potentially contribute to reductions in joint range of motion, and, indeed, several studies[6,36,37] that have compared joint range of motion in patients with diabetes and controls have found reduced range of motion in diabetic patients. Komatsu et al[37] compared range of motion in large joints in 72 adolescents with diabetes and 46 nondiabetic controls and reported reduced range of motion in the diabetic group associated with higher glycated hemoglobin levels and accumulation of advanced glycation end products. Similarly, in a small study that specifically examined associations between diabetes and range of motion in the ankle, Salsich et al[38] compared ankle range of motion in an age-matched sample of 17 people with diabetes and 17 without diabetes and reported a reduced range of motion for dorsiflexion in patients with diabetes compared with controls. In a similar, but much larger, study, Duffin et al[36] compared range of motion in the ankle and foot joints of 302 adolescents with diabetes and 51 nondiabetic controls and found that patients with diabetes had less range of motion in the subtalar joint and in the first metatarsophalangeal joint compared with nondiabetic controls. Duffin et al[36] also reported double the prevalence of hammer and claw toes in patients with diabetes compared with controls, indicating that the changes in joint range of motion in the foot associated with diabetes were also associated with the development of foot abnormalities.

Therefore, the damage to proteins that can be caused by the oxidative stress and glycation associated with diabetes may adversely affect connective tissue structures around joints, leading to reduced range of motion in a variety of joints, including the ankle. These changes in range of motion seem to predispose patients to the development of equinus and potentially to the development of foot and lower-leg abnormalities.

Prevalence of Equinus

Without a universal definition of equinus, or a standardized method for the assessment of ankle range of motion, it is difficult to establish the prevalence of this condition. This point was emphasized in a review by Digiovanni et al,[5] who indicated that most of the literature reporting on the prevalence of equinus was based on observational or anecdotal evidence, making it difficult to estimate the true prevalence of the condition.

DiGiovanni et al[8] used an equinometer to examine ankle joint range of motion in patients with foot pain (n = 34) and in controls without foot pain (n = 34) matched for weight, age, and sex. Using ankle dorsiflexion of less than 10° as the criterion for equinus, DiGiovanni et al[8] reported that the prevalence of equinus in the group with foot pain was 65% compared with 24% in the control group and suggested that the prevalence in their control sample was generalizable to the population. However, the sample used in this study was limited to service veterans and their spouses, and the findings are, therefore, unlikely to be generalizable to the broader population.

Thus, at present, few studies have assessed the prevalence of equinus, with most based on observational or anecdotal evidence. Moreover, no reliable data are available on which a valid estimate of the prevalence of equinus can be based. Further work is required to establish the prevalence of this condition.

Complications of Equinus

During the stance phase of gait, when the knee extends immediately before heel lift, the gastrocnemius and soleus muscles work eccentrically to decelerate the forward momentum of the leg over the foot,[10,35] and if the range of dorsiflexion is limited during this stance phase, loading of the forefoot can be increased.[7,39] Thus, equinus may be associated with increased forefoot loading during locomotion.

Without a minimum of 10° of dorsiflexion at the ankle, when the leg and trunk move over the foot during locomotion, the heel will lift prematurely, which will increase forefoot pressure, or the foot will pronate excessively to compensate. It would be expected that the greater the limitation in dorsiflexion, the greater the loading on the forefoot. This proposition was supported by findings from Orendurff et al,[7] who reported that peak forefoot pressure was increased during gait in people with limited dorsiflexion. Indeed, the magnitude of the reduction in dorsiflexion was inversely related to forefoot pressure such that a greater limitation in dorsiflexion was associated with greater loading of the forefoot during locomotion. Subsequently, DiGiovanni et al[8] indicated that individuals who lacked the ability to dorsiflex the foot as a result of equinus developed pain in the midfoot, the forefoot, or both. This development of pain was most likely related to the increased forefoot loading reported by Orendurff et al[7] and excessive repetitive compensation at the midfoot and forefoot joints.

More recently, Kelly et al[40] proposed that equinus is commonly associated with structural breakdown of the foot and, if left unaddressed, could lead to unstable and inefficient gait, which would increase the risk of foot deformity and negatively affect walking ability.

Apart from increasing forefoot loading and increasing foot pain, evidence suggests that equinus may also be associated with an increased risk of ankle sprain, with a recent meta-analysis of 13 studies[41] reporting that reduced ankle joint range of motion was a predictor of ankle sprain. Ankle joint stability increases when the foot is dorsiflexed owing to the tapered nature of the talus, allowing it to fit more tightly between the tibia and fibula heads. Thus, a reduced ability to dorsiflex would reduce ankle stability during gait, predisposing to a risk of ankle sprain.

Conclusions

Equinus is defined as a reduction in the range of motion for dorsiflexion at the ankle, but there is no consensus regarding the magnitude of reduction required to constitute a diagnosis. Various levels of reduction in dorsiflexion have been suggested as constituting equinus, with 0°, less than 5°, and less than 10° of dorsiflexion being proposed as thresholds for diagnosis. Range of motion for dorsiflexion of less than 5° has been shown to significantly increase forefoot pressure during gait compared with dorsiflexion of 5° to 10°, and we recommend a two-stage definition of equinus, with stage 1 reflecting less than 10° of dorsiflexion and stage 2 reflecting less than 5° of dorsiflexion. Assessment of range of motion with sufficient precision for accurate diagnosis should be possible provided that the practitioner is using a reliable tool, with a low standard error of the measurement similar to that for devices already reported in the literature. There are no data indicating the longer-term effects of impaired dorsiflexion range of motion and increased forefoot pressure, and long-term prospective studies are required.

Apart from the lack of a standard definition for the diagnosis of equinus, there is also no standardized method for measuring ankle joint range of motion. Ankle joint range of motion has previously been measured primarily using manual goniometry, but in recent times a variety of purpose-built devices have been described and evaluated in the literature that provide better reproducibility of assessment. There remains no consensus on which device is most appropriate for use, as all have limitations that reduce their utility. In particular, they all provide non weight bearing measures of ankle joint range of motion, which may limit their ability to predict dynamic function. Nevertheless, the device designed by Meyer et al[11] seems to be the one that meets the most desirable criteria for such a device and so may be the most useful for clinical and research applications of those currently available; however, it may not be the most appropriate in all situations.

Without a standard definition of equinus or a standard method for assessing ankle range of motion, it is difficult to determine the prevalence of this condition or to investigate its etiology. Nevertheless, there is some evidence that equinus may be congenital or acquired, with some suggestion that its prevalence may increase with age and in response to complications of diabetes.

Further research should aim to standardize the method of assessment of ankle range of motion and develop a standardized definition for the diagnosis of equinus. This will facilitate investigation of the true prevalence of this condition and its etiology and allow for assessment of the adverse health effects of the condition and the efficacy of potential treatments.

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Paper 3: The design, development, and reliability testing of a new innovative device to measure ankle joint dorsiflexion.

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JAPMA ranks 2nd internationally for podiatry journals and is rated as a Q1 journal by the SCImago Journal Ranking system with an Impact Factor of 0.574.

The Charles Device has been filed for patented under the Australian Federal Governments new Innovation Patent, IP Australia batch reference number SPBI-0000894688 and IP Right Number 2016100376.

Author Contribution Statement

As sole author of the paper James Charles was responsible for all aspects of this research and development of the manuscript.

Abstract

Background: In a clinical and research setting, there is a need to reliable measure ankle joint dorsiflexion. Dorsiflexion is often measured by goniometry, but intra-rater and inter-rater reliability of goniometry have been reported as poor. Many other devices to measure dorsiflexion have been developed for use in clinic and research. An evaluation of twelve current tools showed that none met all desirable criteria. The purpose of this study is to design and develop a device that rates highly in all criteria, and can be proven to be highly reliable.

Methods: Participants were asked to lie supine on a treatment table. The participants had their foot placed in the Charles device and ankle joint dorsiflexion measured three times and all three readings recorded on a digital inclinometer. The mean of the three readings was determined to be the ankle joint dorsiflexion.

Results: The analysis used was intraclass correlation coefficient (ICC). There was very little difference in ICC single or average measures between left and right foot, so data was pooled, giving total n = 28. The single measure ICC was 0.998 with a 95% confidence interval of 0.996 to 0.998. The average measures ICC were 0.998 with a 95% confidence interval of 0.995 to 0.999. Limits of Agreement (LOA) for average measure were also very good: -1.30 to 1.65 degrees.

Conclusion: The Charles device meets all desirable criteria and has many innovative features increasing its appropriateness for clinical and research applications. It has a suitable design for measuring dorsiflexion, has high intra and inter-rater reliability.

Key Words: Ankle Joint, Dorsiflexion, Innovative and Reliability

Background

In a clinical and research setting there is a need to reliably measure ankle joint dorsiflexion. Clinically this is often measured by manual goniometry, however, this method introduces a number of potential sources of error. Intra-rater and inter-rater reliability of manual goniometry measurements of ankle joint range of motion have been reported as poor in a number of studies [1-3]. Thus, while manual goniometry may be useful in some clinical contexts, its utility as a mechanism of ongoing monitoring and for research is very limited.

Many other devices to measure ankle joint range of motion have been developed for use in clinical and research settings [4-15]. However differing aspects of design of these devices may affect both the validity and reliability of the measurements. Several studies have previously identified design criteria required for a device to measure ankle joint dorsiflexion effectively which can be applied to existing available equipment [3, 16]. An evaluation of twelve current measurement devices [16] showed that none met all desirable criteria i.e. requiring only a single operator for use; being relatively inexpensive to build or purchase; being portable; and having the ability to align the device axis of rotation with the approximate axis of rotation of the ankle joint; remove any potential for parallax error when reading measurements; facilitate the adoption of standardized body and limb positions; hold the foot securely in a neutral position throughout the ROM; and, provide reliable measurements [3, 16]. Although some tools reviewed rated highly with some of these criteria, none rated highly in all criteria [16]. The purpose of this study was to develop a device to measure ankle joint dorsiflexion that rates highly in all criteria, and show high levels of reliability.

Design and Development

The design of any device to measure dorsiflexion needs to be innovative and precise to meet all desirable criteria, and proven to be reliable. The Charles device was developed by the author in two pieces, one attaching to the anterior aspect of the tibia (tibial plate) with Velcro. The second part attaches to the plantar aspect of the foot (foot plate) with Velcro securing around the ankle, mid-foot and fore-foot, holding them securely. Both the tibial and foot plates of the Charles device are made of 5mm Perspex plastic, which is very strong, rigid and durable, but also transparent and lightweight. The use of Velcro also allows for adaptation to various leg and foot sizes. The distal part of the tibial plate fans out around the lateral and medial malleoli with a series of holes (figure 1) which allow for adjustment to the approximate location of the axis of the ankle (the tip of the lateral and medial malleoli) [17-20]. To be able to adjust the axis of the device to the approximate position of an individual's ankle axis is an innovation for measuring ankle joint dorsiflexion [16]. Attaching the tibial plate to the anterior aspect of the tibia allows for standardisation of measurement [4, 11].

The foot plate allows for uniform force to be applied with no adjustment of torque required for different foot length [13]. The rear or proximal aspect of the foot plate fans out over the medial and lateral malleoli (re-enforced with a steel plate), with a series of holes corresponding with the tibial plate holes. When the holes of both plates are matched to the approximate ankle axis, lateral and medial custom bolts are inserted. This locks the two plates together creating a hinge for rotation at an individual's approximate ankle axis (Figure 1).

The foot plate has an EVA heel cup fitted (small, medium and large), designed to eliminate most rear-foot movement [4, 11]. A tri-planar wedge (small, medium and large) is attached to the foot plate with Velcro, which allows the wedge to be adjusted for different foot sizes. The use of the tri-planar wedge is an important innovation, designed to limit pronation at the mid-foot and rear-foot, and help to hold the foot in neutral throughout measurement [16]. It is important to prevent foot pronation during the measurement, as a study has found that if the foot is allowed to pronate, it can increase the amount of dorsiflexion by as much as 10 degrees [21]. Although there is some research demonstrating that there is a small amount of difference in the amount of dorsiflexion between neutral and a supinated foot (between 2.5 and 3.5 degrees) [22-24], given the greater amount of possible change in ankle joint dorsiflexion occurring in conjunction with foot pronation, the goal of the triplanar wedge for the Charles device was to limit foot pronation.

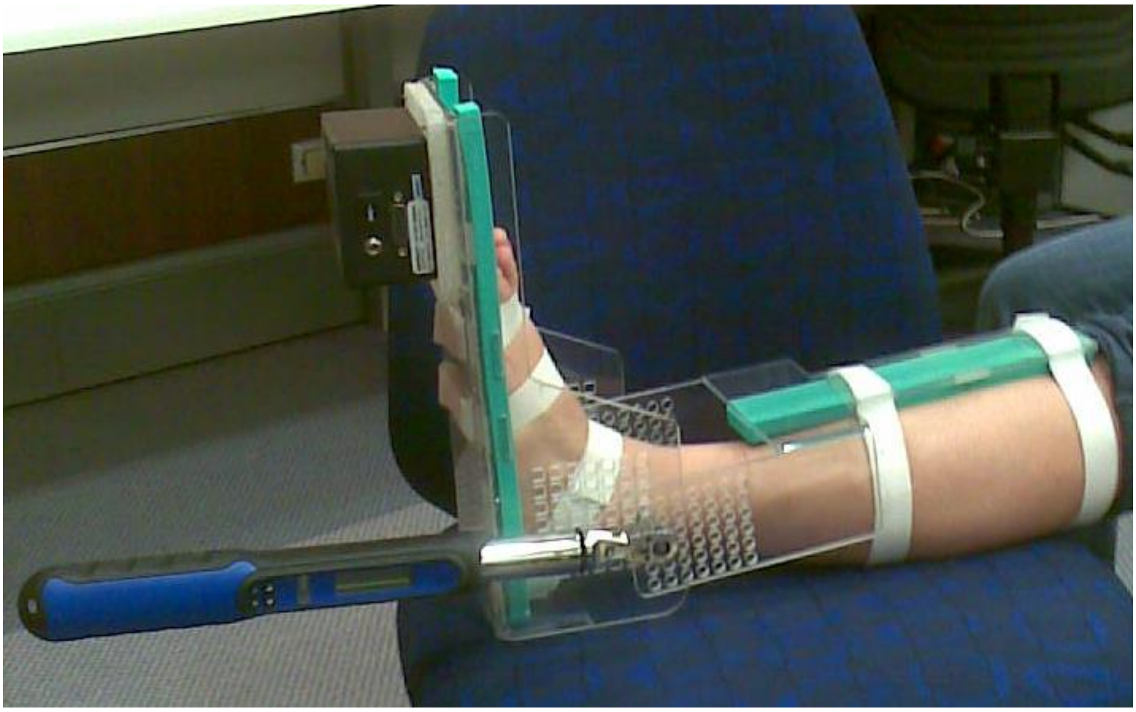

Figure 1 Charles Device

Torque: The torque to produce ankle joint dorsiflexion is applied via a digital torque wrench, attached to the custom locking bolts, which are inserted in the holes matching the tips of the medial and lateral malleoli. The torque wrench rotates the foot plate via the bolt, an innovation that allows the torque to be applied at the approximate axis of the ankle (Figure 1). The Warren and Brown® (WB) digital torque wrench (378000) was chosen for its accuracy. The WB digital torque wrench has a torque accuracy of +/- 1% (www.warrenandbrown.com.au). It also can operate with warning buzzer and LED flash indication for pre-settable target torque. The WB digital torque wrench is therefore extremely accurate and the digital display is an innovation that eliminates parallax alignment errors with reading dials and gauges [25].

Inclinometer: The digital inclinometer is attached to the distal aspect, or top of the base of the foot plate, which will eliminate parallax alignment error [25] from the paramount aspect of determining the ROM in degrees (Figure 1). The Reiker ® digital inclinometer [Reiker Electronics Inc.] RDI series, was chosen because it is extremely accurate to 0.01 degrees, Null repeatability <0.05 degrees, also can be used in single axis, and has LCD display (www.riekerinc.com).

Standard Body and Limb Position: The body and leg position needs to be standardised for ankle joint dorsiflexion testing [16]. Many body and leg positions have been tried in various publications, including supine, prone, sitting upright, hip and knee flexed [3-14]. If the hip and knee are flexed it will reduce the effect of the gastrocnemius, which can exert a significant effect on range of ankle joint dorsiflexion. If the participant is sitting upright, with hips flexed and knees extended, this will reduce the amount of dorsiflexion [3, 26, 27]. This is due to the nervous system, being continuous from the neck to the plantar nerves and the dura mater being most stretched in this position [27-29]. As this position does not replicate dorsiflexion when standing or walking, or a muscular or osseous restriction at the joint, the author believes that the ideal standardised body and leg position for measuring ankle joint range of dorsiflexion is lying supine with hip and knee joints in a neutral position [3, 16].

Ethics Approval: Ethical approval was granted from the Human Research Ethics Committee (HREC) at the University of Newcastle (Protocol Number 2010-1315). Fourteen participants volunteered to have their ankle joint dorsiflexion tested with the Charles device, by two raters. The participants were given an information sheet to read, if participants agreed to participate, a consent form was given to sign, and then an identification number given. All participants were required to be free of any ankle or foot injury, and be able to stand and walk independently.

Operators: The Charles device only requires one operator to measure ankle dorsiflexion, which also meets another important criterion set previously for a desirable device [16]. To test inter-rater reliability two different raters are required. The first rater was the designer of the Charles device and podiatrist James Charles, the second rater had no podiatry or research experience. The purpose of using a rater with no podiatric or research experience was to test if research or podiatry experience may play a role in improving reliability with the Charles device.

Procedure

The participants were asked to lie supine on a level treatment table. Then each rater marked the approximate centre of the distal tips of the lateral and medial malleoli with a black texta marker [6, 25]. The tibial plate was attached to the anterior aspect of the lower leg, with the distal aspect over the lateral and medial malleoli, and the participant's foot was secured in the foot plate (Figure 1). The custom bolts were inserted in the holes in both plates corresponding with malleoli texta marks, allowing the device to rotate at the individual's approximate ankle axis (Figure 1). The WB digital torque wrench was attached to the custom bolt. The participant was asked to relax and not to assist or restrict in any foot movement. The torque wrench was set at 8Nm as a similar torque was used in other studies [4, 5, 7, 8, 16], and this torque produced a wide range of dorsiflexion in this study i.e. -12.2 to 38.9 degrees (supplementary file 1), supporting this as an appropriate torque. Before the measurements were taken, one practice was performed to help prevent creep and relax the participant [9]. The torque was applied three times and all three readings recorded on the inclinometer. For the purpose of standardising measurements, zero degrees was when the foot and foot plate were perpendicular to the ground. The mean of the three readings was calculated and determined to be the ankle joint dorsiflexion. This exact procedure was conducted on both left and right feet by both raters. Once the first rater had completed all six measurements, the second rater waiting outside was asked to conduct the procedure, while the first rater waited outside. The participants were not told of the readings until after all 12 readings were complete.

Data Analysis: Statistical analysis was performed using the Statistical Package Social Science software version 21.0 (SPSS Chicago, Illinois, USA). Intra-class correlation coefficients (ICC) using a two-way mixed model with 95% confidence intervals (CI) were calculated to determine the level of agreement between raters for the average of three measurements and for the first measurement only of the left and right ankle of each participant. ICCs were interpreted according to cut-offs suggested by Fleiss: >0.75 denotes excellent reliability; 0.40–0.75 denotes fair to good reliability; and <0.40 denotes poor reliability [30-32]. An ICC is a statistical test which can be used to determine the level of agreement of quantitative measurements. It is a description of how strongly measurements in the same group resemble each other [33]. ICCs have been used by other similar studies measuring reliability of ankle joint dorsiflexion [3, 16], which makes it easier for comparison with other research. Paired t-tests were performed for test-retest ankle joint dorsiflexion measurements to determine whether a statistically significant difference existed between scores. The level of significance was set at $p < 0.05$. The 95% limits of agreement (LOA) were calculated to determine the range in which 95% of the differences between the measurements performed by each rater would be expected to lie. Normality testing of the data was conducted to justify the use of the paired t-tests.

Results

Fourteen participants volunteered for the reliability study, 7 female (age 18-45 yrs.) and 7 male (aged 18-50 yrs.), with a total age range of 18-50 years. This number of participants was based on other similar studies using less or a similar number [5, 6, 9, 11, 13, 14, 16]. The participants had good range of dorsiflexion, -12.2 to 38.9 degrees, (supplementary file 1) which is ideal to confirm the reliability of the Charles device with a variety of foot types.

The inter-rater reliability for the first measurement taken was very high with an ICC of 0.998 (96% CI 0.996 to 0.998) suggesting excellent reliability. The paired t test showed no significant difference in the measurement between the raters (p=0.229) and the limits of agreement were less than 4 degrees in total. Inter-tester reliability was also excellent for the average of three measurements with an ICC of

0.998 (95% CI: 0.995 to 0.999). There were no significant difference between measurements between raters (p=0.362) and smaller LOAs than when the first measurement only was used (LOA -1.30 to 1.65 degrees).

	Mean (SD)	ICC	95% CI	P value	LOA(degrees)
First Measurement					
Rater 1	9.83 (13.06)	0.998	0.996 to 0.998	0.299	-1.60 to 1.76
Rater 2	9.68 (13.10)				
Average Measurement					
Rater 1	9.82 (13.09)	0.998	0.995 to 0.999	0.362	-1.30 to 1.65
Rater 2	9.65 (13.08)				

Table 1 Intertester reliability of range of ankle joint dorsiflexion measured with the Charles device (N=14, 28 ankles).

ICC= intra-class correlation coefficient
95% CI= 95% confidence interval
95% LOA = 95% Limits of agreement

Discussion

Overall the ICCs with the first measurement and the average of three measurements demonstrated the Charles device has excellent inter-tester reliability and is comparable to other studies [16] (Table 1). Specifically the ICC was higher or equal to the highest ICC results in similar studies [4-6, 8-13], with reported ICCs for ankle joint dorsiflexion measurement in the literature ranging from 0.97 – 0.99, with only Mayhew [8] having slightly better results, with an ICC of 1.00. The LOAs were slightly wider when the first measurement of each tester was used in the reliability analysis, however the range was still less than 4 degrees indicating a relatively small change in the measurement is highly likely to represent a true change rather than chance.

In this present study data for the left and right limbs were pooled. Although this has been done in similar studies, use of pooled data is debated in the literature due to the assumption of independence of data [34, 35]. However with studies where the foot is being examined in isolation and not being compared with outcomes from a disease, there is less concern with pooling data. With the results of this study and many other similar studies, there are often different readings for left and right feet, with no correlation therefore the independence assumption has not been breached [34, 35].

The Charles device is designed specifically to measure ankle joint dorsiflexion. The Charles device has an innovative design, with precision tools, standardisation of the leg and body, and attempts fixation of all other foot joints except the ankle joint. The adjustable axis of rotation of the Charles device that can be aligned with the approximate axis of rotation of an individual's ankle axis is paramount to the effectiveness of this device, as this does not force the multi-planar movement [17] of the ankle to move in a uni-planar manner. The standardisation of the body and leg position used when measuring with the Charles device is also an important addition to achieving a reliable measurement, as incorrect position has been demonstrated to increase or decrease ankle dorsiflexion [3, 26, 27]. Applying the torque to the approximate axis of the ankle is an innovation which replicates best the natural foot movement. The use of a heel cup [4, 11], adjustable arch support (tri-planar wedge), and fixation of the ankle, mid-foot and fore-foot with Velcro straps is the most important innovation that limits pronation and attempts to hold the foot in neutral throughout measurement [36] and is likely to have significantly contributed to the high inter-rater reliability of this device. The precision of the tools used i.e. WB digital torque wrench and the Reiker digital inclinometer also increases accuracy and eliminate parallax errors (www.riekerinc.com, www.warrenandbrown.com.au).

Limitations: A limitation of the Charles device is that it is not appropriate for young children with small feet, although a smaller version could be produced. The cost ($2000 AUD) may inhibit some practitioners for clinical use, however as the majority of cost is associated precision measurement tools, substitution with less expensive alternatives could be investigated. Although the participants in this study were asked to not assist or restrict in any foot movement while being tested this was not controlled, which may have affected dorsiflexion, but not likely affected reliability. Although every effort has been made to hold the foot in a neutral position and prevent pronation, there is likely to still be some movement. The reliability testing of the Charles device was conducted by the designer and developer of the device. Although this may be considered a weakness with a conceived possibility of bias, the author believes that all procedures were followed precisely. Although training was provided to the rater with no podiatry or research experience, it was limited and locating the tips of the malleoli by this rater may not have been consistent, however this may have also been the case with the experienced podiatrist.

Conclusion

Although there is no consensus on desirable criteria for a device to measure ankle joint dorsiflexion, the Charles device meets all the desirable criteria set in two previous reviews [3, 16]. It has a suitable design for measuring ankle joint dorsiflexion, it is easy to use, stops most unwanted foot motion (measures ankle movement), attempts to hold the foot in neutral throughout measurement, has adjustment of axis to match approximately an individual's ankle joint axis, applies a standard torque at the approximate ankle joint axis, eliminates parallax error, is extremely portable, only requires one operator, is relatively inexpensive, and has high inter-rater reliability. Although the device has innovative features increasing its appropriateness for clinical and research applications, it must be stated that other researchers and clinicians may have other criteria not met by this device. However the author contends that the Charles device meets some shortcomings of other previous devices.

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Paper 4: An evaluation and comprehensive guide to successful Aboriginal health promotion.

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Acknowledgement: I would like to acknowledge the traditional owners of all the many Aboriginal and Torres Strait Islander Nations that make the great continent of Australia. I would like to pay my respects to the Aboriginal and Torres Strait Islander elders past and present, also the young community members, as the next generation of leaders and representatives.

Disclaimer: In some instances in this paper I will be using the term 'Aboriginal' to describe both Aboriginal and Torres Strait Islander Peoples. This is due to word restrictions, and no disrespect is intended to any individual or group.

There is an obligation and desire to publish and present some of the outcomes of this Aboriginal research in free, open access Aboriginal health journals to disseminate the findings more easily to the Aboriginal community. Therefore the guide to health promotion and the results of the ankle dorsiflexion was published in a peer reviewed Aboriginal health journal, Australian Indigenous Health*Bulletin.*

Citation: Charles J (2015) An evaluation and comprehensive guide to successful Aboriginal health promotion. *Australian Indigenous HealthBulletin* 16(1).

Author Contribution Statement

As sole author of the paper James Charles was responsible for all aspects of this research and development of the manuscript.

Abstract

Objective: The object of this paper is to examine and evaluate an Aboriginal Health Promotion program, including its effectiveness in reducing injury, poor foot health, smoking, alcohol consumption and improving diet in young Aboriginal People in a rural community. In addition study aimed to provide a comprehensive guide to successful health promotion in Aboriginal communities.

Methods: Evaluation of assessments, results and feedback on a comprehensive Aboriginal Health Promotion package, which consisted of education session, and practical hands on sessions, designed to reduce injury, poor foot health, educate on the effects on smoking, alcohol consumption, and poor diet, particularly related to exercise, training and playing sport.

Results: Rates of ankle, knee and back injury were very high for participants on entry to the program. Only one participant that reported back pain at the 4 month follow up had an injury in that period and all participants stated that they had better knowledge of how to prevent injury. Of participants that gave feedback at the 4 month follow up, 6 out of 16 (37.5%) had lost between 1 and 3 kg. 5 out of 16 (31%) had attempted or have now quit smoking, 3 out of 16 (19%) had reduced or quit drinking alcohol and 3 out of 16 (19%) had increased their intake of fruit and veg.

Conclusions: The multifaceted health promotion was very successful. Attendance at session was very high, which was a huge part of the success. The education sessions were flexible, and very practical and encouraged participation. The program was delivered how and when the Aboriginal community wanted it. Due to community ownership there was real enthusiasm for the program, and this was one of the main reason for the success.

Implications: The information gained from this evaluation will assist in identifying and developing a formula for success in Aboriginal Health Promotion that could be duplicated in any Aboriginal community on any topic.

Introduction

The World Health Organisation (WHO) states health promotion is giving people power to have control over their own health outcomes (1). It is also a thorough social and political process, which improves the skills and builds capabilities of people, but importantly community participation is paramount to successful health promotion (1). The Ottawa Charter 1986 has three basic strategies for health promotion, these are advocacy, enabling and mediating (2). Although the Ottawa Charter has very good principles for health promotion in 1997 WHO Jakarta Declaration added very importantly, and very relevantly to the Aboriginal community, that people need to be central to health promotion and, that community participation is essential for success (3). The Jakarta Declaration also promoted community capacity building and empowerment (3). The most recent advice on health promotion from the WHO, the Helsinki Statement in 2013, calls on government to provide more involvement and funding (4).

The funding for the Aboriginal health promotion being evaluated is this paper was provided by the NSW State Government via Hunter New England Health with their Aboriginal Health Promotion Program. Aboriginal People suffer with a high prevalence of chronic conditions which accounts for approximately 60% of the premature morbidity and mortality occurring in this population (5). A number of these chronic conditions including diabetes, heart disease and peripheral vascular disease are highly prevalent within Aboriginal communities, and, have been shown to be associated with poor health outcomes (6-8). Many chronic conditions are associated with being overweight or obese, smoking, alcohol consumption, and sedentary life style, which were a target of the health promotion examined in this paper.

The key overarching focus of the health promotion being reviewed in this paper is preventing musculoskeletal injury and keeping Aboriginal People active and playing sport. Aboriginal Australians are very athletic, and have been for many thousands of years (9, 10), this has been an evolutionary process (11), developed through survival skills required to thrive in a very harsh environment (12). Sport and athletics is very important to many Aboriginal cultures, not just for survival but ball games were played and were witnessed by colonist in 1840, who reported the Kaurna (Aboriginal Tribe) people playing ball games (10). Obviously athletics was also essential for hunting, which would have required great acceleration and speed, but also great endurance at times (13). The great running speed of ancient Aboriginal Australians has been documented in foot prints at Lake Mungo in the Willandra Lakes area of NSW (14), were an Aboriginal man was running at approximately 30Km/h (approx. 20,000 years ago) (15). This athleticism has continued with Aboriginal men participation in the Australian Football League (AFL) and Nation Rugby League (NRL), estimated to be approx. 20% (16) and high percentages in most other sports and athletics.

With the importance of participation in sport at all levels for individual and Aboriginal communities, injury diagnosis, understanding the cause of injury and prevention of injury are extremely important. There has been limited research into ankle, knee and back injury in Aboriginal populations, but a study showed that the most common musculoskeletal injury in rural and remote areas was lower back injury and the commonly reported pain level was 'high' (17), with a specific survey (18). Research in an Aboriginal population in Queensland reported that there was a higher prevalence of chronic musculoskeletal problems than in the non-Aboriginal population, and the pilot study also found that this was partly due to labouring type of employment (19). A study of chronic conditions in an urban Aboriginal population in Melbourne found that 14% of chronic conditions were musculoskeletal problems (20). Researchers also reported that approximately 30% of Aboriginal men and 50% of Aboriginal women had a long term lower back complaint (21) and another study reported similar percentages in indigenous communities around the world (22).

Objectives

The health promoters targeted Aboriginal male and female rugby league players, as they were healthy and active, and where considered to benefit the most from the program. An important objective was to access Aboriginal community members for foot problems which are a risk for injury, and potentially prevent physical activity in sport. The program also was designed to educate individuals on their personal musculoskeletal system, body function and sport specific training regimes which empower individuals with the ability to manage and prevent injury. It was an objective to produce a health promotion program that could be delivered in any Aboriginal community with some modification.

An important objective was to encourage participants to have better dietry intake, especially fruit and vegitables. Being over-weight or obese is a problem for all Australians with 56-60% of the Australian population tested were overweight or obese but percentages are higher for Aboriginal People with the exception of some Aboriginal men cohorts (23), so it was anticipated that if participants improved their diet they would also lose weight. Smoking tobacco in the Aboriginal population is reported to be 45% compared with 22% for non-Aboriginal Australians (24), and it was an objective to educate participants of the implications on health due to smoking. Also reducing alcohol consuption was another objecvtive, especially high levels of consuption, because approx 19% of Aboriginal People over 15 years are drinking at levels putting them at risk of harm (25). To prevent musceloskeletal injury and increase knowledge about basic treatment of injury was also an important objective. Other objectives were to promote and encourage being active, exercising, training, and participation in sport. The promotion of all these objectives will decrease obesity, chronic conditions and prevent premature morbitiy and mortality in the Aboriginal population.

Aboriginal Health Promotion Program

The program was designed specifically for the local Worimi Aboriginal community in Forster/Tuncurry NSW. The unwritten theme for the program was Aboriginal community engagement, consultation and ownership. The engagement and consultation meant the program was delivered how, and when the community wanted it, which created real enthusiasm for the program and 95% of participants attended all sessions. The program was flexible and the theory session's delivery times were changed at the communities request and presented on a weekend which proved successful. A local Aboriginal advisory committee was setup which is extremely important for any Aboriginal health promotion, as the committee can not only give advice but act as a liaison between health promoters and the local Aboriginal community.

There was an Introduction session outlining the program, then a series of educational sessions on smoking, alcohol, diet, and injury prevention. There were also practical session on good training techniques and injury prevention, including ankle and knee strapping. The theory education sessions were important but they were also interactive, which encouraged engagement, via questions and comments. The theory education sessions used plain language, also pictures and animation to demonstrate theory. A written resource in the form of a booklet was produced, but also importantly an audio visual resourse (DVD) was provided for those participants that may have literacy difficulties. There was also an injury evaluation session on each individual, which was educational for individuals and the group, e.g. participants identified when ankle strapping would be appropriate to prevent injury, and then shown how to provide the strapping. All theory-based educational session's entailed PowerPoint presentations, but, to keep the participants actively engaged, many practical examples were given, and relevant storytelling used as a meaningful and engaging way for the participants to interact and learn.

Traditional Aboriginal Health Promotion

Many Aboriginal tribes have been practising health promotion for millennia with Dreaming. Many Dreamtime stories are about creation but many are also about learning. They are often set in conflict, right and wrong, jealousy, arguments, disagreements, and listeners are able to learn from the mistakes made by animals, creators and people in these stories. Traditional lifestyles were able to be guide people through Dreamtime stories, which will keep people safe and well e.g. eating the right foods, in the right amount, at the right time of year, which is like modern day health promotion. When Australia was colonised the colonist tried to change Aboriginal Peoples way of life through health promotion. Unfortunately it was inappropriate health promotion, and was unsuccessful. Mostly because they were forcing western ideas, with no consultation, engagement or involvement of Aboriginal People. Unfortunately a lot of modern health promotion in Aboriginal communities is still culturally inappropriate.

Often well-meaning people go into Aboriginal communities wanting to deliver health promotion. Often they already know the health topic and have the health promotion already developed, but it may not be a priority of the local Aboriginal community and it may not be how they want it delivered. Looking at the Ottawa Charter, Jakarta Declaration and the Helsinki Statement (2-4), for any health promotion to work the community must be involved and take ownership. There also needs to be appropriate language used, community engagement, local community consultation and involvement.

Aboriginal Artwork

A local Aboriginal artisit (Terry Johnston) was comissioned to do some specific art for the program. Each piece of art had a story which was relevant to the local Aboriginal community e.g. figure 1 Dolfins are important in Worimi culture. The art was used in all the sessions on PowerPoint slides, booklet, DVD and promotional material. The art was bright, traditional and used relevant stories, and all the participants connected strongly with the art, this facilitated community ownership and belonging.

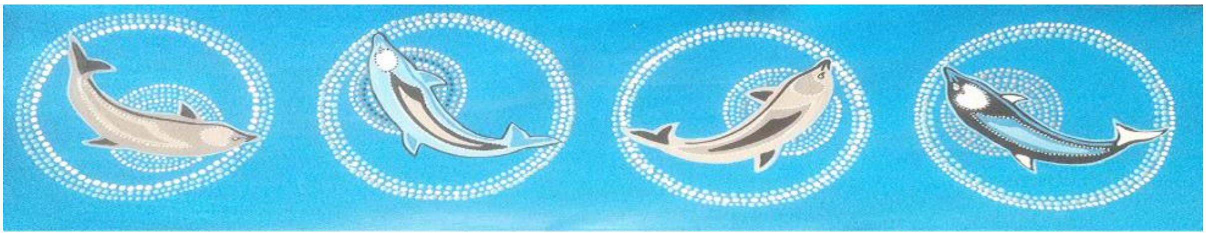

Figure 1: Terry Johnston

Support

The health promotion had great support from Tobwabba Aboriginal Medical Service staff and management to implement the program. The program also had support from the Forster Hunter New England Health, Aboriginal Health Education Officer; who helped with organisation and provided some euipment, and also participated in practical demostrations, and the Aboriginal football team coordinators (men and women for Aboriginal rugby league Knockout), who liaised with the community to coordinate the program. The National Indigenous Television (NITV) also came to film the program in progress. This network of wide support from different Aboriginal individuals, groups and organisation is essential and played a huge role in the success.

Baseline

The focus of the assessments was to evaluate each individual's risk of injury, which could prevent those individuals from being active and playing sport. The assessment also recorded current smoking status, alcohol consumption, fruit and vegetable intake, past and present injury, and current levels of activity and weight. The Aboriginal art below (figure 2) represents injury to bone.

Injury assessments

Injury was assessed with a customised musculoskeletal assessment survey (Appendix 4). In the past two years there were a total of 27 injuries, six knee, 10 ankle and 11 back injuries, which were evenly spread between males and females. Females had five ankle, three knee and five back injuries. Males had five ankle, three knee and six back injuries. Bearing in mind that some individuals had an ankle, knee and back injury in the past two years, never the less this is a very high rate of injury, and back injury was very similar prevalence to research studies in a rural Aboriginal community (21). What is surprising is the very high rates of ankle injury at approx. 42% which is approx. 40 times high than a study in 2004 (17).

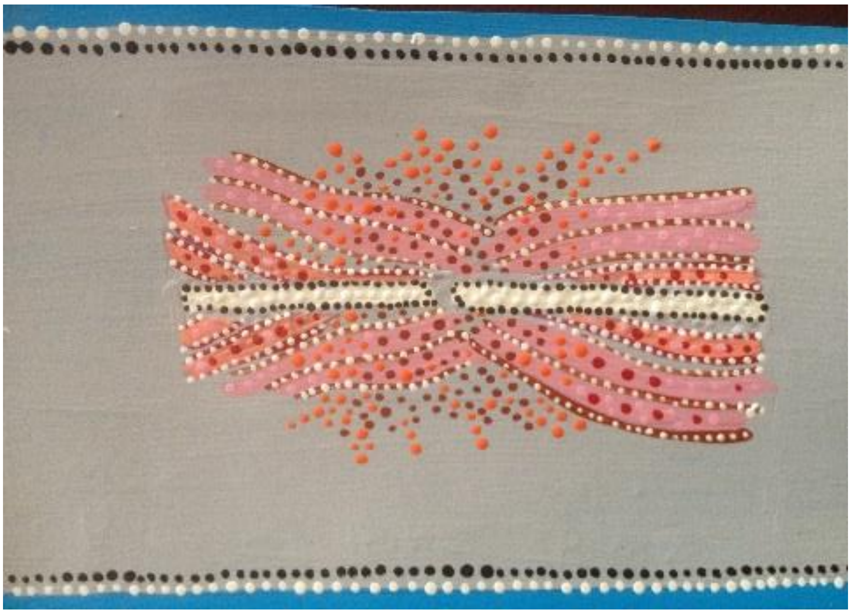

Figure 2: Terry Johnston

Foot Health Assessments

The art below (figure 3) represents foot injury and pain in the community. One important screening tool was arch height i.e. low, normal and high. Low and high arch have been associated with different foot injury and complications (27-35). Fifty-seven percent of participants had a high arch, and this has been associated with ankle instability, strain and pain (36). Ankle range of motion (ROM) was tested by a qualified podiatrist. Limited dorsiflexion ROM at the ankle can precede foot, lower leg pain and injury (37, 38), but has also been associated with athleticism in young people (39). Those people with less than 10 degrees of dorsiflexion are consider to have equinus of the foot (37). This has also been further categorised to stage 1 <10 degrees and stage 2 <5 degrees, with stage 2 putting the individual at great risk of foot complication (37, 38). The participants had their ankle joint dorsiflexion measured with an accurate and reliable device (41). The assessments showed all Aboriginal men tested had less than 10 degrees of ankle dorsiflexion but 83% had less than 5 degrees (stage 2). 27% of women had less than 5 degrees (stage 2) but the remaining 73% had a very healthy average of 25 degrees. These results suggest the Aboriginal men that participated in this injury health promotion are at greater risk of foot complication. The findings are extremely interesting and do put these people at risk of the injuries mentioned above in future, but fortunately the health promotion program did educate on how to prevent these types of injury.

Figure 3: Terry Johnston

Results

Only one participant that reported back at the 4 month follow up (participant sixteen) had a musculoskeletal injury in that period and all stated that they had better knowledge of how to prevent and treat injury. Of the 16 participants that gave feedback at the 4 month follow up six out of 16 had lost between 1 and 3 kg, even though advice in education sessions was not specific about weight loss. Five out of 16 had attempted or have now quit smoking, three out of 16 had reduced or quit drinking alcohol and three out of 16 had increased their intake of fruit and veg.

Participant Compensation

It is extremely important to compensate Aboriginal participants for the time to attend sessions, it is respectful and reciprocity is important in many Aboriginal cultures. The funds from the project did enable the health promoters to provide good quality shoes which protect and prevent foot strains and pain, and were good general shoes for activity. Basic inserts which are able to prevent injury e.g. lateral wedges to put in shoes to prevent ankle instability and sprain. Also arch support (orthotics) was provided for those that had low arch (flatfeet) to prevent or treat plantar fascia strain. Heel lifts were provided for those participants that had reduced range of motion at the ankle to reduce and prevent calf muscle and Achilles tendon strain. Health promoters need to be aware that when any testing or assessments are conducted, if any health issues are discovered, treatment needs to be provided. The compensation provided in this health promotion was ideal in many ways, it provides something participants valued, and will improve health and prevent complication in future.

Sustainability

Sustainability health promotion is extremely important, Aboriginal People and communities don't want 'one off' projects, they want continuality and 'on going' projects that they can provide themselves. A poster and booklet/pamphlet was produced and provided to all participants, which has all the relevant educational information for the project, which could be provided to any Aboriginal community anywhere in Australia. A DVD was also provided to all participants with all the education sessions, this also gives participants another option other than reading material. This is important as many Aboriginal people are visual learners and have been learning orally for thousands of years. Although literacy and numeracy is improving in some Aboriginal communities there are still issue with literacy. Providing this material also empowers the Aboriginal community to build their own capacity to learn and share skills and information.

Feedback

Participants were required to give feedback on the programs education sessions 4 months after they had been delivered. All participants that gave feedback at the 4 month follow up, all participants reported having more knowledge about the effects of smoking, alcohol, diet and correct training, on their health and performance in sport and activity. The personal feedback about the program from participants and other community members that observed the program was very positive. Most importantly participants said they had a better understanding about the musculoskeletal system and how to identify an injury.

Conclusion

The Aboriginal Health Promotion examined was successful for several reasons. The local Aboriginal community was asked what type of health promotion they would like, on what topic and how would they like it delivered. No one should go to an Aboriginal community with their health promotion already prepared. It is paramount to consult, engage and involve the Aboriginal community, ask the community, the what, when, and how, they need to have ownership for it to be successful. Another reason this health promotion was successful was a local Aboriginal advisory group was setup to represent the community for advice and liaison. Humour is a big part of Aboriginal society, it is advisable to make any health promotion light hearted when possible. It is ideal to make the health promotion message straight forward, use simple language, with not too much reading material. If Aboriginal art, music, colours, language and slang, is used Aboriginal people will affiliate more with the program. Ideally a local Aboriginal person should be used to deliver the health promotion, preferably with some connection with the health issue, and well known, as others will connect. The toll should be as practical and hands on as possible. Some compensation should be provided to the Aboriginal participants/community for their time. Ideally it would be something health related, that may help or improve health in some way. Other Aboriginal organisations, groups and individuals in the community should be involved. Often Aboriginal People are very competitive by nature, and very good a games and ball sports, so a good strategy is to incorporate games, challenges and other activities into health promotion. There needs to be a follow up, not just to evaluate the effectiveness of the health promotion but also follow up with participants to give them the opportunity to give feedback on the program.

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Paper 5: The relationship between ankle joint range of dorsiflexion, arch height and barefoot plantar pressures in Aboriginal Australians.

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Disclaimer: In some instances in this paper I will be using the term 'Aboriginal' to describe both Aboriginal and Torres Strait Islander Peoples. This is due to word restrictions, and no disrespect is intended to any individual or group.

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Author Contribution Statement

By signing below I confirm that James Charles made substantial contribution to the conception, design of the study, acquisition of data, drafting the article, revising it and final approval of the version to be submitted, entitled: The relationship between ankle joint range of dorsiflexion, arch height and barefoot plantar pressures in Aboriginal Australians.

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Co-authors: Andrea Coda and Vivienne Chuter

Date 16/06/16

Signature of Co-Authors:

Andrea Coda:

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Abstract

Introduction: High plantar pressures are associated with pathologies such as foot pain, plantar fasciitis, Achilles tendonitis and midfoot arthritis. Recent research suggests Aboriginal Australians may have a high prevalence of a high arched foot type and ankle equinus due to isolated gastrocnemius tightness, which may significantly contribute to increased plantar pressure and foot pathology. The aim of this study was to investigate the relationship between arch type, ankle dorsiflexion and plantar pressures in a cohort of Aboriginal Australians.

Methods: This was a cross sectional study undertaken between May 2012 and May 2015. A volunteer sample of fifty Aboriginal Australians from three regions in New South Wales, Australia participated in this study. Ankle dorsiflexion measurement, and classification of arch type were assessed, also forefoot and midfoot Peak Pressures (PP) and Pressure Time Integrals (PTI) were measured.

Results: Reduced ankle dorsiflexion was moderately and significantly correlated with increasing midfoot PP (r= -0.301, p=<0.01) and PTI (r= -0.367, p=<0.01), and increasing PTI at the lateral forefoot (MTPJ 2-5) (r= -0.388, p=<0.01). A low arch foot type was moderately and significantly correlated with midfoot PTI (r=0.442, p=<0.01). Regression analysis showed the only significant predictors of lateral forefoot PTI were BMI (beta=0.301 p=0.007) and ankle dorsiflexion (beta = -0.258, p=0.01). For midfoot PTI, BMI (beta =0.286, p=0.01) and foot arch type (beta =-0.234, p=0.04) where the only significant independent predictors.

Conclusion: Our study demonstrated an independent relationship between reduced ankle dorsiflexion and increased lateral forefoot PTI. We also found a low arched foot type was an independent predictor of increased midfoot PTI. These findings suggest these biomechanical variables make a significant contribution to plantar pressures in Aboriginal Australians, and this may contribute to pathology.

Key Words: Aboriginal, Dorsiflexion, Arch Type, Foot Pressure, Complications

Introduction

High foot plantar pressures are associated with pathologies such as foot pain, plantar fasciitis, Achilles tendonitis, midfoot arthritis, also increased risk of falling in older people and the development of foot ulceration in diabetes cohorts (1-3). It is well established that the incidence of foot complications associated with elevated plantar pressures, including foot ulceration and amputation are significantly higher in Aboriginal Australians than in those in the general population (4). In relation to foot pressure there is some suggestion that normally foot pressures under the metatarsal heads are less than 10 kg/cm^2 (5). A small study (n=16) also found normal foot pressure i.e. nomalized maximum pressure to be approx. less than 5 kg/cm^2 for both children and adults (6). Foot deformity, body weight and presence of neuropathy are all known to be associated with increased plantar pressures (7). However biomechanical risk factors for high plantar pressures have also been proposed, including foot type and restricted ankle joint dorsiflexion. Recent research suggests Aboriginal Australians may have a high prevalence of a high arched foot type and ankle equinus which may significantly contribute to increased plantar pressures in this population (4), and to foot pathology.

Studies investigating the relationship between measures of arch height and plantar pressures have demonstrated both high and low arched foot types can alter plantar pressures compared to a normal foot type (8, 9). A low arched foot type has been shown to be weakly correlated with increases in dynamic plantar pressures under the hallux and medial longitudinal arch in healthy adults (8). A low arch foot type has also been shown to create near statistically significant increases in medial plantar loading in people with diabetes (8). Conversely a high arched foot type has been found to be associated with increased levels of foot pain and elevated forefoot plantar pressures compared to those with a normal arch foot type (9).

Restricted ankle joint dorsiflexion, or ankle equinus, is also proposed to elevate plantar pressures via compensatory gait changes including sagittal plane disruption of the midfoot joints, and altered timing of heel lift, resulting in prolonged weight bearing on the forefoot (10, 11). Prevalence of ankle equinus in the general population has been estimated to be approximately 25%, but this has been not conclusively established as most reports are observational and/or anecdotal (12, 13). In diabetes cohorts the condition has been found to affect up to 37% of the diabetic population and has been suggested to be a key contributor to the development of pressure related foot ulceration (14). The first author has previously demonstrated a high incidence of equinus in a small cohort of healthy Aboriginal Australians (13/24 participants with <5° non-weight bearing ankle joint dorsiflexion) and has suggested that plantar pressures may be significantly affected by this condition (15). It is possible that gait compensation as a result of ankle equinus may contribute to elevated forefoot and midfoot plantar pressures in Aboriginal Australians, increasing the risk of pressure related foot complications (15). The aim of this study was to investigate the relationship between arch type, ankle joint equinus and plantar pressures in a cohort of Aboriginal Australians without diabetes. Examining a cohort without diabetes will eliminate the effects of diabetes on these variables, and allow an examination of the effects on the non-diabetic Aboriginal population.

Methods

This was a cross-sectional study undertaken between May 2012 and May 2015. A volunteer sample of Aboriginal Australians without diabetes participated in this study from three regions in New South Wales, Australia i.e. Western Sydney, the Hunter Region and the Mid North Coast. Four Aboriginal organizations supported this project, Western Sydney Aboriginal Medical Service (Western Sydney), Awabakal Aboriginal Medical Service (Hunter Region), the Wollotuka Institute (Newcastle), and Tobwabba Aboriginal Medical Service (Mid North Coast). All participants provided informed consent prior to participation in this research. Ethical approval was granted from the Human Research Ethics Committee (HREC) at the University of Newcastle (Protocol Number 2012-0385) and the Aboriginal Health and Medical Research Council Ethics Committee (Reference Number 895/12).

Inclusion criteria were Aboriginal people aged over 18 years, with proficient English (unless a suitable interpreter was available) and without diabetes, neuropathy or history of foot amputation/major trauma. Exclusion criteria were inability to stand or walk independently due to an acute or chronic condition and inability to provide informed consent. Participants were free to withdraw at any time, or not participate in any aspect of the assessment without any explanation required.

Procedure

Participants recruited to this study underwent assessment of ankle joint dorsiflexion, foot arch type classification and barefoot plantar pressures. All participants were assessed by the same Aboriginal researcher and podiatrist (first author). Each visit was completed within 30-50 minutes, depending on the age and mobility of the participant.

Ankle Joint dorsiflexion Assessment

Ankle joint dorsiflexion was measured non-weight bearing, using the Charles Device®. This device consists of a tibial plate which attaches to the anterior aspect of the tibia and a foot plate. The device is held in place with Velcro straps at the ankle, midfoot and forefoot. The foot is held in a secure position during the measurement with an ethyl vinyl acetate (EVA) heel cup and an adjustable tri planar wedge positioned under the medial longitudinal arch designed to help hold the subtalar joint in a neutral position (16-19). The torque to produce ankle joint dorsiflexion is applied via a digital torque wrench, and a digital inclinometer attached to the foot plate measures dorsiflexion. This device has been demonstrated to have high inter and intra-tester reliability, and has been described in detail in a previous publication (16).

Arch Type

Arch type was determined using a pedograph, a footprint-taking system. This system was developed to provide reliable information regarding the foot structure and arch height of participants (20, 21). The foot ink prints where taken with a standard Ruckgaber Orthopadie ink plate developed by Ruckgaber Bruggemann (http://ruckgaberbruegg emann.de/). The Ruckgaber Orthopadie ink plate was used to evaluate and categorise the participants arch height as either low, normal or high (Figure 1).

Figure 1: low, normal and high arch (www.underpronation.org)

One single static weight bearing ink print was recorded of each foot, of each participant. The participant was asked to stand and place their foot in the Ruckgaber Orthopadie inkpad, and the footprint is transferred to the footprint recording paper. This process produced an ink footprint, as per the manufacturer's instructions (20, 21). The foot ink prints were analysed using a visual method to categorise them to low, normal or high and a visual non-qualitative inspection method developed by Dahle et al (1991) (22) to categorise the foot supinated (high), normal or pronated (low). This process by Dahle et al (1991) was found to have 73% agreement between examiners (22).

Barefoot Plantar Pressure

Plantar pressures were collected using the HR Mat Pressure Measurement System (TekScan® Inc. Boston, USA). This lightweight (1.7 kg), 0.6cm (thick), 43.6 x 36.9 cm (area), with 2288 sensors, and Maximum Pressure Range of 345-862 kPa has previously been shown to have adequate reliability (23-25). Participants were barefoot when weight measurement and calibration of the system were performed. This was conducted prior to three walking trials, using the two-step protocol, being recorded for each foot (26-28). An average of the three readings of the foot selected for inclusion in the statistical analyses was used as this has previously been demonstrated to produce a reliable measurement (16, 29). Participants undertook the trials at self-selected walking speed.

Data Analysis

Statistical analysis was undertaken using Statistical Package Social Science software version 22.0 (SPSS Chicago, USA). Pearson and Spearman correlation coefficients were calculated to examine the strength of association between ankle joint dorsiflexion (in degrees), foot plantar pressure variables (mean peak pressure [PP] and pressure time integral [PTI]) and arch type (low, normal or high). For the purpose of the statistical analysis, plantar pressure data were mapped as the first metatarsophalangeal joint (MTPJ), the lateral forefoot (2-5 MTPJs), the midfoot and the rearfoot. Only forefoot and midfoot plantar pressure variables were used in the analyses. Contact time was used as a surrogate for walking speed to determine if there was an association with BMI (2). The left or right leg was selected randomly for each participant using computer generated random allocation. Arch type was categorised as low, normal or high based on pedograph classification. Correlation coefficients were interpreted in accordance with Cohen (1988) i.e. 0.1 denotes poor/weak strength, 0.3 moderate strength and 0.5 strong strength, with significance level set at $p<0.05$ (30). For reporting the prevalence of ankle equinus, ankle joint restriction was categorised as stage 1 or stage 2 (19). Stage 1 ankle equinus was considered present when there was less than 10°and more than 5° of dorsiflexion available, while stage 2 was present when there was less than 5° of dorsiflexion available (19). Two hierarchical logistic regression models were used to determine the ability of ankle joint dorsiflexion to predict change in lateral forefoot (2-5 MPTJ) and mid foot PTI controlling for body mass index (BMI). Preliminary analysis was conducted to ensure no violations of assumptions for normality, linearity, multicollinearity and homoscedasticity.

Results

A total of 50 Aboriginal community members volunteered to take part in this study and met the inclusion criteria. Regional distribution of participants was as follows: Mt Druitt (Western Sydney): (N=16), Newcastle (Hunter Region): (N=14), and Forster (Mid North Coast): (N=30). Participant's characteristics and assessment results are included in Table 1. Overall there was a high prevalence of a high arch foot type and some degree of ankle equinus with 41 participants having less than 10° of ankle joint dorsiflexion available.

Gender (N, %) (N=50) Male Female	 20 (40%) 30 (60%)
Age (years) (N=50) Mean Range	 43.42 18-76
Weight (kg) (N=42) Mean SD	 82.83 22.28
Height (cm) (N=38) Mean SD	 167.44 8.28
BMI (N=38) Mean SD	 29.57 6.51

Ankle joint DROM (°) (N=33) Mean SD	 7.49 6.79
Ankle equinus (N=48) Stage 1(5-10°) Stage 2 (<5°)	 28 13
Foot arch type (N=42) High Neutral Low	 27 9 5
1MTPJ PP (KPa) Mean SD	 943.26 176.97
1MTPJ PTI (KPa/s) Mean SD	 139.76 56.27
2-5 MTPJ PP(KPa) Mean SD	 465.51 186.51
2-5 MTPJ PTI (KPa/s) Mean SD	 130.10 72.76
Midfoot PP(KPa) Mean SD	 638.33 102.56
Midfoot PTI (KPa/s) Mean SD	 58.79 13.36
Contact Time (ms) Mean 95% CI	 756.76 701.27 to 996.68

Table 1: Participants descriptive details and assessment results

BMI: Body mass index

MTPJ metatarsophalangeal Joint

PP: Peak pressures

PTI: Pressure time integral

Ankle Joint range of dorsiflexion

Univariate Analysis

Reducing ankle joint dorsiflexion was moderately and significantly correlated with increasing midfoot PP and PTI, and PTI at the lateral forefoot (MTPJ 2-5) (Table 2). It was also weakly and significantly correlated with first MTPJ PP and PTI (Table 2). A low arch foot type was moderately and significantly correlated with midfoot PTI and significantly and weakly with midfoot PP. Foot arch type was not associated with measures of forefoot plantar pressures (Table 2). There was no significant association between BMI and contact time ($r=0.127$, $p=ns$) however a low foot arch type was moderately and significantly correlated with increasing BMI ($r=0.325$, $p<0.01$) (Table 2).

Plantar pressure correlations with ankle joint DROM		
Variable	R value	p value
1MTPJ PP	-0.213	<0.05
1MTPJ PTI	-0.224	<0.05
2-5 MTPJ PP	-0.173	ns
2-5 MTPJ PTI	-0.388	<0.01
Midfoot PP	-0.301	<0.01
Midfoot PTI	-0.367	<0.01
Correlations with arch type		
1MTPJ PP	0.093	ns
1MTPJ PTI	0.072	ns
2-5 MTPJ PP	0.176	ns
2-5 MTPJ PTI	0.162	ns
Midfoot PP	0.206	<0.05
Midfoot PTI	0.442	< 0.01

Table 2: Univariate Analysis Results

ns=non-significant

Bivariate Analysis

Based on the results of univariate analysis the extent to which ankle joint dorsiflexion contributed to PTI at the lateral forefoot, also the amount arch type contributed to midfoot pressure was examined in two regression models. In each model BMI and contact time were entered at Step 1. Ankle joint dorsiflexion was entered at Step 2. For the model examining midfoot PTI, arch type was then entered in Step 3. For the lateral forefoot PTI model, variables entered at Step 1 accounted for 17.2 % of the variance in PTI. After entry of ankle joint dorsiflexion at Step 2, the model predicted 24.4% of the total variance. Ankle joint dorsiflexion therefore explained an additional 7.2% of the variance in lateral forefoot PTI. In the final model, BMI (beta=0.301 p=0.007) and ankle joint dorsiflexion (beta =-0.258, p=0.01) were the only significant independent predictors of lateral forefoot PTI. For the midfoot PTI regression model, the variables entered at Step 1 explained 10.4% of the variance, after ankle joint dorsiflexion was entered in step 2, the model explained 14.7 % of the variance in PTI and when arch type was entered at Step 3 the model accounted for 19.9% of the variance in PTI. In the final model

BMI (beta =0.286, p=0.01) and arch type where the only significant independent predictors of midfoot PTI (beta =-0.234, p=0.04) while ankle joint dorsiflexion was near statistically significant (beta =-0.232, p=0.053).

Discussion

This study investigated the relationship between the biomechanical variables of ankle joint dorsiflexion and arch type on midfoot and forefoot plantar pressures in Aboriginal Australians. In the participants recruited to this study there was a high prevalence of ankle equinus, suggesting that restricted ankle joint dorsiflexion could possibly be more prevalent in this population than the general community estimates. This finding is also consistent with the author's previous findings of high rates of ankle equinus in a small sample of healthy Aboriginal adults (15). The higher prevalence of restricted ankle joint dorsiflexion in Aboriginal Australians found in both studies suggests there may be biomechanical differences contributing to the development of ankle equinus that are associated with Aboriginality itself. This greater prevalence of equinus in the Aboriginal population and the association with increased foot pressure, may contribute to poor foot health outcomes in this population.

The participants in this study had very high BMI with a mean of 30 (Table 1) and this high BMI has been shown in other studies, especially for Aboriginal women (31). Therefore BMI was included in the regression models for this study as it is known to be associated with plantar pressures. Both models demonstrated that BMI was a significant independent predictor of both lateral forefoot and midfoot PTI. It is possible that a slower walking speed in those with a higher BMI may have contributed to periods of longer loading at the forefoot and midfoot. In this study contact time was used as a surrogate marker of walking speed and was not found to be significantly related to BMI, suggesting BMI is an independent contributor to the differences in PTI observed. This method was chosen due to the challenges of data collection in a community-based setting where this research was undertaken and it is still possible that differences in walking speed between individuals affected the predictive relationship between BMI and midfoot and lateral forefoot PTIs.

In relation to ankle joint dorsiflexion, our results demonstrated reduced range of movement was associated with increasing PP and more strongly, increasing PTI at the midfoot and increasing PTI at the lateral forefoot. The greater effect of ankle joint dorsiflexion on PTI compared to PP is noteworthy. Reporting of both PTI and PP is controversial, with a recent systematic review finding reporting of both variables for investigations of plantar pressures in diabetes to have little additional benefit (32). Several studies have found measurements of these parameters to be highly interdependent (33, 34), and therefore they would be expected to be affected by ankle equinus similarly. Although this was the case at the midfoot with both PTI and PP increasing with reducing ankle joint dorsiflexion, only PTI was significantly affected by reduced motion at the lateral forefoot. PTIs and PPs have previously been shown to be significantly different at the forefoot in people at risk of diabetic foot ulcer, suggesting these variables do not always demonstrate a homogenous response to changes in foot structure or function (35). It has also been suggested that forefoot PTI may be a more appropriate method of measuring changes in forefoot plantar pressures occurring as a result of ankle equinus, as an early heel lift associated with this condition, is likely to cause prolonged forefoot loading rather than increases in peak pressures (36). In relation to lateral forefoot pressures, the findings of this present study appear to support this premise.

Foot arch type in this study was found to be moderately and significantly correlated with BMI, with higher BMI occurring in those with a low arch foot type. Foot arch type was also found to be associated with significant differences in PP and PTI at the midfoot, with increased plantar pressures in this region associated with a low arch foot type. These findings are consistent with previous investigations which have demonstrated loading under the midfoot is associated with foot arch type determined by arch index in older people (37) and people with diabetes (8) and, that arch index is associated with navicular drop in healthy people (38). Interestingly the level of association between midfoot PTI and foot arch type was stronger than that between foot arch type and midfoot PP. As there was no significant relationship between contact time and BMI, it is unlikely that differences in walking speed between participants, i.e. that a slower walking speed in those with a higher BMI and low arched foot type, produced the stronger association with PTI. This suggests that those with a low arched foot type loaded the midfoot area for longer than those with neutral and high arch foot type.

The lack of relationship between foot arch type and forefoot plantar pressures is inconsistent with previous research which has demonstrated a low arch is associated with increased plantar pressures under the medial forefoot (8) and a high arch foot type is associated with increases in forefoot pressure (9). The lack of relationship found in this study between foot arch type and forefoot plantar pressures may have been associated with the high prevalence of high arched foot type in this population confounding any potential associations. It is also possible increased plantar pressures at the forefoot were compensation for restricted ankle joint dorsiflexion which was also highly prevalent, and this may have prevented a relationship between foot arch type and forefoot pressures being observed. Alternatively, the visual method used to classify foot type may have confounded the results. Although this technique has been demonstrated to have adequate inter-tester reliability the relationship between this particular measure of static foot assessment and dynamic plantar pressures is unknown. Using a technique such as the Foot Posture Index where foot type is determined through the combinations of forefoot and rearfoot position across all three body planes (39) and association with dynamic foot motion has been demonstrated and may have altered these results (40, 41).

Limitations

The result of this study need to be considered in light of several limitations. As previously discussed, the method of controlling for walking speed and determining arch type may have affected the extent of the relationship between BMI, foot type variables and plantar pressure changes. In addition, this study used a relatively small sample size and not all assessments were undertaken on all enrolled participants, as they were allowed to choose not to participate in any aspect of the study. Nevertheless, the findings of this study relating to high rates of ankle equinus in an Aboriginal

Australian population are consistent with previous research and may contribute to development of foot problems in this population. This contribution to foot problems may be particularly evident in those with additional risk factors for foot injury, including those who smoke and those with diabetes.

Conclusion

This study demonstrated high rates of restricted ankle joint dorsiflexion in a population of Aboriginal Australians. We also found that reducing ankle joint dorsiflexion and a low arched foot type are independent predicators of lateral forefoot PTI and midfoot PTI respectively. We also found that PTI are more strongly associated with reduced ankle joint dorsiflexion and foot arch type than PP. This finding suggests that prolonged loading of the midfoot and the forefoot rather than significant increases in peak pressure. These findings suggest the biomechanical variables of foot arch type and ankle joint dorsiflexion may play a role in the development of pressure related injury of the foot and increase risk of complication for Aboriginal Australians, particularly those with diabetes.

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Conflict of interest

The authors received no funding for this research and have no conflict of interest to declare.

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Paper 6: The relationship between ankle equinus, bare-foot plantar pressures and diabetic neuropathy in Aboriginal Australians.

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Acknowledgement: I would like to acknowledge the traditional owners of all the many Aboriginal and Torres Strait Islander Nations that make the great continent of Australia. I would like to pay my respects to the Aboriginal and Torres Strait Islander elders past and present, also the young community members, as the next generation of leaders and representatives.

Disclaimer: In some instances in this paper I will be using the term 'Aboriginal' to describe both Aboriginal and Torres Strait Islander Peoples. This is due to word restrictions, and no disrespect is intended to any individual or group.

This paper is currently under review at the Diabetes Research and Clinical Practice journal on the submission number (DIAB-S-16-00541). SCImago Journal Ranking: 1.02, impact factor: 2.583.

Author Contribution Statement

By signing below I confirm that James Charles contributed to the design of the trial, data collection, analysis of the data and drafted the original of the publication entitled: The relationship between ankle equinus, bare-foot plantar pressures and diabetic neuropathy in Aboriginal Australians.

List: Charles J, Spink M, Chuter V. The relationship between ankle equinus, bare-foot plantar pressures and diabetic neuropathy in Aboriginal Australians.

Co-authors: Martin Spink and Vivienne Chuter

Date 12/04/16

Signature of Co-Authors:

Signed version is in PDF (Appendix 3)

Abstract

Aims: To determine the contribution of ankle joint function and peripheral neuropathy to elevated forefoot plantar pressures in Aboriginal people with diabetes.

Methods: A cross sectional study delivered between May 2012 and May 2015. Seventy-six Aboriginal adult participants diagnosed with diabetes were recruited on a volunteer basis from three Aboriginal communities in New South Wales, Australia.

Results: The sample population had a high prevalence of both neuropathy (50%) and reduced ankle dorsiflexion (72%). Equinus was also more prevalent among men (90%) compared to women (50%). Forefoot pressure peak time integrals (PTI) were moderately and negatively correlated with equinus ($r=-0.38$, $p<0.01$) as well as moderately correlated with neuropathy ($r=0.42$, $p<0.01$). Being male was also moderately and significantly correlated with equinus ($r= -0.36$, $p<0.01$). Equinus explained a 9.1% of the variance in forefoot PTI after controlling for demographic variables.

Conclusions: Equinus was found to be an independent predictor of forefoot PTI and may play a role in the development of pressure related ulceration in Aboriginal people with diabetes. In the majority of cases, equinus was due to lack of gastrocnemius flexibility, and not associated with neuropathy. Equinus was more prevalent in men, indicating that men are at greater risk of associated foot complications. These findings suggests that equinus may be due to Aboriginality and being male rather than diabetes status, and this may explain why Aboriginality has been previously shown to be associated with ulceration.

Keywords: Aboriginal, Diabetes, Equinus, Neuropathy and Foot Pressure.

Introduction

Diabetes is one of the most common chronic diseases worldwide, affecting approximately 9% of the global adult population (1). The condition is associated with a wide range of potentially life threatening complications including the development of foot ulcers. Life-time incidence of foot ulceration for those with diabetes is estimated to be 15% to 25% with both foot ulceration and related lower limb amputations significantly contributing to the socioeconomic costs of the disease (2). Diabetes-related lower limb amputations account for 85% of all lower limb amputations (3) and comprise approximately 10% of health care costs associated with diabetes (2). In Australia, diabetes affects 1.2 million people or 5.1% of the total population (4). In the Aboriginal community the rate of diabetes is estimated to be three times that of the general population (5) as well as having high rates of undiagnosed disease and poorer long-term health outcomes (6). Aboriginal Australians also have significantly increased risk of diabetic foot complications, with Aboriginality shown to be independently associated with a 4.8 fold increase in likelihood of foot ulceration (7). Rates of lower limb amputation have also been shown to be up to 38 times greater than that of age matched non-Aboriginal Australians (8).

The association between the development of foot ulceration and elevated plantar pressures in people with diabetes is well established (9-11). Neuropathy has been shown to significantly contribute to the development of high plantar pressures associated with foot ulceration (12). In addition, limited ankle joint dorsiflexion (ankle equinus) due to a process of non-enzymatic glycosylation, causing thickening of the Achilles tendon, is suggested to create biomechanical changes that elevate plantar pressures, particularly of the forefoot (13-15). Ankle equinus is proposed to cause a restriction in forward movement of the tibia over the foot during stance phase, resulting in gait compensations which lead to prolonged forefoot loading (16, 17). Several studies have demonstrated ankle equinus to be co-existing with neuropathy in diabetic cohorts with a history of diabetic foot ulceration (18-20). Ankle equinus has also been found to be associated with delayed ulcer healing (21, 22) and increased likelihood of ulcer recurrence (22). However these associations have not been investigated in an Aboriginal Australian cohort.

The incidence of diabetic foot ulceration and amputation is significantly higher in Aboriginal Australians than in the general population (23, 24). However the contribution of ankle equinus to high plantar pressures and foot ulceration in this population has not been investigated. There is some evidence to suggest that the prevalence of ankle equinus in Aboriginal Australians, even without diabetes, is high, particularly in males. A small study (n=24) conducted in a regional Aboriginal community in New South Wales, Australia, found all the male Aboriginal participants (n=12) had less than 10° of ankle dorsiflexion, with 10 participants having less than 5° (25). These findings suggest that Aboriginal Australians with diabetes may be particularly at risk of high plantar pressure due to ankle equinus. The purpose of this study was to firstly investigate the relationship between ankle joint range of dorsiflexion, and forefoot plantar pressures and secondly investigate the association between neuropathy and ankle equinus in an Aboriginal population with diabetes.

Methods

This was a cross sectional study undertaken between May 2012 and May 2015. Participants were recruited on a volunteer basis from three Aboriginal communities, Mt Druitt (Western Sydney) (n=32), Newcastle (Hunter Region) (n=26) and Forster (Mid North Coast) (n=18) in New South Wales, Australia. Four Aboriginal organizations supported this project, Western Sydney Aboriginal Medical Service (Western Sydney), Awabakal Aboriginal Medical Service (Hunter Region), the Wollotuka Institute (Newcastle), and Tobwabba Aboriginal Medical Service (Mid North Coast).

All participants provided informed consent prior to participation in this research. Ethical approval was granted from the Human Research Ethics Committee (HREC) at the University of Newcastle (Protocol Number 2012-0385) and the Aboriginal Health and Medical Research Council Ethics Committee (Reference Number 895/12). Inclusion criteria were Aboriginal people aged 18 years with diagnosed diabetes. Exclusion criteria were inability to comply with the study protocol including walking independently and safely and unable to understand or speak English (unless a suitable interpreter was available).

Procedure

Medical history, including diagnosis of diabetes, HbA1c and lower limb amputation was collected from a self-report survey. Resting blood glucose levels (BGL) were measured using an Accu-Check Performa Monitor (Roche Diagnostics Australia, Castle Hill, Australia), performed by a qualified podiatrist, and the BGL was taken at the time of the assessment. Barefoot plantar pressure, ankle joint range of dorsiflexion, BGL and neuropathy measurements were taken in a random order. The equipment was set up and used in accordance with the manufacturer instructions.

Plantar Pressure Measurement

Barefoot plantar pressures were collected using the TekScan High Resolution Pressure Measurement System (TekScan Inc. Boston, USA). This lightweight, 5mm thick, 432mm by 368mm rectangular plate, with 2288 sensors, allows for measurement of barefoot plantar pressures and has been demonstrated to have acceptable reliability (26, 27). Participants were asked to remove their shoes and socks, then weighed and a calibration of the TekScan device was performed. Once calibration was complete, plantar pressure data was captured with three walking trails using the two-step protocol (28) which has been found to be reliable (29). Three recordings were taken of each foot, for each participant, as the average of three readings was found to be an appropriate number of readings to produce reliable foot pressure data (30).

Ankle Joint Dorsiflexion

Ankle joint range of dorsiflexion was measured, non-weight bearing, using the Charles device (31). The Charles device (Figure 1) consists of one piece attached to the anterior aspect of the tibia (tibial plate) and a second piece attached to the plantar aspect of the foot (foot plate) with Velcro securing around the ankle, midfoot and forefoot, to hold the foot securely (31). The foot plate has an EVA heel cup fitted, designed to minimise rearfoot movement (32, 33). A tri-planar wedge is attached to the foot plate with Velcro, which is designed to limit pronation at the mid-foot and rear-foot, and to hold the foot in neutral throughout measurement (34). The torque to produce ankle joint dorsiflexion is applied via a digital torque wrench, and a digital inclinometer is attached to the foot plate, to measure dorsiflexion. This device has been demonstrated to be highly reliable, and has been described in detail in a previous publication (31).

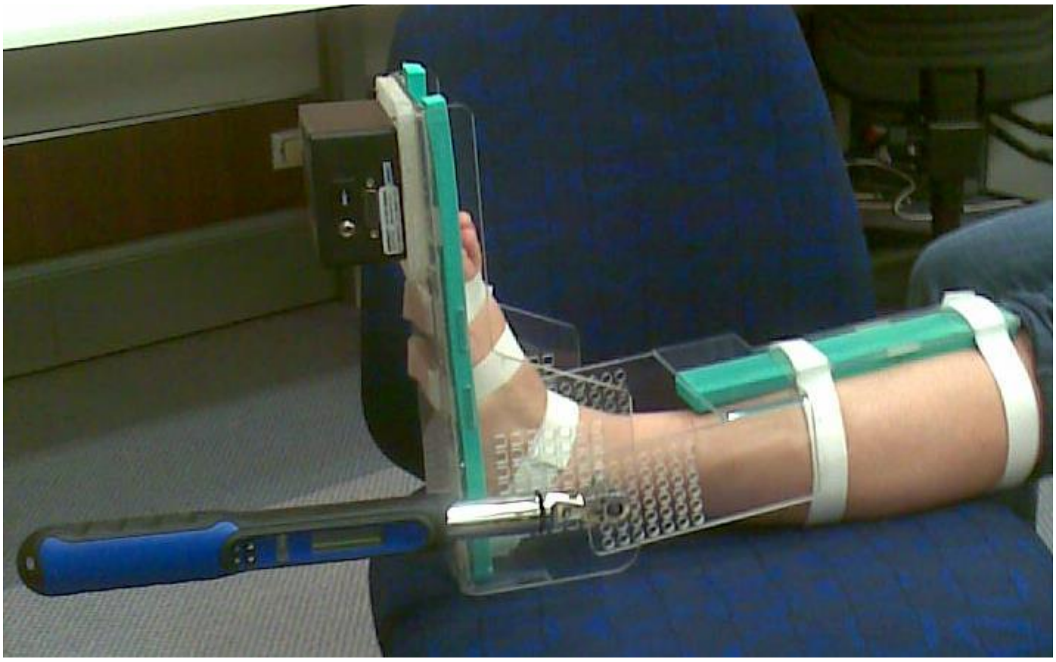

Figure 1: Charles device for measuring ankle dorsiflexion

For this measurement participants were positioned supine on a level treatment table and asked to relax and not to assist or restrict any foot movement (31). Before the measurements were taken, one practice measurement was performed to help relax the participant and to provide an initial stretch of the gastrocnemius and soleus muscles to ensure maximum dorsiflexion was being measured in subsequent measurements (35). An ankle dorsiflexion torque of 8Nm was applied and the amount of ankle dorsiflexion was recorded using a digital inclinometer. The mean of three tests was used to determine the ankle joint dorsiflexion range of motion (31). The procedure was conducted twice, firstly with the knee extended to test any restriction from gastrocnemius and then with the hip and knee flexed at 90° to test any restriction from soleus. This exact procedure is explained in detail in a previous paper (31) and was conducted on both left and right feet.

Neurological Assessment

Neurological assessment was performed using a 4-site monofilament test (36). If the participant felt three or less sites, this was considered to be diagnostic of neuropathy (36). Peripheral neuropathy was assessed using a 6g Semmes-Weinstein monofilament (North Coast Medical, California, USA) which have been found to be highly reliable (37, 38). A recent study recommends the use of a 6g monofilament, in preference to the more commonly used 10g monofilament, for nerve function testing as it has been shown that participants with some neurological loss will still be able to feel the 10g monofilament (39).

Data analysis

Statistical analysis was undertaken using Statistical Package Social Science software version 22.0 (SPSS Chicago, USA). Pearson and Spearman correlation coefficients were calculated to examine the strength of association between range of ankle joint dorsiflexion, foot plantar pressure variables (mean peak pressure [PP] and pressure time integral [PTI]), and neuropathic status (normal or abnormal). Specifically, correlations were performed between ankle joint dorsiflexion and demographic variables (age, gender & BMI), forefoot PP, forefoot PTI and neuropathy status. Correlations were also performed between neuropathy status and forefoot PP and forefoot PTI. Plantar pressure data were mapped as the forefoot, midfoot and rearfoot. For reporting the prevalence of ankle equinus, ankle joint restriction was categorised as stage 1 or stage 2 (34). Stage 1 ankle equinus was considered present when there was less than 10° and more than 5° of dorsiflexion available while stage 2 was present when there was less than 5° of dorsiflexion available (34). Correlation coefficients were interpreted in accordance with Cohen (1988) i.e. 0.1 denotes poor/weak strength, 0.3 moderate strength and 0.5 strong strength, with significance level set at $p<0.05$ (40). As pre-planned in this study, for the purposes of statistical analysis, the limb with the most abnormal ankle range dorsiflexion (gastrocnemius or soleus in the direction of equinus) was used and neuropathy and plantar pressure results in the same limb were reported per participant. Hierarchical logistic regression was performed to determine the ability of ankle joint dorsiflexion to predict change in forefoot PTI controlling for demographic variables including age, gender and BMI. Preliminary analysis was conducted to ensure no violations of assumptions for normality, linearity, multicollinearity and homoscedasticity

Results

Seventy-six Aboriginal participants were recruited to this study. Participant characteristics and assessment results are shown in table 1. Overall the sample population was overweight (mean BMI= 34.3) with a high incidence of neuropathy (50%) and Stage 1 and 2 ankle equinus (approx. 70%).

Description		
Gender (N, %) (N=76)	Male Female	33 (43.4%) 43 (56.6%)
Age (years) (N=76)	Mean (SD) Range	55.32 (14.10) 18-79
Weight (kg) (N=71)	Mean (SD) Range	96.58 (26.14) 57.00-186.00
Height (cm) (N=69)	Mean (SD) Range	166.90 (9.89) 145.00-185.00
BMI (N=69)	Mean (SD) Range	34.30 (9.37) 21-69
Diabetes (N=76)	Type 1 Type 2	2 (2.6%) 74 (97.4%)
BGL (mmol/L) (N=59)	Mean (SD) Range	11.41 (5.07) 4.20 -28.50
HbA1c (% NGSP units) (N=24)	Mean (SD) Range	8.70 (2.19) 5.40-12.40
Ankle joint range of dorsiflexion (°),(N=56)	Mean (SD) Range	4.8 (7.4) -8.00 to 32.00
Neuropathy (N=76)	Left Right	39 (51.3%) 36 (47.4%)
Amputation (N=76)		8 (10.5%)
Peak pressures (kPa): Forefoot (N=76)	Mean (SD)	491.93 (201.48)
Pressure-time integral (kPa/s): Forefoot (N=76)	Mean (SD)	94.88 (33.73)

Table 1: Participant characteristics including ankle joint dorsiflexion and plantar pressures. SD=standard deviation.

Description			
Ankle joint ROM (degrees) gastrocnemius right	Mean (SD) Range	2.64 (4.24) -4.00 to 14.00	8.82 (8.69) -5.00 to 32.00
Ankle joint ROM (degrees) gastrocnemius left	Mean (SD) Range	*2.76 (5.05* -3.00 to 13.00	*8.65 (8.85)* *-8.00 to 32.00*
Ankle equinus stage (gastrocnemius) right	Stage 1 (5°-10°) Stage 2 (<5°) Total Equinus	*6 (28.6%)* *13 (61.9%)* *19 (90.5%)*	*5 (14.6%)* *13 (38.2%)* *18 (52.9%)*
Ankle equinus stage (gastrocnemius) left	Stage 1 (5°-10°) Stage 2 (<5°) Total Equinus	*3 (13.6%)* *16 (72.7%)* *19 (86.4%)*	*5 (14.6%)* *13 (38.2%)* *18 (52.9%)*

Table 2: Ankle joint dorsiflexion by gender.

Univariate Analysis

Forefoot PTI was moderately, negatively and significantly correlated with ankle joint dorsiflexion (r=-0.377, p<0.01) (table 3). Being male was moderately and significantly correlated with a reduced ankle joint dorsiflexion (r= -0.364, p<0.01). There was no significant association between ankle joint dorsiflexion and forefoot PP, neuropathy, age or BMI. Presence of neuropathy was moderately and significantly correlated with higher forefoot PTI (r= 0.419, p< 0.01) and higher forefoot PP (r= 0.495 p< 0.05). Over 90% of men had equinus compared only 53% of women (table 2). HbA1C data were not included in the analysis due to the large amount of missing data for this variable. Duration of diabetes data were not included as these data could not be accurately elicited form the study population.

Bivariate Analysis

Based on the results of univariate analysis the extent to which demographic factors (including age, gender and BMI) and range of ankle joint dorsiflexion contributed to PTI was examined in the regression model. Age, gender and BMI were entered at Step 1. Ankle joint dorsiflexion was entered at Step 2. Demographic variables entered at Step 1 accounted for 11.6 % of the variance in forefoot PTI. After entry of ankle joint dorsiflexion at Step 2 the model predicted 20.7% of the total variance. Ankle joint dorsiflexion therefore explained an additional 9.1% of the variance in forefoot PTI after controlling for demographic variables. In the final model ankle joint dorsiflexion was the only measure to approach statistical significance (beta=-0.306 p=0.054).

Correlations with ankle joint range of dorsiflexion		
Variable	R value	p value
Gender (Male)	-0.364	<0.01
Age	-0.069	ns
BMI	-0.202	ns
Forefoot PP	-0.144	ns
Forefoot PTI	-0.377	<0.01
Neuropathy status	0.223	ns
Correlations with neuropathy		
Forefoot PP	0.495	p< 0.05
Forefoot PTI	0.419	p< 0.01

Table 3: Univariate analysis results

ns=non-significant

Discussion

To our knowledge this is the first study to investigate the relationship between neuropathy, ankle joint dorsiflexion and forefoot plantar pressures in an Aboriginal cohort with diabetes. We have demonstrated reduced ankle joint dorsiflexion is highly prevalent in a community-based Aboriginal population with diabetes. Furthermore reduced ankle joint dorsiflexion is inversely related to forefoot PTI but is not associated with the presence of neuropathy.

Consistent with existing research in the general population, we found neuropathy to be most strongly associated with high forefoot PTI and high forefoot PP in Aboriginal Australians with diabetes. Diabetic sensory neuropathy has previously been shown to be present in more than 82% of foot wounds (41) and considered the initiating factor in up to 78% of cases of ulceration (42). Our community-based population had a high rate of neuropathy (approximately 50%) which is more than three times higher than the prevalence of 13.1 % reported for diabetic neuropathy in non-Aboriginal Australians (43). Although the sample size for this present study was small, the high rate of neuropathy supports previous research which has shown a five-fold increased risk of foot ulcer associated with Aboriginality (7). It also supports previous findings that the risk of diabetes related amputation up to 38 times for Aboriginal Australians compared to the general Australian population (8). Several studies have also demonstrated high prevalence of other risk factors for diabetic foot ulcer in the Aboriginal community, including those with diabetes being twice as likely to suffer from untreated skin lesions (callus and corns) (44) and up to 68% to have structural pathology of the foot (45).

In this present study increased forefoot PTI was moderately and significantly associated with reduced ankle joint dorsiflexion. In contrast forefoot PP correlations with ankle joint dorsiflexion were weak and non-significant. Previous research has suggested that PTIs are better able to differentiate between diabetic groups with and without foot ulceration than plantar pressures (18). It is also suggested that PTIs may be a more accurate measure of alterations to forefoot loading occurring as a result of ankle equinus, likely because ankle equinus will cause an increase in application of load over time rather than significant changes to peak pressures (46). In this context PTIs have also been suggested to be more likely to be associated with development of diabetic foot ulcers (24, 47). Our findings of an association between restriction in range of ankle dorsiflexion and higher forefoot PTIs, but not higher forefoot PPs, supports the potential for such a relationship to exist. However, the results or our regression analysis demonstrated that ankle joint dorsiflexion accounts for only 9% of the variance in forefoot PTI, indicating a number of factors contribute to the loading of the forefoot.

Of note approx. 65% of all participants in this study had equinus, and nearly 40% had stage 2 equinus which is approx. 3 times the rate of the general population (48). Also of note is that over 90% of the men had equinus compared to only 53% of the women. Glycation of collagen proteins as a results of diabetes is known to reduce stretch and elasticity in the gastrocnemius (13, 49-51), and occur in the presence of neuropathy (52) which was also highly prevalent in participants in this study. However reduced ankle dorsiflexion has also been found at very high levels in young Aboriginal people without diabetes (25), indicating that it may be Aboriginality that is associated with equinus. The findings of our study appear to support this hypothesis. If reductions in ankle dorsiflexion in our participants were only a result of glycosylation caused by diabetes, it is likely to have affected both muscles (i.e. gastrocnemius and soleus), as muscles and tissues have previously been demonstrated to be affected uniformly (13, 49-51) and also would affect men and women equally. However we found the high rates of equinus were largely attributed to a restriction of gastrocnemius range of motion and far higher in men. Range of ankle dorsiflexion was tested with knee and hip flexed i.e. eliminating the influence of gastrocnemius and testing soleus, only two participants were classified as having any form or equinus compared to 42 participants when gastrocnemius was tested. In addition neuropathy and ankle joint dorsiflexion were not associated with each other which was a surprising result. This indicates that the restricted ankle joint dorsiflexion may not have been a consequence of diabetes, although it is possible the lack of statistical relationship between these two variables may be a consequence of the high prevalence of both neuropathy and equinus in the participant population.

Limitations

Although efforts were made to conduct assessments on a representative sample, the cross-sectional nature of this study means it was not a true random sample. Therefore, the findings of this project are not truly representative of all Aboriginal Peoples but pertinent to the adult population of Western Sydney and the Hunter and Mid-North coastal regions of NSW, Australia. The sample size in the study is small and a larger population needs to be investigated to conclusively determine the prevalence of ankle equinus in the Aboriginal Australian population and the relationship between ankle joint dorsiflexion and forefoot pressures. In addition the role of these variables in the development of diabetic foot ulcers needs to be determined.

Several variables including HbA1C and duration of diabetes were not included in the final analysis due to incomplete data and inaccuracies associated with reliance on self-report of this information. In addition not all assessments were undertaken on enrolled participants. It is appropriate to allow participants to withdraw or choose not to participate in any aspect of the study and several participants chose not to participate in certain aspects of the assessment such as BGL.

Conclusion

Ankle joint dorsiflexion was found to be an independent predictor of forefoot PTI suggesting that it may have a role in the development of pressure related ulceration in Aboriginal people with diabetes. Restriction in range of ankle dorsiflexion was also found, in the majority of cases, to be due to lack of gastrocnemius flexibility, and not to be associated with neuropathy. The percentage of equinus was far higher for men than in women, indicating men are at great risk of pressure related foot complication. The findings suggests that ankle equinus may be due to Aboriginality and being male rather than diabetes status alone. Further research in a larger population is required to conclusively establish this relationship and to determine the relationship between ankle equinus and foot ulceration in Aboriginal Australians. The information gained in this project may lead to improvements in the prevention of poor foot health outcomes in these Aboriginal communities via the treatment and management of ankle joint equinus.

Conflict of Interest

The authors have no conflict of interest.

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Conclusion

This thesis by publication set out to investigate the factors contributing to poor foot health in Aboriginal and Torres Strait Islander Peoples i.e. to trial a culturally appropriate health promotion strategy to improve foot health and lifestyle behaviors, and to determine the prevalence and contribution of ankle equinus to plantar pressures in this population. To investigate these factors as possible mechanisms contributing to the development of foot complications in the Aboriginal and Torres Strait Islander community.

By review of the literature, a high prevalence of foot complications was found in Aboriginal and Torres Strait Islander Peoples, including peripheral vascular disease, diabetic foot ulcerations and peripheral neuropathy. A number of risk markers and risk factors for poor foot health were identified, including age, gender, location of residence, obesity and smoking. However, there are several limitations to these findings. The search revealed a paucity of available data and it is possible that the search process conducted was not exhaustive, although the use of a broad inclusion criteria and multiple databases in the search process is likely to mitigate some of this risk. The small amount of available data that was retrieved was frequently region specific, making it difficult to generalize the findings of this review to all Aboriginal and Torres Strait Islander Peoples. Additionally, as all studies were retrospective or involved a series of cross-sectional observations, it is not possible to identify risk factors for Aboriginal and Torres Strait Islander Peoples developing chronic lower limb complications. Nevertheless, the findings of this review including high prevalence of chronic disease and associated foot complications in Aboriginal and Torres Strait Islander Peoples is consistent with similar research conducted in other Aboriginal populations globally.

Reid et al (2006) conducted a cross-sectional cohort study of 169 Aboriginal Canadians and found that 51% of subjects had a foot deformity, the most prevalent was hallux valgus (31%) (36). Poor foot health outcomes have been investigated in First Nation People of Canada with a retrospective review of notes and interviews of 110 Aboriginal Canadians finding 44% reported callus (37). In another retrospective review of foot ulceration, Rose et al (2008) found being Aboriginal Canadian was significantly associated with early major amputation (n=325) (38). In addition, studies conducted into the impact of gender on First Nation Peoples foot health by Senior et al (2007) found that Aboriginal Canadian men where twice as likely to have amputation, and this risk increased with age (39). Reduced “quality of life” associated with Charcot foot has also been linked to Aboriginal ethnicity and rural residence, possibly because of limited access to timely specialty healthcare (40). Dannels (1986) was so concerned about Native American foot structure and function impacting on foot health outcomes like amputation, they conducted corrective metatarsal surgery to prevent ulcer and amputation due to metatarsal deformity (41). This research, in addition to the literature review undertaken to meet Aim 1, highlights the need for further investigations of foot health in Aboriginal and Torres Strait Islander Peoples, to ensure effective prevention and management strategies can be implemented.

In order to conduct accurate assessment of ankle equinus in Aboriginal and Torres Strait Islander Peoples, a second review of the literature was conducted relating to the definition, assessment, diagnosis, prevalence, and complications of equinus. Through this review we demonstrated a deficiency in standardisation of diagnostic criteria for ankle equinus and method of assessment. We also found limited data were available regarding the prevalence of this condition in the general population. These findings need to be considered in light of a number of limitations. The goal of this review was to describe a number of aspects of ankle equinus, including its effect on foot function. Due to the wide ranging topics included, it was not systematic in nature and it is likely that some research was not located or overlooked. However this review is a valuable resource for clinicians, providing a comprehensive overview of how ankle equinus is defined, measured and the potential biomechanical implications, particularly in relations to foot function and plantar pressure. From the results of this review we proposed a method of diagnosing equnius based on staging of the severity of the condition i.e. with stage 1 reflecting less than 10° of dorsiflexion but greater than 5°, and stage 2 reflecting less than 5° of dorsiflexion. This was based on the differing biomechanical consequence that have been demonstrated between the two ranges of restriction and will be a valuable tool for future research in this area. In addition, importantly, the review highlighted that lack of available reliable measurement techniques, leading to the development of a new device for measuring ankle joint dorsiflexion to be used in subsequent research.

Following on from the review of ankle equinus, a device (the Charles Device) to measure ankle joint dorsiflexion was designed, developed and tested for reliability. Investigation of the inter- and intra-tester reliability demonstrated them both to be excellent. As a highly reliable, portable device this equipment has the capacity to make a significant contribution to the field of biomechanical measurement, including for podiatry, physiotherapy and other professions. This device is an improvement on design of other similar devices. Several features of the device including the standardisation of the body and leg position to improve replication of movement (48-50), inclusion of fixation of the ankle, midfoot and forefoot in neutral with Velcro straps (51). Also the use of precise measurement tools including a digital torque wrench and digital inclinometer to increase accuracy and eliminate parallax errors, are likely to have contributed to high reliability of this device. However there is still further development required of the Charles Device and measurements of ankle dorsiflexion. In addition, determination of the validity of this measurement device needs to be performed, as it is possible that movement of other joints in the midfoot and rearfoot are contributing to the measurement (i.e. not only ankle joint dorsiflexion being measured).

As part of the research program, a lower limb assessment and health promotion program was then developed for the local Worimi Aboriginal community in Forster/Tuncurry, New South Wales. This program was highly successful in improving knowledge and awareness of foot health, injury, and promoting healthy lifestyle behaviours. The health promotion also had high rates of participation by young Aboriginal and Torres Strait Islander adults demonstrating its success. In addition, the assessment components of this project found high rates of lower limb injury and high prevalence of ankle equinus in a young adult Aboriginal and Torres Strait Islander population.

The strengths of the development for this program lay in the focus on community engagement, consultation and ownership. The engagement and consultation meant the program was delivered how and when the community wanted it, which created real enthusiasm for the program and 95% of participants attended all sessions. The program was flexible and the theory session's delivery times were changed at the communities request and presented on a weekend which proved successful. Use of a local Aboriginal advisory committee to support delivery of the program was paramount to success. The success of this framework for healthcare delivery demonstrates high levels of participation and behaviour change can be achieved. However these findings are limited to the participants, who were young and free from chronic disease. In addition the size and scope of the program was limited by time and budgetary demands with participant numbers restricted at 24. The outcome of this study therefore need to be considered in the context of a small sample size from a specific geographical region. Nevertheless given the paucity of data evaluating outcomes of health promotion programs for Aboriginal and Torres Strait Islander people, particularly for the lower limb, these findings make an important contribution to elements contributing to program success in such communities. Further investigation, using a similar delivery framework needs to be undertaken in those at risk of, and with current chronic disease. More specific foot health outcomes also need to be measured to determine the effectiveness of such a program in prevention and management of foot complications.

To test the hypothesis that high prevalence of ankle equinus in Aboriginal and Torres Strait Islander Peoples contributes to increased forefoot plantar pressures, two cross-sectional cohort studies were undertaken in Aboriginal communities from three region across New South Wales. High prevalence of ankle equinus was found in Aboriginal and Torres Strait Islander adults of all ages, with higher rates in males. In addition the presence of equinus appeared to be independent of diabetes related changes, including limited joint mobility, suggesting Aboriginality may possibly be contributing to these findings. In addition, reduced ankle joint dorsiflexion was found to affect PTI to a greater extent than PP in the forefoot and to be an independent predictor of PTI. This suggest ankle equinus contributes to duration of, rather than magnitude of load and this may make a significant contribution to the development of pressure related foot complications in those with chronic disease.

This research has provided valuable initial data in relation to the prevalence of ankle equinus in Aboriginal and Torres Strait Islander communities and the effect of this condition on foot pressures. However the findings are limited by the cross-sectional design, meaning the role of ankle equinus in the development of foot complications has only a theoretical basis. In addition, both studies had relatively small sample sizes, and there were significant amounts of missing data, perhaps reflecting some of the difficulties conducting Aboriginal community based research. This includes allowing participants to choose which assessment they would like to undertake, collecting data in a manner that is least intrusive and time consuming to individuals, often reducing the degree to which potential confounders can be controlled. This was particularly relevant to possible effects of walking speed on plantar pressures which were assessed using contact time as a surrogate marker.

Importantly this cross-sectional research was conducted in a culturally appropriate manner, by an Aboriginal researcher with understanding and empathy for the participants. The project was community centred, with the care of the Aboriginal and Torres Strait Islander participant's welfare paramount. The participants were recruited from a variety of locations and communities e.g. inner city location (western Sydney), a regional centre (Newcastle) and rural locations (Karuah, Forster, Mindaribba and Taree). The researcher had support from four Aboriginal Community Controlled organisations in different geographical location i.e. Western Sydney, The Hunter Region and the Mid North Coast of New South Wales. Throughout the course of recruitment and assessment, many Aboriginal and Torres Strait Islander community members that participated, received treatment e.g. general foot care, and treatment for biomechanical issues with "off the shelf" and "custom" orthotics, also heel raises, flip flops, socks and shoes were provided. The provision of treatment such as orthoses to the participants not only helped to treat foot complications but also provided something of value to the participants that were potentially beneficial to foot health.

Finally, as an appendix to this thesis, visual assessment of skeletal remains, including the calcaneus and talus bones of a small number of Kaurna People and 21,000 years old fossilised footprints of the Paakantji, the Ngiyampaa and the Mutthi Mutthi Peoples in Lake Mungo was conducted. These were examined for arch height, indications of biomechanical characteristics of the foot and ankle and possible relationships with biomechanical function with modern day Aboriginal and Torres Strait Islander Peoples. This was largely an exploratory study and the visual inspections undertaken where basic. However evidence of bone spurring on the calcaneus and a high arch foot type give weight to a possible hereditary link in relation to biomechanical function of the ankle joint. However it is important to note that due to the difficulty obtaining ethics approval to undertake this work and the nature of this assessment, this work can only be viewed as anecdotal and is largely based on assumption. The findings were from a small number of bones and it is possible that the spurring may have been associated with normal physical activity rather than a true biomechanical difference. Nevertheless it does provide a fascinating insight into some of the habitual activities and raise some possible links between biomechanical characteristics of modern day Aboriginal and Torres Strait Islander Peoples and their ancient ancestors (Appendix 7).

Concluding Statement

From conception i.e. the literature review, this thesis has established that there has been limited research into Aboriginal and Torres Strait Islander Peoples foot health, especially in relation to biomechanical function of the lower leg and foot. The research conducted as part of this thesis demonstrated ankle equinus is highly prevalent in Aboriginal and Torres Strait Islander Peoples. The subsequent effect on forefoot loading may contribute to the increased incidences of foot complications and poor foot health in this population, particularly where there is co-existing chronic disease.

Future research in the Aboriginal and Torres Strait Islander population relating to foot and ankle biomechanics and the relationship with foot complications needs to be conducted prospectively, in a larger sample. It needs to be more representative of rural, regional and metropolitan populations as this is likely to impact the incidence, nature, chronicity and outcomes of foot disease. In addition, the effectiveness of intervention with a simple calf stretching program on forefoot plantar pressures including PP and PTI in Aboriginal and Torres Strait Islander Peoples with ankle equinus should be evaluated. This may provide an easily applied, cost-effective method of reducing risk of foot complications associated with equinus in the Aboriginal and Torres Strait Islander population.

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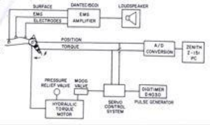
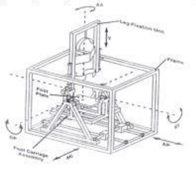
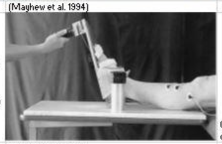
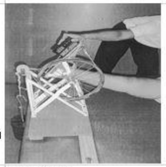
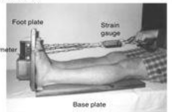
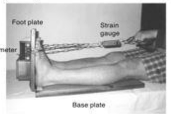
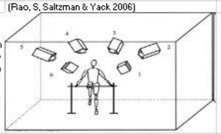
Appendix 1

Tittle and Tool	Picture	No. of Operators	Paralax Issues	Expense	Reproducibility	Axis of rotation	Position and fixation of body and Limb	Fixation of Foot	Torque Force	Portability	Reliability	Validity	Summary and Rating
Reliability of a torque motor system for measurement of passive ankle joint stiffness in control subjects (torque motor ankle testing unit)	 (Chesworth & Vandervoort 1988)	It is unclear how many people are required to opperate this device, but it would appear 1 person could conduct the measurement	It does mention the use of a strain gauge and there are parallax is issues associated with there use.	Costs are not metioned but there would be great expence in producing a tool like this	The article does not elaborate on exactly how the tool opperates e.g. how the motors turn the foot plate and they developed data acquisition and analysis programs especially for this project. This would make this tool difficult to reproduce.	Axis of rotation was considered to be a midway point between the distal extent of the malleoli	The subjects where test lying in a prone position with the knee extended and in a kneeling, knee flexed at 90 degrees position	Starting position was considered when the footplate was 90 degrees to the fibular. The forefoot and mid-foot is fixed to the foot plate	Controlled motor driven torque force, which imposes a controlled rotation of the joint, a strain gauge was used to measure force	The motors and other equipment used with this tool would limit its protobility	Only tested Intra-rater reliability ICC ranged from 0.77 to 0.79 knee extended and 0.89 to 0.94 with knee bent. 10 female subjects aged 26 to 46 were measured on 2 consecutive days. The ankles were moved through 10 degrees of plantarflexion to 10 degrees of dorsiflexion 6 times. They eliminate the first cycle because it was considered an "acclimatization" cycle and the next 5 measurements were averaged. Only dorsiflexion was analysed. Angular displacement was measured with a potentiometer attached to the axis of rotation. computerized analysis of stiffness curves (torgue v's angular displacement)where used to evaluate reliability	An electromyographic (EMG) amplifier was used to monitor calf muscle activity, a high setting was used to detect even slight contraction but there is doubt about if EMG can monitor stretch in muscle.	Considering this is the oldest tool in this review, it is ahead of it time and possibly served as insaration for the many other tools that followed. It would have helped to see a photograph of the tool the diagram was incomplete. If a strain gauge was used to measure the force, parallax issues, would have produced different forces. Expensive. Difficult to reproduce. Axis sounds good but difficult to be sure. Dont believe there was any real fixation of the leg or foot. Torque force likely not constant and line of pull unknown. Limited portability. Not great intra-rater reliability ICC , 0.77 to 0.79 for knee extended. Used EMG to validate this tool but EMG monitors nerve conduction, not muscle stretch.
Measurement of passive ankle dorsiflexion: Procedure and Reliability (Lidcombe Template)	 (Moseley, A 1991)	2 people are required to opperate this device	There will be several parallax issue with using this tool e.g. reading the strain gauge, taking the photograph produce parallax, reading the lines on the photo with the goniometer.	Very affordible device, little expence in producing or using it.	This tool is of very simple design and would be very easy to reproduce.	It is difficult to determin, it could be argued that the axis of rotation is unknown but because a foot plate is not used it could be that the axis is the true axis at the ankle joint	The patient is sitting up supine, which could effect dorsiflexion of the foot. The knee was extended and a 10cm diameter cylinder was placed under the knee. This was desidned to standardize the knee position but would have effected the dorsiflexion range.	There is no fixation of the foot and this is a weakness with this tool	The force was a pplied at the 5th met head level so different foot lengths had different torque force ranging from 12 to 16.8Nm, the force applied could be adjusted to apply equal torque force. The line of pull of this device will cause the torgue force to change constantly as the force is not perpendicular the the lever arm	Extremely protable, a real strength of this tool, it could be used anywhere	They claim intra and inter-rater reliability ICC of 0.97 for both measures. Stating 77% of the time the measurement will be +/- 5 degrees. They do state the reliability is for head injury and this study could not be generalized. The landmarks on boney prominance were all marked by the same person and were used by all examiners on all testing days. All markings are a large source of error and this does cast doubt on intra and inter-rater reliability results.	This study has not attempted to validate this tool	Very simple design. 2 people to opperate. Many parallax issues. Cheap and easy to reproduce. Difficult to be sure but axis could be very good. Not good body position, no fixation of the leg or foot, knee has 10 cm cylinder underneath with will lead to different ROM. Not constant torque force 12-16.8Nm. Extremely protable, Good intra and inter-rater reliability 0.97. Validation was not attempted
A method to determine the range of motion of the ankle joint complex, in vivo (six-degrees-of-freedom apparatus)	 (Allinger & Engsberg 1993)	Article does not specify how many opperaters are needed but it may be more than one	No parallax issues but movement of the skin markers during movent will cause error in the video analysis	This tool would be expensive to build, many hours of work, 4 video cameras and potentiometer.	Would be difficult to reproduce, very complecated design, many hours of work, difficult to build exactly the same.	They claim that the axis of rotation is close to the physiological ankl joint axis but it is not adjustable for different foot size/shape	The subject is sitting with knee flexed at 90 degrees held with a velcro strap. The lower leg is fixed in the device with 2 c-clamps	Foot was placed a laboratory shoe and was fixed to the foot plate with 3 velcro straps. They did test the difference between barefoot and the shoe and found the shoe gave larger ROM.	Torque force of 6Nm was used to dorsiflex the foot, the artcle does not say how this is measured or calculated but states there was a 100N verticle force.	This tool would not be portable, particapants will have to come to the clinic	7 young(20-35years) and 10 old (55-80years) subjects were tested, each subject was tested 4 times over 2 days. This testing procedure uses active range of motion and with dorsi flexion, this may test the strength of muscle rather then passive stretch. Some muscle strength will have been deeded to move the device itself. Potentiometers were used to measure range of motion of foot plate. 6 markers on the foot and leg and 4 videocameras were used to measure movement. The report that the lower leg moved a max of 0.8 degrees with dorsiflexion in the device. Placing markers on boney landmarks is a source of error	The subject is sitting with knee flexed at 90 degrees, this will influence ROM due to iliminating gastrocnemius influence	Extremely complex design. May need more than one opperator. Markers on skin may move during movement leading to error. Expensive and hard to reproduce. May have good axis but difficult to be certain. Sitting and Knee flexed only. Foot in shoe that is fixed to foot plate. Working against 6Nm in dorsiflexion. Not portable. Testing muscle stregth to produce ROM. Knee flexed only eliminating gastroc effect on dorsiflexion. Safisticated tool but many sources of error and need to be able to measure subject in lying position, non-weight bearing, knee extended.
Performance characteristics of the Kin-Com dynamometer (Leg Press)	 (Mayhew et al. 1994)	One person opperator.	No parallax issues	$24,000	Not reproducible	Axis may be at the true physiological axis but hard to be positive.	Can be adjusted to have patient stting-up or lying down supine, knee flexed or extended. No fixation of the leg or knee.	The forefoot is fixed to the foot plate with a padded cuff but the heel may be able to lift. Starting position was when the foot plate was vertical	Kin-Com dynamometers don't allow the subject to move the foot plate like some other dynamometers. Force is produced by hydrolic motor controlled by computer and processed by load cells in the lever arm, via the systems analog-to-digital board displayed on computer. The direction of force remained perpendicular the lever arm	No portable	Angle or ROM was obtained by potentiometer attached to the foot plate. Testing was conducted on two consecutive days. Reported very good intra and inter-rater reliability ICC 0.99 from the 4 different opperators and inter-rater reliability was very impressive 1.00.	The study does not set-out to validate this tool	Safisticated equipement and design. One person opperator. $24,000. No parallax. Not reproducible. May have good axis. Completely adjustable to measure ROM in any desired position. Knee and rearfoot not fixed which could lead to error. Constant torque force. No portible. Excellent reliability intra and inter-rater reliabilty 0.99 and 1.00 respectfully. Not validated. The study does not test a particular limb, joint or movement, it uses known weights, angle and forces and compares them with the results from Kin-Com.
A randomized trial assessing the effects of 4 weeks of daily stretching on ankle mobility in patients with spinal cord injuries	 (Harvey et al. 2000)	One person opperator.	No parallax issues	Not too expensive	Not an extremely complicated design but likely difficult to reproduce exactly the same.	They claim that the axis of rotation is aligned with the lateral malleolus but the picture shows it is not adjustible and not in line with the lateral malleolus.	Patient lying supine, knee extended and flexed, not fixation of body, knee or leg	They do not mention if the foot is fixed but the picture is not clear but shows that the foot may have a velcro strap holding it to the foot plate.	A 5 kg weight applies a constant torque force of 7.5Nm	This tool is relatively portable	Digital inclinometer was used to measure angles, ICC for baseline angle and angle were .84 and .90 but the slope value was a low .31, the reliability of this tool is not convincing	Electromyographic activity of tibialis anterior and gastrocnemius were recorded supposedly validating this procedure but there are doubts about this	All patients were men. Power calculation indicated that (N=14) would give a 90% probability of detecting a 5 degree change if SD = 5 degrees and alpha = .05. Digital inclinometer was used

Normative data for passive ankle plantarflexion-dorsiflexion flexibility (manually controlled instrument footplate)	 (Moseley, AM, Crosbie & Adams 2001)	One person opperator.	no parallax issues	moderately expensive	This tool is a simple design that could be relatively easy to reproduce	The axis appear to be approx at the lateral malleolus but it is not adjustible.	Patient is lying supine, body knee or leg are not fixed	The foot has been fixed at toe and met heads with 2 velcro straps .	a constant torque force of 12.0Nm was applied to the footplate via a load cell	This tool may need to be used in the lab.	A rotary potentiometer was mounted on the axis to measure angle, 6 stretch cycles were calculated, with the last 5 used for analysis. Torgue versus displacement curves were used for analysis, with ICC test-retest values ranging between 0.87 and 0.94, only knee extended was measured	The researchers do not claim validity	Quite a sophisticated tool and complicated analysis with some research possibilty but limited clinical use
Design and Validation of an Instrument Package Designed to increase the Reliability of Ankle Range of Motion Measurements	 (Weaver K 2001)	One person opperator.	Some parallax issues with aligning shank in line with fibula	Possible very expensive	Complecated design that could be reproduced but not easily.	The axis appear to be approx at the lateral malleolus and may have some room for adjustment anteriorly and posteriorly.	Patient is lying supine, body knee or leg are not fixed but the device is attached to the leg which possily the best way of fixation.	The rearfoot has been fixed with a heel cup but the cup is held by the opperators hand and this is prone to error.	Constant torque force (10Nm) applied by load cell perpenticular to foot plate	This tool may need to be used in the lab.	Only tested Intra-rater reliability ICC = 0.983, with SD = 0.45 degree and only tested knee extended.	The researchers do claim validation of this tool but this is debatable, EMG can only detect activity not muscle stretch, so the research has not proved it is measuring ankle joint ROM	This is a very good tool, it fixes device to the leg, load cell allows constant torque force, it has semi-adjustable axis of rotation helps start the rotation at 90 degrees to tibia but this is not perfect, atempts to prevent rearfoot compensation with heel cup, maintain muscle relaxation with EMG but other tools have been shown to be reliable without EMG, it may even be said that the researcher have a misunderstanding af validation and this tool needs to be tested for inter-rater reliabilty. They compare their relative success to goniometers that are known to be unreliable
Reliability of a device designed to measure ankle mobility	 (Harvey L 2003)	One person opperator	No parallax issues	Not too expensive	Simple design but not easy to reproduce exactly	Axis of rotation is designed to be at the lateral malleoli, but it is only approx and it isnot adjustable.	Patient is lying down supine with hip flexed, creating a force about the knee that may produce hyper extension, due to the wheel not allowing the device to sit on the floor. There is no fixation of body or limb	They state that the foot was securely fastened but does not say how	They claim a constant torque force of 17 Nm from hanging 11 kg from the wheel but it could be argued with the serious of pulleys, the foot plate and the wheel rotating together in may be hard to be sure exactly what the true force would be, but it will be a constant force. The ankle was stretched for 3 mins to avoid creep	It appears to be semi-portable	Only tested people with spinal cord injury, repeated measures of 2 or 3 days by 4 opperators, the ICC = 0.95indicating that day 1 was 3 degrees of measurements on day 2 77 % of the time	the research is not designed to validate this tool	
Measurement of Foot Dorsiflexion: A Modified Lidcombe Template (Modified Lindcombe Template)	 (Scharfbillig & Scutter 2004)	2 person opperator	Parallax issue reading and holding strain gauge	very cheap to build	very easy to reproduce	Axis of rotation is posterior/distal heel where the footplate and baseplate hinge, should be at true axis of ankle joint or at the lateral malleoli.	Patient is sitting supine, the body or limb is not fixed but 10cm cylinder is held under the knee.	The foot is not fixed.	They claim that thee is a constant torque force but using a strain gauge, it would be unlikely to be truly constant and it is not true torque because the line of pull is not perpendicular and it is continually changing	very portable	Excellent reilability, tested intra and interrater reliabilty with 14 subjects and 2 testers ICC = 0.99 for both aspects	The research was not designed to validate this tool, but do claim face validity.	A very portable,inexpensive and easy to build clinical tool with excellent reliability but lack validity and qualities for this criteria

Measurement of Foot Dorsiflexion: A Modified Lidcombe Template (Modified Lindcombe Template)	 (Scharfbillig & Scutter 2004)	2 person opperator	Parallax issue reading and holding strain gauge	very cheap to build	very easy to reproduce	Axis of rotation is posterior/distal heel where the footplate and baseplate hinge, should be at true axis of ankle joint or at the lateral malleoli.	Patient is sitting supine, the body or limb is not fixed but 10cm cylinder is held under the knee.	The foot is not fixed.	They claim that thee is a constant torque force but using a strain gauge, it would be unlikely to be truly constant and it is not true torque because the line of pull is not perpendicular and it is continually changing	very portable	Excellent reilability, tested intra and interrater reliabilty with 14 subjects and 2 testers ICC = 0.99 for both aspects	The research was not designed to validate this tool, but do claim face validity.	A very portable,inexpensive and easy to build clinical tool with excellent reliability but lack validity and qualities for this criteria
A Mechanical Equinometer to Measure the Range of Motion of the Ankle Joint: Interobserver and Intraobserver Reliability	 (Meyer D 2006)	One person opperator	There are parallax issues reading the goniometer attached to the hinge intersections.	relatively cheap	possibly difficult to reproduce exactly	They claim the axis is instantaneous center of rotation but this is debatable, Axis of rotation is a hinge which lies outside of the foot and is not adjustable.	With measurement in knee flexion patient is supine with hip felexed and lower leg supported with a stand, lower leg is fixed to the device with 2 velcro strapps, with knee extension patient is prone with lower limb hanging over table edge, seeming to hyper extend the knee.	the foot/ankle is fixed to footplate with 1 velcro strapp, heel cup used to support rearfoot.	Constant torque force of 10 Nm via unique battery opperated, electronic, torque sensative crank handle	very portable	3 testers, conducted 3 measures, held for 5 sec of 16 feet, they applied a pre test for 5 secs, the tool was removed and reattached by the different testers. Intra-rater ICC = 0.98 and inter-rater ICC = 0.89 for knee extension and knee flexion was 0.99 and 0.97 respcetfully, mean error was 0.6 degrees with knee extesion and 1.2 with knee flexed	The researchers do not claim validity	A unique tool that is very portable,inexpensive tool with good reliability. By strapping the tool to the tibia they can be relatively sure that they start the rotation at 90 degrees to the tibia which no other tool addresses, axis of rotation is way off and parallax issues do lower the rating
Three-dimensional in vivo motion of adult hind foot bones	 (Mattingly et al. 2006)	One person opperator	No parallax issues	extremely expensive	possibly difficult to reproduce exactly		patient lying supine, body knee or lower leg have not been fixed	the foot has been fixed with 2 velcro strapps, believed to hold the foot in neutral position and at 90 degrees to leg				This tool is valid, a series of 64 MR images - 1.5 mm thick in 10 degree increments of motion. Analysis was performed by 3D VIEWNIX, tibia,talus, calcaneus, navicular and cubiod were indentified and outlined and movement measured	
Ankle ROM and stiffness measured at rest and during gait in individuals with and without diabetic sensory neuropathy	 (Rao, S, Saltzman & Yack 2006)												
Asymmetry of the active nonweightbearing foot and ankle range of motion for dorsiflexion-plantar flexion and its coupled movements in adults	 (Virgilio F. Ferrario 2007)												

Appendix 2a

Aboriginal Medical Service
WESTERN SYDNEY CO-OPERATIVE LTD.

27/07/12

Frank Vincent (Chief Executive Officer)

Re: Proposed foot health research to be conducted by James Charles

To Whom It May Concern

The Aboriginal Medical Service Western Sydney (AMSWS) has been in correspondence with James Charles (podiatrist) about the AMSWS supporting some Aboriginal foot health research.

The AMSWS has been involved with many research projects over the years, and we do intend to continue to be involved with research projects in the future. We are particularly supportive of Aboriginal researchers like James conducting research in the Aboriginal community.

As CEO I have made the AMAWS board aware of James's request to conduct his foot health research with the AMSWS. The AMSWS board was very interested in the proposal and has given general support for James and his foot health research. Of course we have informed James that before the board can give full approval for his research, he must get ethics approval. We require ethics approval from the University in which James is associated and also approval from the Aboriginal Health & Medical Research Council Ethics Committee, through the Aboriginal Health & Medical Council of NSW.

James has informed me that he is committed to his research and intends to meet all requirements of the AMSWS and its board. We believe that foot health research is desperately needed in the Aboriginal community. We wish James all the best getting ethics approval and look forward to working with him in the near future.

Yours Sincerely

Frank Vincent

CEO Aboriginal Medical Service Western Sydney

Aboriginal Medical Service Western Sydney Co-operative Ltd. 2 Palmerston Rd, Mt Druitt Village NSW 2770 ABN 82 174 391 271
Phone: 02 9832 1356 Fax: 02 9625 4152 Email: amsws@amsws.org.au
Funded by the Commonwealth Department of Health and Ageing and supported by NSW Health Department

Appendix 2b

03/10/12

Professor John Lester

Director of the Wollotuka Institute

University of Newcastle

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

To Whom It May Concern

Re: Foot Research Support Letter

James Charles has worked at the Wollotuka Institute for over 2 years and is a valued employee. I recognise that James is very passionate and enthusiastic about his proposed foot research. As an Aboriginal education and research centre we are very supportive of Aboriginal researchers like James completing their PhD. We believe that James's is a very capable individual and his research will add to the body of knowledge in the area of Aboriginal and Torres Strait Islander foot health. We are more than happy to assist James were ever possible to complete his research, including advertising his research in the Birabahn Building and recruiting Aboriginal and Torres Strait Islander community members interested.

We support James and wish him all the best with the challenges ahead conducting his valuable research, and we expect his research to make a positive contribution to improving Aboriginal and Torres Strait Islander health.

Yours Sincerely

John Lester

Appendix 2c

ABN: 32 875 039 858

Tobwabba Aboriginal Medical Service

Providing quality holistic healthcare for the people in the Worimi Nation

68a Macintosh Street Forster NSW 2428

T: 6555 6271 F: 6555 6864 E: clinic@tobwabba.org.au

9 May 2012

To whom it may concern

Re: Support Letter for podiatry research

James Charles has been providing a podiatry service at Tobwabba Aboriginal Medical Service for 12 months. James is a very friendly, easy going person who is hard working, and very professional. He has built good relationships with his patients, the staff at Tobwabba and the Aboriginal community of Forster Tuncurry. I know he is passionate about improving foot health in the Aboriginal population, by providing podiatry service and conducting foot health research.

Tobwabba AMS is supportive of James and his foot health research. As an Aboriginal Medical Service, Tobwabba would like to support James.

We believe it essential that Aboriginal people like James conduct culturally appropriate research and I am happy to seek Board Approval to enable him to display a recruitment poster in our clinic and for him to recruit participants from the Tobwabba AMS.

Yours Sincerely

Jackie Trotter
Practise Manager
Tobwabba Aboriginal Medical Service

Re: Support Letter for James Charles

To whom it may concern

I have known James Charles for about 6 months, he is the consultant Podiatrist in the Chronic Care Enhancement Program here at the Awabakal AMS. I have found him to be a very friendly, cooperative person. James displays high standards and is a highly skilled podiatrist. I know he is passionate about improving foot health in the Aboriginal population.

James is committed to conducting foot health research with the Aboriginal population and as an Aboriginal Medical Service, Awabakal would like to support him in anyway we can. We would certainly be happy for James to display a recruitment poster in our clinic and for him to recruit participants from the Awabakal AMS.

It is critical to see Aboriginal people like James leading research which could improve the health of the Aboriginal community. We support James and wish him all the very best with his research.

Yours Sincerely

Liz Harwood
Health Service Manager
Awabakal Aboriginal Medical Service

By signing below I confirm that James Charles contributed to the design of the trial, data collection, analysis of the data and drafted the original of the publication entitled: The relationship between ankle equinus, bare-foot plantar pressures and diabetic neuropathy in Aboriginal Australians.

List: Charles J, Spink M, Chuter V. The relationship between ankle equinus, bare-foot plantar pressures and diabetic neuropathy in Aboriginal Australians.

Co-authors: Martin Spink and Vivienne Chuter

Date 12/04/16

Signature of Co-Authors:

Vivienne Chuter:

Martin Spink

Appendix 4

Australian Indigenous HealthBulletin
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The Aboriginal Multiple Injury Questionnaire (AMIQ): The development of a musculoskeletal injury questionnaire for an Australian Aboriginal population.

Charles J (2017)

Suggested citation

Charles J (2017) The Aboriginal Multiple Injury Questionnaire (AMIQ): The development of a musculoskeletal injury questionnaire for an Australian Aboriginal population. *Australian Indigenous HealthBulletin* 17(3)

Acknowledgement: I would like to acknowledge the traditional owners of all the many Aboriginal and Torres Strait Islander Nations that make the great continent of Australia. I would like to pay my respects to the Aboriginal and Torres Strait Islander elders past and present, also the young community members, as the next generation of leaders and representatives.

Disclaimer: In some instances in this paper I will be using the term 'Aboriginal' to describe both Aboriginal and Torres Strait Islander people. This is due to word restrictions, and no disrespect is intended to any individual or group.

Abstract

Objective: Studies have shown Aboriginal People have high rates of ankle, knee and back injury, also foot health is poor. However there is no specific questionnaire for musculoskeletal injury for Aboriginal Australians to investigate the impact of injuries on quality of life. A musculoskeletal injury questionnaire needs to be developed specifically for Aboriginal People.

Methods: A search of literature for musculoskeletal injury questionnaires was conducted to find an appropriate questionnaire that could be modified to use in an Aboriginal population and for different types of injury. Five appropriate questionnaires were discovered and assessed against desirable criteria for a culturally appropriate injury questionnaire.

Results: The Bristol Foot Score (BFS) was found to be the most appropriate questionnaire, particularly as it is patient centred. However, in its original format it did not meet all the desirable criteria and modifications were required for use in the Aboriginal community and for use with different types of injuries.

Conclusions: Aboriginal people have high percentages of musculoskeletal injuries. An Aboriginal Musculoskeletal Injury Questionnaire (AMIQ) has been developed from a modified Bristol Foot Score (BFS). The AMIQ can assess the impact of foot, ankle, knee and back injuries on quality of life in the Aboriginal community.

Implications: The AMIQ is designed to evaluate access to treatment by the Aboriginal community. The AMIQ also provides a quantitative summary score which can be used to gauge the impact of injury on the Aboriginal community and this can be used to investigate improvement of injury over time. It is important to have a culturally appropriate AMIQ to use for the Aboriginal community.

Key Words: Aboriginal, Musculoskeletal, Questionnaire and Injury

Contents

Core funding is provided by the Australian Government Department of Health

Australian Indigenous HealthInfoNet

AUSTRALIA ECU EDITH COWAN UNIVERSITY

Background

Aboriginal Australians are athletic [1-4], sport and physical activities are very important to many Aboriginal cultures [2, 5, 6]. Aboriginal Australians participate in sport and athletics at all levels, from social to elite [7], in very high numbers [8-11]. Although it is important for Aboriginal individuals and communities to participate in sport and physical activities, research has shown ankle, knee and back injuries are very high [12-14]. It has also been shown that Aboriginal foot health is poor, and exponentially getting worse [15]. Studies have found that musculoskeletal injury is higher for Aboriginal Australians than non-Aboriginal Australians [16], and these injuries are often higher for Aboriginal women [17]. Research found these high rates of injury were also highly prevalent in young Aboriginal Australians [14]. Similar injury rates were found in other Indigenous populations around the world [18]. However none of these studies looked at the impact these injuries had on mobility, weight gain, quality of life or social and emotional wellbeing for Aboriginal Australians. Therefore a specific, culturally appropriate, musculoskeletal injury questionnaire is required to evaluate injury in the Aboriginal community.

Desirable Criteria: Patient centred, subjective measure, non-specific for group or injury, not complicated or ambiguous, not time consuming, makes no assumptions, quantifiable, able to be modified, freely available, no cost, reliable and valid. These criteria were derived from what the author considered to be the most practical and desirable for collecting information on musculoskeletal injuries in the Aboriginal community.

Culturally Appropriate Criteria: One of the most important criteria for an Aboriginal questionnaire is being patient centred, or patient focused i.e. the questionnaire should give the patients perspective. It is central to being culturally appropriate to consult and engage, giving the Aboriginal community a 'voice' in their health care, education and involvement in research [19]. In the past, Aboriginal people have been examined, had tests, been diagnosed, given treatment e.g. medication(s), without explanation or engagement. This lack of engagement, and consultation is likely why these interventions have not always been successful [20]. Aboriginal Australians must be consulted and seen as key 'stakeholders' in decision making [21]. A patient focus and giving Aboriginal people a 'voice' is also related to the need to have a questionnaire that is subjective i.e. giving the Aboriginal participant the opportunity to tell their story of musculoskeletal injury and how these injuries have effected them. Ideally the questionnaire would be broad and not too specific for any condition or cohort, as the questionnaire is proposed to be used on a broad range of injuries in the Aboriginal community. It is well documented that education and literacy levels are low in many Aboriginal communities [22, 23]. Therefore there is a need to use a questionnaire which is not complicated to understand, or ambiguous, and the questions can be asked by the health professional, educator or researcher i.e. does not require the participant to read questions. Not requiring Aboriginal participants to read the questions or write their answers is also culturally appropriate, as most Aboriginal cultures did not record their history or culture in writing, it was told in story, and actively listening [24]. There is a lot of research being conducted in Aboriginal communities, and some Aboriginal individuals and communities are becoming fatigued. It is not important in many Aboriginal cultures for individuals to dedicate vast amounts of time talking about themselves, especially about pain and suffering. Therefore it is desirable and culturally appropriate to keep the questionnaire concise, and not too time consuming. Many questionnaires make judgements about participants e.g. education level, literacy levels, employment, but many Aboriginal people don't value western knowledge, and prefer Aboriginal ways of knowing, being and doing [25, 26]. Therefore it is culturally appropriate to have a questionnaire that does not make assumptions about Aboriginal participant's western education. Many Aboriginal people have English as a second or third language, and traditional language is central to culture [24, 27], so it is culturally appropriate to have a questionnaire that is unambiguous. It is extremely likely that any questionnaire would need to be modified at some level to meet all criteria, so it is important that any potential questionnaire lend itself to modification easily. As there is a need to use a pre-existing questionnaire, it is paramount to find a questionnaire that is freely available and at no cost to any individual or community. In many Aboriginal cultures, sharing and reciprocity is very important [28], so it is culturally appropriate to produce a questionnaire that is freely available to anyone. It is also important to have a freely available questionnaire because it is well documented Aboriginal Australians have less income than non-Aboriginal Australians [29].

Questionnaire

To gauge the prevalence of musculoskeletal injury and the impact on the Aboriginal community, a subjective, culturally appropriate, injury quality of life measure is required. A subjective (self-reported), patient centred questionnaire is also a culturally appropriate method of gaining this type of information. It is essential to allow the Aboriginal community to have a 'voice' [19] and be able to tell the health professional or researcher what their injury problems are, and how this is affecting their day to day activities. Rather than a health professional, educator or researcher providing their opinion of what the Aboriginal community problems are and how this is affecting them.

A literature search was conducted, musculoskeletal injury questionnaire/survey papers were identified by searching the

EMBASE, Medline, PubMed, EBSCOhost, and Cinahl databases. The search was conducted using the search terms: injury, pain, musculoskeletal, foot, survey and questionnaire. This search produced five potential questionnaires/surveys that could be adapted for developing an Aboriginal Multiple Injury Questionnaire (AMIQ). The five questionnaires/surveys were evaluated against desirable criteria, which were specific for the AMIQ and culturally appropriate for the Aboriginal community. It should be noted that none of the questionnaires/surveys evaluated were designed specifically for the use with Aboriginal Australians.

Questionnaire/Survey Evaluation: The Foot Health Survey (FHS) Redmond (2008) [30, 31] was developed by the Charcot Marie Tooth Association of Australia (CMTAA) appears to be a well-designed survey. Although it is a weakness that it has been developed specifically for people with Charcot Marie Tooth (CMT). CMT sufferers often have extreme problems with their feet, and these complications can make walking very difficult, which may limit the transferability of the FHS. The FHS is very long and time consuming, it has been developed by the members of the CMTAA for their specific needs. The FHS has not been validated and has not been cited, likely because of its specific focus. The FHS has some potential for use in the Aboriginal community and for other injuries but would require huge modification and not ideal for the development of an AMIQ due to time required of participants.

The Oxford Ankle Foot Questionnaire (OAFQ) developed by Morris et al. (2009) [32] is a very well-constructed questionnaire, which has been validated. It has been cited 46 times and appears to be a very good quality questionnaire. It has been developed and designed for qualitative research with focus groups, and the questions are audio recorded and analysed which may complicate the process and introduce ethical considerations with its use with the AMIQ. The OAFQ has been developed for children that have injuries or disabilities that may require surgery. The line of questioning is very much focused on child activities, which is not the proposed focus of the AMIQ. Although a very well designed questionnaire it does not appear that the OAFQ would be adaptable or appropriate for the use with an adult Aboriginal population.

The Foot Function Index (FFI) developed by Budiman-Mak et al. (1991) [33] appears to be a very straight forward, unambiguous questionnaire. It is subjective with quantitative results from 23 questions which were developed by health professionals. The questions are under three topics i.e. pain, disability and limitations with a 10 point scale which makes it quantifiable. It appears the FFI would not be time consuming, easy to use and with no personal questions. It has 1,913 citations and has been validated by Budiman-Mak et al. (1991), but that was only for the use with participants with arthritis. Agel et al. (2006) examined the FFI for reliability and found that it may not be appropriate for people who have normal foot function [34]. The FFI was tested for reliability by Landorf et al. (2006) with the use of orthotics for plantar fasciitis and found it had good test retest reliability and a high degree of internal consistency [35]. The FFI has potential with some modification, and met many of the AMIQ criteria. It may have some potential to be adapted for other uses, but it may require a great deal of modification for use in the Aboriginal population and for other types of injuries e.g. ankle, knee and back.

The Foot Health Status Questionnaire (FHSQ) developed by Bennett et al. (1998) [36] has been widely used and has been cited 270 times. It is subjective and reportedly only takes between 3 to 5 minutes to conduct [36]. It seems a little ambiguous and the questions make some assumptions e.g. that all people wear shoes and work [36] which may not be appropriate for the AMIQ. The FHSQ was developed to assess patient's pre and post-surgery which is not ideal for the development of the AMIQ. Contact was made via email and an automatic reply was received, informing the enquirer where the AU$150 could be sent to use the questionnaire, and permission for modification was not given. It has been validated, and was found to have good test-retest reliability. However the questions are developed from a health professional's perspective, which is not ideal for use in the Aboriginal community. This questionnaire is not freely available, may not be appropriate for Aboriginal Australians or for use with other types of injuries. The FHSQ is possible not ideal for the objectives of the AMIQ and the cost may be prohibitive.

The Bristol Foot Score (BFS) developed by Barnett et al. (2005) [37] and has been cited 496 times. Over 400 community based podiatric patients were used to develop the questions in the BFS. Dr Barnett started with 41 original questions, gradually eliminating inappropriate questions based on participant feedback e.g. insufficient detail, too long, people chose not to answer, repetition. The remaining 15 questions were used in the final version (version 5) of the BFS. Factor analysis showing three main areas of relevant questions i.e. pain, mobility and general foot health. It was developed for general use, for people of all ages and conditions, which is an important criteria for AMIQ. The BFS is unambiguous, is very simple to use, and not time consuming (only takes 3-5 mins) [37]. There are no general or personal assumptions made about participants. The BFS has been validated and it was found to have an excellent test-retest score and internal reliability, with a Cronbach alpha of 0.9036 [37]. The BFS was also shown to produce reliable results over time which is very important for accessing injury or pain over time [37]. It was specifically designed as a subjective measure of foot health, which reflects the participants perceptions of their own foot health [37], which is a paramount criteria for the AMIQ. The questions were developed to collect information on the impact on peoples everyday life [37] i.e. a quality of life measure which is also an important criteria for the AMIQ. It was designed as a 'self-administered' questionnaire [37] but these questions could easily be asked by a health professional, educator or researcher, which is important due to literacy issues with some Aboriginal community members [22, 23]. The BFS is quantifiable with all questions having a three to six point rating system with a numerical value attachment to each answer, which can be accumulated to give a total injury score [37]. The BFS is specifically designed to be 'patient centred' and focuses on perceptions of pain from the patients perspective and not to reflect the health professionals or researchers opinion [37]. The BFS is 'freely available' [37] but contact was made with Dr Barnett, permission to use and modify the BFS was granted. The BFS meets most of the AMIQ criteria and can easily be modified to be used for other types of musculoskeletal injury. The BFS is the most appropriate questionnaire/survey and therefore was chosen to be modified for development of the AMIQ.

Modified Bristol Foot Score: There are some modifications that would be needed to make the BFS more culturally appropriate for use in the Aboriginal community and suitable for other musculoskeletal injuries. One of the things that makes the BFS most appropriate to be modified to be used for other musculoskeletal injuries is that replacing the word 'foot' with ankle, knee and back doesn't change the meaning or the structure of the questions. The BFS will be modified to develop an Aboriginal Multiple Injury Questionnaire (AMIQ). The AMIQ will be culturally appropriate for Aboriginal Australians, by being patient centred, unambiguous, not time consuming, makes no assumptions, freely available, and at no cost. The AMIQ will also be able to investigate foot, ankle, knee and back injuries, however it can be used to just investigate just one specific injury, if preferred. The AMIQ will include questions on the impact of injury on weight gain (from the participants perspective), and record access to treatment for injury, as self-reported by participants. The BFS asks participants to reflect over the past two weeks, but it is desirable to have the AMIQ get participants to reflect over the past 6 months, so this will be modified to change '2 weeks' to '6 months' in all relevant questions. The BFS Question 6: asks participants to state how often they are 'conscious of my feet' [37] and this may not be clear to some participants and this question has been removed. The BFS Question 7: states how often have you 'felt fed up about my feet' [37] this may not be clearly definable to all participants and it has been removed. The BFS Question 8: asks participants 'I have felt worried that my feet will get worse in the future' [37] however the AMIQ is concerned about the current situation and recent history, so this question was removed. The BFS Question 9: asks 'I have felt my feet are not really part of me' [37] this question was deemed slightly ambiguous and was also removed. The BFS Questions: 11, 12 and 13 all ask about footwear/shoes [37] and although the AMIQ will investigate foot injury, many Aboriginal people do not wear shoes or only wear slip-on open-toed footwear [38] so these questions have been removed. The BFS Question 15 asks about 'general health' [37] but the AMIQ is investigating musculoskeletal injury, so question 15 was also deleted. The remaining questions were included in the new AMIQ, reducing these unwanted questions also reduces the time to complete the AMIQ. The BFS lends itself to modification for use with other musculoskeletal injuries very easily e.g. the questions are generic, if the word 'foot' is replaced with ankle, knee, or back, the question still has the same meaning. The three to six point scale for answers also remains relevant when 'foot' is exchanged with ankle, knee or back. This ability of the BFS to be so flexible and modifiable was not likely by design but the BFS has proven to be ideal for conversion to use with other musculoskeletal injury and the development of the AMIQ.

Aboriginal Multiple Injury Questionnaire (AMIQ): The AMIQ (see Appendix 1) asks participants if they have ever had previous and/or have a current foot, ankle, knee and back injury. These questions are important to establish some injury history and current status of injury. The preliminary questions also direct the health professional or researcher to the appropriate injury questionnaire i.e. if the participant say they have a current foot, ankle, knee, or back injury, then the relevant questionnaire for that injury(s) is conducted.

Being over-weight or obese is a problem for many Australians but this is even worse for Aboriginal Australians, especially Aboriginal women [39], therefore it was considered appropriate to include a question about weight gain in relation to injury i.e. AMIQ question 'Due to your "……." Injury have you put on weight in the last 6 months?' and then if participants answer 'yes' they are required to nominate the amount of weight they believe they have gained i.e. yes 1kg or less, yes 1-5kg, yes 5-10kg, yes 10kg or more. This is to try and gauge the impact of injury on weight gain from the Aboriginal communities' perspective.

Access to treatment for musculoskeletal injury and other health problems is an issue for many Aboriginal communities, especially in rural and remote areas [40]. Place of residence is considered an extremely important aspect of Aboriginal health, particularly access to health service in different residential areas [40]. Approximately 34% of all Aboriginal people live in cities, and 22% live in inner regional centres, with 21% living in outer regional areas, compared to 71%, 18% and 9% respectfully of non-Aboriginal Australians [41]. The greatest difference in residence between Aboriginal and other Australians is remote and very remote, with approximately 7 times more Aboriginal people living in remote areas [41]. Location of residence makes a difference to access to health care, and life expectancy at birth for Aboriginal people [42]. Therefore it was considered important to ask where participants live, and include a question in the AMIQ about treatment for injuries i.e. AMIQ question 'Over the past 6 months, have you had treatment for your

"……" injury?'. This is designed to allow the Aboriginal community an opportunity to directly provide information about treatment they have or have not received for their injuries.

The AMIQ has a total of 11 questions, with a minimum Total Accumulative Score (TAS) of 9 and a maximum TAS of 59. The TAS from the AMIQ can be used as a guide to the level an injury is negatively effecting an individual. The TAS can be interpreted as: a score (<10) not a problem, (10-22) minor problem, (23-35) moderate problem, (36-47) major problem, and (48-59) extreme problem. The TAS can also be used to ascertain improvement or worsening of injury after a period of time or treatment, by repeating the AMIQ at a later date. The validation of the BFS was an extensive process [37], and the BFS was used as the basis of the AMIQ. However the AMIQ was also pilot tested on a small group (n=24) of Aboriginal rugby league players, 12 male and 12 female, participating in an injury prevention health promotion program [14].

Discussion

There has been limited investigation in to foot health in the Aboriginal population but research suggests it is poor and not improving [15] and the AMIQ will provide an opportunity investigate foot injury. Ankle injury has been investigated in an Aboriginal population, and a report with a very small sample (n=24) showed 42% of participants had an ankle injury in the past 6 months [14]. There has been some investigation into knee injury in an Aboriginal population, and a report (n=24) stated 1 in 4 of participants had a knee injury in the past 6 months [14]. There has been some previous research finding high levels of back injury or pain in Aboriginal populations [12, 13, 17, 18]. A Vindigni et al. 1996 study reported 42 (48.3%) Aboriginal male (n=87) and 33 (32.4%) Aboriginal females (n=102) reported having a back injury in the previous 7 days [12]. Others also found similar results for back injury or pain in an Aboriginal population [13, 14, 17, 18]. Foot, ankle, knee and back injuries and the associated pain, can be debilitating, causing sufferers to reduce activity, training and sport. This can have effects on health directly but can also limit cultural and social activities. Reduced physical and cultural activities can also effect quality of life and social and emotional well-being. Reduction in activity, training and sport can also lead to weight gain, and obesity, which is very high in the Aboriginal population [39]. The AMIQ will allow the Aboriginal community to express how injuries are affecting their day to day lives, and social and emotional well-being, and also provide information on the prevalence of these injuries in the community.

Limitation

The literature search conducted was not systematic review, and therefore some other relevant questionnaires/surveys may not have been discovered or evaluated in this study. Health professionals, researchers and Aboriginal community members may have wanted to include other criteria for the AMIQ but the author has tried to include all relevant and appropriate criteria.

Conclusion

Studies have identified high rates of musculoskeletal injuries in the some Aboriginal populations. Injury, the associated pain and the reduced activity that follows, in some cases may results in weight gain, which can lead to chronic disease. The AMIQ can provide a culturally appropriate questionnaire and will provide valuable information on the impact of foot, ankle, knee and back injuries. The AMIQ will also produce a numerical summary of injury i.e. TAS which will give health providers, educators, policy makers, researchers and the Aboriginal community new reliable data on injury and its impact on Aboriginal People. The AMIQ will be freely available, at no cost to any individuals, or organisations interested in investigating musculoskeletal injury in the Aboriginal community.

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Appendix 1

Aboriginal Multiple Injury Questionnaire (AMIQ)

Participants Name	________________________
Date	____/____/________
Male or Female	________________________
Date of Birth	____/____/________
Town of Residence	________________________

Have you ever had an ankle injury?	Yes / No
Do you have a current ankle injury? If answered "yes" go to the Aboriginal Ankle Injury Questionnaire.	Yes / No
Have you ever had a knee injury?	Yes / No
Do you have a current knee injury? If answered "yes" go to the Aboriginal Knee Injury Questionnaire.	Yes / No
Have you ever had a back injury?	Yes / No
Do you have a current back injury? If answered "yes" go to the Aboriginal Back Injury Questionnaire.	Yes / No
Have you ever had a foot injury?	Yes / No
Do you have a current foot injury? If answered "yes" go to the Aboriginal Foot Injury Questionnaire.	Yes / No

Aboriginal Ankle Injury Questionnaire

Which ankle is injured? Left or Right

1. How often have you had ankle(s) pain? (Please tick in one box only)

All of the time	☐	6
Most of the time	☐	5
A good bit of the time	☐	4
Some of the time	☐	3
A little of the time	☐	2
None of the time	☐	1

2. How painful has your ankle(s) been (Please tick in one box only)

Not painful	☐	1
Very slightly painful	☐	2
Slightly painful	☐	3
Moderately painful	☐	4
Very painful	☐	5
Extremely painful	☐	6

3. Do problems with your ankle(s) affect you when standing still? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1

4. Do problems with your ankle(s) affect you when walking a short distance? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to walk.	☐	9

5. Do problems with your ankle(s) affect when you play sport or other activity? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to do this.	☐	9

6. Do problems with your ankle(s) affect you when walking on bumpy or stony ground? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to do this	☐	9

7. Over the past 6 months how often has your ankle(s) affected your day to day living? (Please tick in one box only)

All of the time	☐	6
Most of the time	☐	5
A good bit of the time	☐	4
Some of the time	☐	3
A little of the time	☐	2
None of the time	☐	1

8. In general would you say your ankle(s) is: (Please tick in one box only)

Excellent	☐	1
Very good	☐	2
Good	☐	3
Fair	☐	4
Poor	☐	5

9. Due to your ankle(s) injury have you put on weight in the last 6 months? (Please tick in one box only)

Yes 10kg or more	☐	
Yes 5-10kg	☐	
Yes 1-5kg	☐	
Yes 1kg or less	☐	
Not at all	☐	

10. Over the last 6 months, have you had treatment for your ankle injury? (Please tick in one box only)

Yes	☐	
No	☐	

11. Because of your ankle(s) injury have you had problems sleeping? (Please tick in one box only)

Yes, very frequently	☐	5
Yes, frequently	☐	4
Yes, sometimes	☐	3
Rarely	☐	2
Not at all	☐	1

AMIQ (Ankle Injury) Total Accumulated Score:

<10 not a problem, 10-22 minor problem, 23-35 moderate problem, 36-47 major problem, 48-59 extremely problem.

Aboriginal Knee Injury Questionnaire

Which knee is injured? Left or Right

1. How often have you had knee(s) pain? (Please tick in one box only)

All of the time	☐	6
Most of the time	☐	5
A good bit of the time	☐	4
Some of the time	☐	3
A little of the time	☐	2
None of the time	☐	1

2. How painful has your knee(s) been (Please tick in one box only)

Not painful	☐	1
Very slightly painful	☐	2
Slightly painful	☐	3
Moderately painful	☐	4
Very painful	☐	5
Extremely painful	☐	6

3. Do problems with your knee(s) affect you when standing still? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1

4. Do problems with your knee(s) affect whether you walk a short distance? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to walk	☐	9

5. Do problems with your knee(s) affect whether you play sport or other activity? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to do this	☐	9

6. Do problems with your knee(s) affect you when walking on bumpy or stony ground? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to do this	☐	9

7. Over the past 6 months how often has your knee(s) affected your day to day living? (Please tick in one box only)

All of the time	☐	6
Most of the time	☐	5
A good bit of the time	☐	4
Some of the time	☐	3
A little of the time	☐	2
None of the time	☐	1

8. In general would you say your knee(s) health is: (Please tick in one box only)

Excellent	☐	1
Very good	☐	2
Good	☐	3
Fair	☐	4
Poor	☐	5

9. Due to your knee(s) injury have you put on weight in the last 6 months? (Please tick in one box only)

Yes 10kg or more	☐	
Yes 5-10kg	☐	
Yes 1-5kg	☐	
Yes 1kg or less	☐	
Not at all	☐	

10. Over the last 6 months, have you had treatment for your knee(s) injury? (Please tick in one box only)

Yes	☐	
No	☐	

11. Because of your knee(s) injury have you had problems sleeping? (Please tick in one box only)

Yes, very frequently	☐	5
Yes, frequently	☐	4
Yes, sometimes	☐	3
Rarely	☐	2
Not at all	☐	1

AMIQ (Knee Injury) Total Accumulated Score:

<10 not a problem, 10-22 minor problem, 23-35 moderate problem, 36-47 major problem, 48-59 extremely problem.

Aboriginal Back Injury Questionnaire

Which part of the back is injured? Low Middle High

1. How often have you had back pain? (Please tick in one box only)

All of the time	☐	6
Most of the time	☐	5
A good bit of the time	☐	4
Some of the time	☐	3
A little of the time	☐	2
None of the time	☐	1

2. How painful has your back pain been? (Please tick in one box only)

Not painful	☐	1
Very slightly painful	☐	2
Slightly painful	☐	3
Moderately painful	☐	4
Very painful	☐	5
Extremely painful	☐	6

3. Do problems with your back pain affect you when standing still? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1

4. Do problems with your back pain affect whether you walk a short distance? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to walk	☐	9

5. Do problems with your back pain affect whether you play sport or other activity? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to do this	☐	9

6. Do problems with your back pain affect you when walking on bumpy or stony ground? (Please tick in one box only)

A major problem	☐	4
A moderate problem	☐	3
A bit of a problem	☐	2
Not a problem	☐	1
Does not apply because I choose not to do this	☐	9

7. Over the past 6 months how often has your back pain affected your day to day living? (Please tick in one box only)

All of the time	☐	6
Most of the time	☐	5
A good bit of the time	☐	4
Some of the time	☐	3
A little of the time	☐	2
None of the time	☐	1

8. In general would you say your back health is: (Please tick in one box only)

Excellent	☐	1
Very good	☐	2
Good	☐	3
Fair	☐	4
Poor	☐	5

9. Due to your back injury have you put on weight in the last 6 months? (Please tick in one box only)

Yes 10kg or more	☐	
Yes 5-10kg	☐	
Yes 1-5kg	☐	
Yes 1kg or less	☐	
Not at all	☐	

10. Over the last 6 months, have you had treatment for your back injury? (Please tick in one box only)

Yes	☐	
No	☐	

11. Because of your back injury do have you had problems sleeping?
(Please tick in one box only)

Yes, very frequently	5
Yes, frequently	4
Yes, sometimes	3
Rarely	2
Not at all	1

AMIQ (Back Injury) Total Accumulated Score:

<10 not a problem, 10-22 minor problem, 23-35 moderate problem, 36-47 major problem, 48-59 extremely problem.

Aboriginal Foot Injury Questionnaire

Which foot is injured? Left or Right

1. How often have you had foot/feet pain?
(Please tick in one box only)

All of the time	6
Most of the time	5
A good bit of the time	4
Some of the time	3
A little of the time	2
None of the time	1

2. How painful has your foot/feet been?
(Please tick in one box only)

Not painful	1
Very slightly painful	2
Slightly painful	3
Moderately painful	4
Very painful	5
Extremely painful	6

3. Do problems with your foot/feet affect you when standing still?
(Please tick in one box only)

A major problem	4
A moderate problem	3
A bit of a problem	2
Not a problem	1

4. Do problems with your foot/feet affect you when walking a short distance? (Please tick in one box only)

A major problem	4
A moderate problem	3
A bit of a problem	2
Not a problem	1
Does not apply because I choose not to walk.	9

5. Do problems with your foot/feet affect when you play sport or other activity? (Please tick in one box only)

A major problem	4
A moderate problem	3
A bit of a problem	2
Not a problem	1
Does not apply because I choose not to do this.	9

6. Do problems with your foot/feet affect you when walking on bumpy or stony ground? (Please tick in one box only)

A major problem	4
A moderate problem	3
A bit of a problem	2
Not a problem	1
Does not apply because I choose not to do this	9

7. Over the past 6 months how often has your foot/feet affected your day to day living? (Please tick in one box only)

All of the time	6
Most of the time	5
A good bit of the time	4
Some of the time	3
A little of the time	2
None of the time	1

8. In general would you say your foot/feet is:
(Please tick in one box only)

Excellent	1
Very good	2
Good	3
Fair	4
Poor	5

9. Due to your foot/feet injury have you put on weight in the last 6 months? (Please tick in one box only)

Yes 10kg or more	
Yes 5-10kg	
Yes 1-5kg	
Yes 1kg or less	
Not at all	

10. Over the last 6 months, have you had treatment for your foot/feet injury? (Please tick in one box only)

Yes	
No	

11. Because of your foot/feet injury have you had problems sleeping?

(Please tick in <u>one</u> box only)

Yes, very frequently	☐	5
Yes, frequently	☐	4
Yes, sometimes	☐	3
Rarely	☐	2
Not at all	☐	1

AMIQ (Foot Injury) Total Accumulated Score:

<10 not a problem, 10-22 minor problem, 23-35 moderate problem, 36-47 major problem, 48-59 extremely problem.

Australian Indigenous HealthBulletin

Australian Indigenous HealthInfoNet

The Australian Indigenous Health*Bulletin* (ISSN 1445-7253) is the electronic journal of the Australian Indigenous Health*InfoNet*.

The purpose of the Australian Indigenous Health*Bulletin* is to facilitate access to information of relevance to Australian Indigenous health. Reflecting the wide range of users – policy makers, service providers, researchers, students and the general community – the Health*Bulletin* aims to keep people informed of current events of relevance, as well as recent research. Research information is provided in two ways – the publication of original research and the presentation of abstracts of research published or presented elsewhere.

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Core funding is provided by the Australian Government Department of Health

AUSTRALIA ECU EDITH COWAN UNIVERSITY

WILLANDRA LAKES REGION
World Heritage Area
MUNGO NATIONAL PARK
Australian Government

4 November 2013

James Charles
University of Newcastle

Dear James Charles,

At the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee & Community Management Council (TSAC & CMC) meeting on 4th September 2013, approval was granted by the TSAC & CMC Members for your request to have access to laser scans of the fossil footprints for use in your PhD thesis. Use of this imagery is limited to non-commercial research purposes only. Subsequent use of imagery for further study or presentation will require separate approvals.

Note that the Traditional Tribal Groups affiliated with the Willandra Lakes are the Paakantji the Ngiyampaa and the Mutthi Mutthi and that acknowledgement must be given to these groups in any published material.

Regards

Richard Mintern
Executive Officer
Willandra Lakes Region WHA
richard.mintern@environment.nsw.gov.au
☎ (03) 5021 8908 0417 204 237

Aboriginal Health & Medical Research Council of New South Wales

AH&MRC ETHICS COMMITTEE

11 December 2012

Mr James Charles
Lecturer, Indigenous Medical Education
University of Newcastle
4 Honey Oak Drive
TORONTO NSW 2283

Dear Mr Charles,

An investigation into the associations of foot health in an Australian Aboriginal population (895/12)

The Aboriginal Health and Medical Research Council (AH&MRC) Ethics Committee has considered your application received on 5 November 2012 for ethics approval for the above project.

The Committee agreed to approve the application subject to the Standard Conditions and Special Conditions of Approval below:

Standard Conditions of Approval (where applicable to the project)

1. The approval is for a period from 11 December 2012 until 31 December 2013, with extension subject to providing a report on the research by 31 December 2013.
2. All research participants are to be provided with a relevant Participant Information Statement and Consent Form in the format provided with your application.
3. Copies of all signed consent forms must be retained and made available to the Ethics Committee on request. A request will only be made if there is a dispute or complaint in relation to a participant.
4. Any changes to the staffing, methodology, timeframe, or any other aspect of the research relevant to continued ethical acceptability of the project must have the prior written approval of the Ethics Committee.
5. The AH&MRC Ethics Committee must be immediately notified in writing of any serious or unexpected adverse effects on participants.
6. The research must comply with:
   - the *AH&MRC Guidelines for Research in Aboriginal Health – Key Principles*
   - *National Statement on Ethical Conduct in Research Involving Humans* (April 2007)
   - the *NSW Aboriginal Health Information Guidelines.*

Funded by NSW Health Department

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ABC/ACN
ABN 66 085 654 397
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7. The final draft report from the research, and any publication or presentation prior to that report where new data or findings are presented, must be provided to the AH&MRC Ethics Committee to be reviewed for compliance with ethical and cultural criteria prior to:
   - any submission for publication; and/or
   - any dissemination of the report.
8. A copy of the final published version of any publication is to be provided to the AH&MRC Ethics Committee.

Special Condition/s

9. Nil.

Please acknowledge receipt of this letter and your acceptance of the above conditions within fourteen (14 days).

We would also appreciate your agreement that the AH&MRC may, on request, obtain access to the data obtained from the research in order to assist the future development of policy and programs in Aboriginal health.

Included, please find an Annual Progress Report pro forma for use at the end of the term.

On behalf of the AH&MRC Ethics Committee,

Yours sincerely,

Val Keed
Chairperson
AH&MRC Ethics Committee

The history and evolution of foot biomechanics and musculoskeletal injury in Aboriginal Australians.

James A. Charles[1], and Vivienne H. Chuter[2, 3]

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2 - School of Health Sciences, University of Newcastle, Australia.
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Disclaimer: In some instances in this paper the term 'Aboriginal' will be used, this will occur when the authors are specifically referring to Aboriginal Peoples.

Warning: Aboriginal and Torres Strait Islander Peoples. This paper has images of bones from deceased Aboriginal (Kaurna) people, however it should be noted the images are copies of pictures using a snipping tool, and not the original photographs.

Background

Aboriginal and Torres Strait Islander Peoples have demonstrated great intelligence and knowledge of their environment, they are very athletic, and have been for millennia (Watkins, Gale et al. 2006, Webb, Cupper et al. 2006). This has been an evolutionary process (Webb 2007), developed through knowledge and understanding of survival skills required to thrive in a very harsh environment (Westaway 2010). Athletics has been part of many Aboriginal cultures, not just for survival but also for recreational activities, which were witnessed by the British colonists in 1840, who reported the Kaurna People (Aboriginal Tribe) playing ball games (Watkins, Gale et al. 2006). This was a type of football called "Parndo" played with a stuffed possum skin (ball), which was kicked up into the air and competition to catch the ball, which the whole community would participate (Watkins, Gale et al. 2006). A similar game was played by Aboriginal tribes in Victoria, Australia, known as marngrook (Robert 1878). Other Aboriginal tribes played ball games e.g. the Narryinyeri tribe, south east of Adelaide, South Australia, played a very physical ball game with aggressive tackling, similar to modern day rugby (Taplin 1879). Successful hunting would have required great intellect, and knowledge of the fauna and country, but obviously athleticism was also essential for hunting, which would have required great acceleration, speed, and endurance at times (Grubb 2011).

In conjunction with the required knowledge, Aboriginal and Torres Strait Islander Peoples may have developed foot structure and function that is conducive to fast running and athleticism required to survive. The authors have recently demonstrated some aspects of foot and ankle morphology and function that are highly prevalent in modern day Aboriginal and Torres Strait Islander Peoples, including a high arched foot type and reduced ankle joint range of dorsiflexion (ankle equinus). In two small community-based samples i.e. one (n=76) with diabetes (Charles J 2016) and one (n=50) on healthy adults (Charles J 2016), found ankle equinus was highly prevalent especially in males and most commonly affected the gastrocnemius muscle (Charles J 2016, Charles J 2016). This previous research indicated that both the foot arch type and the range of ankle joint dorsiflexion affected plantar pressures, with a tendency to increase the duration and degree of forefoot loading (Charles J 2016, Charles J 2016),these are coming up with although due to the cross-sectional nature the findings are not generalizable to the total Aboriginal population.

Although not generalizable it is possible both an ankle equinus and a high arch foot type are an evolutionary biomechanical development to increase running speed and thereby improve hunting ability and survival (Nigg, Cole et al. 1993). The great running speed of ancient Aboriginal Australians has been documented in 21,000 year old foot-print trackways at Lake Mungo in the Willandra Lakes World Heritage area of NSW, Australia (Johnston 2014) (Figure 1).

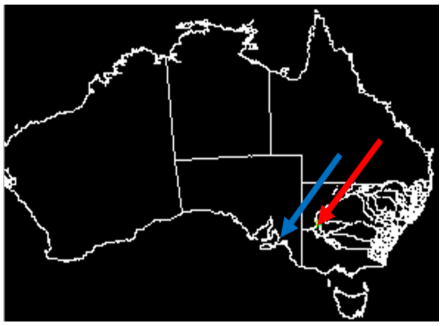

Figure 1: Map of Australia with red arrow indicating Lake Mungo in NSW and blue arrow indicating Hindmarsh, Adelaide SA.
(Image courtesy of the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and the Community Management Council.)

All the footprints at Lake Mungo have been GPS marked, some of the men running, are taking approx. 25 steps to travel an approx. 50 metres or 50 steps to travel 100m (figure 2). This stride pattern is similar to some of the modern world's fastest athletes. Usain Bolt took 41 steps to travel 100 metres to win the gold medal in the London 2012 Olympic games, to reach a top speed of 37km/h (Ingle 2012). Using 50 steps to travel 100m would take an estimated 10 seconds to run 100m (Faccioni 2016). Using a pace calculator (Net 2016) this is an estimated top speed of 35Km/h. It must also be considered that these men were running barefoot, in the mud, and likely carrying a weapon(s) and/or other item(s). It must be considered that these calculations of the ancient Aboriginal men running 100m is an estimate based on an extrapolation of a 50m run, and there is no way of knowing if these men could have maintained this stride pattern.

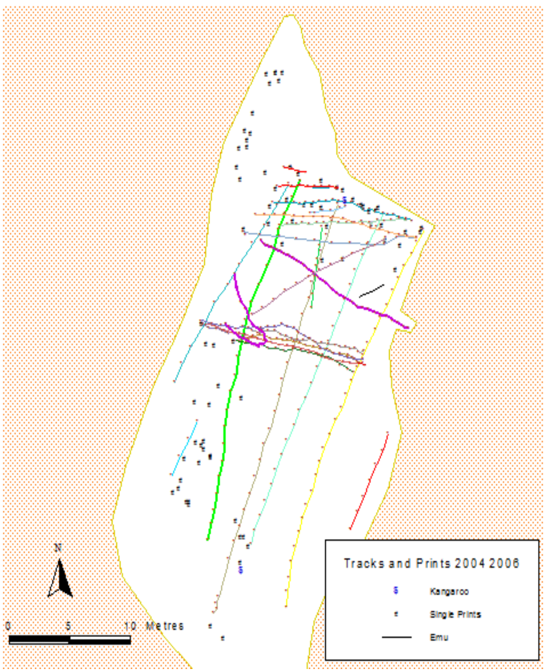

Figure 2: GPS Tracking of Footprints, yellow, green and grey and trackways of Aboriginal men running.

(Image courtesy of the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and the Community Management Council.)

The aim of this research project was to visually examine skeletal remains and fossilised footprints of Aboriginal people for evidence of links to, or similarities with, foot structure and function in modern Aboriginal People or that would have been indicative of osseous pathology.

Ethics Approval

Written approval form the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and the Community Management Council (TSAC and CMC), representing the Paakantji, the Ngiyampaa and the Mutthi Mutthi Aboriginal Peoples was provided to visit their country and inspect the 21,000 year old fossil footprints. In addition the first author was given access to data previously collected. Also approval from Uncle Lewis O'Brien (Kaurna Elder) and the South Australian Museum was granted to inspect skeletal remains of the first author's ancestors. The Kaurna People from the grave site in Karraundo-ngga which were housed in the South Australian museum archives. Many skeletal remains of the Kaurna People were found in a grave site in Karraundo-ngga near the area now known as Hindmarsh, Adelaide, South Australia and removed from the grave site by British colonist to transport back to the United Kingdom and other places.

Methods

Footprints from Lake Mungo were visually examined to predict foot arch height. The skeletal remains from Adelaide including the calcaneus and talus were examined for evidence of bone spurring at the calcaneus which may be indicative of ankle equinus and other bony changes that may have been indicative of habitual behaviour or osseous pathology.

Equipment

3D Laser Scans of the fossilised human trackways in the Willandra Lakes World Heritage Area were taken (figure 8). The processed scans can be viewed using RapidForm Basis, the standard software for 3D scanner RapidForm Basis copyright 1998-2006 INUS Teck Inc (www.rapidform.com). The report and record card documents are in Microsoft Word format. The scan data are accessed via thumbnail images. All footprints were marked with three GPS markers in a triangle around each footprint to access distance between footprints and direction of travel.

Lake Mungo

Willandra Lakes Region World Heritage area is a group of prehistoric lakes that have been dry (absent of water) for approx. 21,000 years. However when these lakes were full of fresh water they were teeming with fish and other animals both in the lakes and the surrounding area, including prehistoric giant kangaroo, emu, and wombat. The fresh water and fish in the lakes and the surrounding flora and fauna would have maintained and sustained many thousands of Aboriginal people. Lake Mungo (shaded lake below, figure 3) was one of the larger lakes in the area and the red arrow points to the site on the edge of the lake were footprint trackways were discovered after wind had removed overlying sand. The site of the Aboriginal footprint trackways is approximate 100-200 metres from the prehistoric lakes edge.

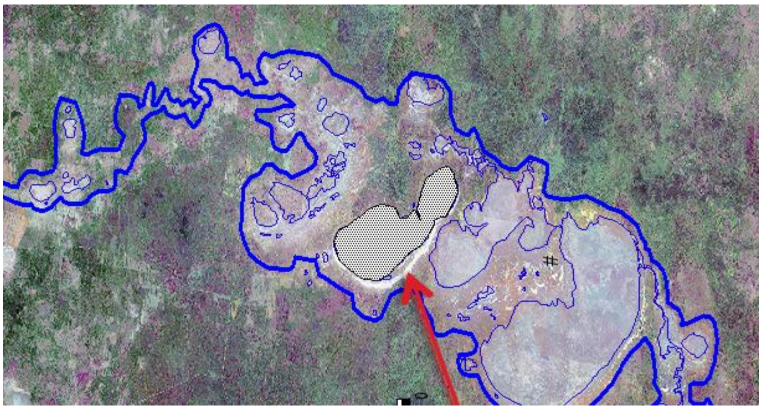

Figure 3: Lake Mungo (shaded), Willandra Lake World Heritage Area

(Image courtesy of the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and the Community Management Council.)

Procedure

The first author visited Lake Mungo to examine fossilised footprints, footprint casts, and was given access to 3D scans of footprints. All fossilised footprints were visually examined for those that arch height could be distinguished. The skeletal remains including the calcaneus and talus of 10 Kaurna men (all approximately 60 years old) were visually examined for facets, spurring and arthritic changes.

Results and Discussion

Kaurna Calcaneus Bones

Four of the ten skeletal remains examined showed very pronounced bone spurring on the calcaneus at the Achilles tendon attachment (figure 4). This spurring is consistent with tight gastrocnemius/soleus muscles (Benjamin, Rufai et al. 2000). It is possible the spurring may also have been associated with symptomatic Achilles tendon injury and may have caused pain or even been debilitating (Benjamin, Rufai et al. 2000). However, as not all spurring is associated with pain, or tight gastrocnemius/soleus tightness, it needs to also be considered that this spurring maybe a normal finding.

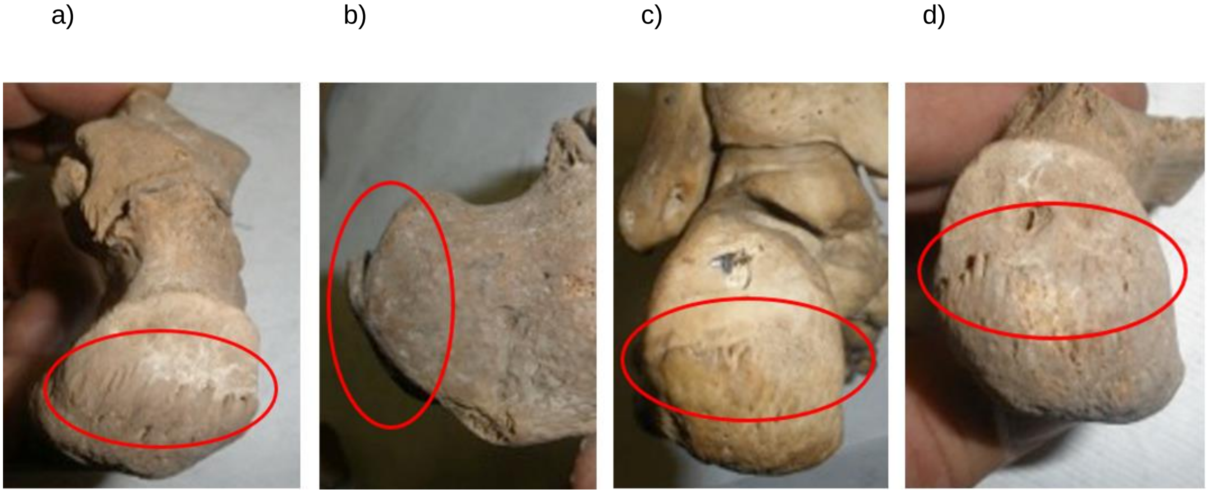

Figure 4 a), b), c) and d) skeletal remains showing bone spurs on calcaneus at the Achilles tendon attachment. (copies of pictures taken by James Charles using a snipping tool)

The authors have previously demonstrated high prevalence of reduced ankle joint dorsiflexion range of motion in a cohort of community-based populations of Aboriginal and Torres Strait Islander Peoples, particularly in males (Charles J 2016, Charles J 2016). The spurring demonstrated on the skeletal remains suggests that these finding may, in part, be an inherited trait. This is consistent with our previous finding of a predilection for ankle equinus to occur in a community-based population independent of the presence of diabetes, which is known to cause reduced ankle joint range of motion (Charles, Scutter et al. 2010, Charles 2016, Charles J 2016). Uncle Lewis O'Brien recalls the Kaurna Elders when he was a child "spurring, I remember the old people on the Mission complaining about it". If the spurring on the ancient calcaneus bones was caused by reduced ankle dorsiflexion (equinus) it may be the evolution of this foot type that has led to so many Aboriginal and Torres Strait Islander People today having equinus. This would especially be the case for men, because traditionally men would predominately been responsible for hunting (Maher 1999).

Kaurna Talus Bones

Of the 10 skeletal remains of the Kaurna Peoples talus bones examined, no squatting facets were clearly observed (figure 5) although it must be stated that defining a facet can be subjective, especially when using photos. However the lack of obvious squatting facets could possibly be due to a different sitting position of the Kaurna People. The Kaurna and many other Aboriginal and Torres Strait Islander Peoples rested on the ground in a sartorial posture i.e. sitting on the ground with crossed legs (Trinkaus 1975), which is also recorded as the sitting position of ancient Egyptian tailors (Hamilton Sue 2007). Although the Kaurna People have a word "Tirendi" to sit like a Kaurna, to squat (Amery 1995), indicating that the Kaurna People squatted when resting. Some Aboriginal and Torres Strait Islander tribes have also been known to stand upright in a resting position with one foot resting on the opposite leg just above the knee, with the knee and hip flexed, perhaps using a spear or other device to maintain balance (aiss-english-10 - Natasha El Khoury). Rao 1966 looked an Aboriginal bones from South Australia and did find some squatting facets but also noted only 3 (1.2%) tali had a medial facet (Rao 1966).

a) b) c) d)

Figure 5 (talus bones a), b), c), d) of the Kaurna People showing no squatting facets) (Copies of pictures taken by James Charles using a snipping tool)

Other Peoples from around the globe that adopted a squatting posture when resting, would have been pathologically stretching their gastrocnemius muscle, which may have resulted in a high range of ankle joint dorsiflexion. In contrast the normal or cultural sartorial sitting posture of Aboriginal and Torres Strait Islander tribes would not have been stretching their gastrocnemius, and therefore this may have contributed to the development of a reduced range of dorsiflexion at the ankle. The authors previously found that the reduced ankle dorsiflexion was due to isolated gastrocnemius tightness, with almost no soleus involvement (Charles J 2016), which is consistent with a sartorial posture and the absence of squatting facets.

Osseous Pathology

Evidence of degenerative changes to the talo-cural joint in skeletal remains of the Kaurna People was apparent, with pitting present at the distal aspect of the fibula in several specimens. This finding is consistent with an early description by Taplin and Woods (1879) who reported rheumatism common amongst Aboriginal tribes in South Australia (Taplin 1879). Kaunra Elder Uncle Lewis O'Brien also remembers the Kaurna Elders "complaining" about "arthritis". Evidence of osteoarthritic changes is unsurprising due to the risk associated with overuse, previous trauma and specific biomechanical alignment (Lohmander, Englund et al. 2007, Valderrabano, Horisberger et al. 2009, Englund 2010) and the estimated older age (approximately 60 years) of the Kaurna people at the time of their death. Although this pitting may be related to degenerative joint disease e.g. rheumatoid arthritis, present prior to colonisation, it must be stated that this is a very small number and not absolutely conclusive evidence.

a) b)

Figure 6 a) and b) red arrow pointing to pitting arthritic changes to the distal aspect of the lateral (fibular malleoli) ankle. (Copies of pictures taken by James Charles using a snipping tool)

Arch Height

We have previously used a Pedograph (footprint-taking system) and a visual categorisation technique to identify foot arch type as low, normal or high to describe arch type in Aboriginal and Torres Strait Islander Peoples (Charles J 2016, Charles J 2016). This method which has been shown to provide reliable information regarding the foot structure and arch height (Clarke 1933, Welton 1992). The researchers found that a very high percentage of community based modern day Aboriginal and Torres Strait Islander Peoples have a high arched foot type N=42 (64%) (Charles J 2016), demonstrated by the inked footprint in Figure 7. Using a similar visual assessment method arch height was classified on distinguishable fossilised footprints (10 prints) from different individuals with the majority 6 (60%) classified as having a high arched foot type very similar to modern day Aboriginal and Torres Strait Islander People (Charles J 2016).

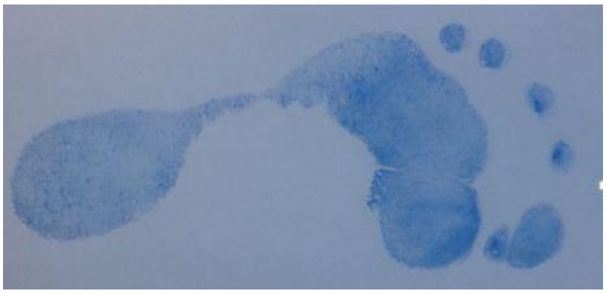

Figure 7 (typical ink print of Aboriginal and Torres Strait Islander foot showing a high arch) (copy of footprint collected by James Charles using a snipping tool)

Our previous finding of high prevalence of a high arched foot type (Charles J 2016) is consistent with similar evidence that ancient Aboriginal People presented with high arches (figure 8), with ancients footprints also being similar to the modern Aboriginal and Torres Strait Islander footprints we collected (figure 9) (Charles J 2016, Charles J 2016).

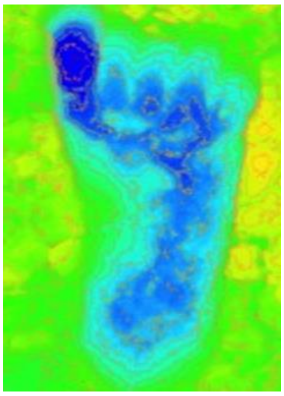

Figure 8: 21,000 year old Aboriginal foot print Image courtesy of the Willandra Lakes Region World Heritage Area Technical and Scientific Advisory Committee and the Community Management Council.

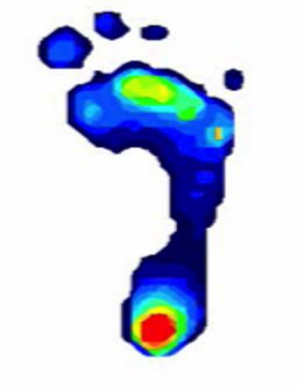

Figure 9: Modern day Aboriginal foot print (Charles J 2016)

Limitations

This project examined fossilised footprints and skeletal remains of Aboriginal people for possible links to characteristics of foot and ankle function in modern Aboriginal and Torres Strait Islander Peoples. Collecting the data were not without significant challenges including enabling access of the first author to the skeletal remains, footprints and associated data and the subsequent examination. Although some of the ancient footprints were preserved very well, many were not preserved well enough to establish arch height. There were footprints of men, women and children however there is no way of knowing if the footprints are a true representation of the Aboriginal population of that time and in that community. The skeletal remains examined were also of very small number and the extent of generalizability of the characteristics of these bones is unknown. Comparison to biomechanical findings in modern day Aboriginal and Torres Strait Islander Peoples to the ancient remains and fossilised footprints required extrapolation to identify possible links between biomechanical structure and function, therefore they are by no means proven. Nevertheless we believe these findings make a valuable contribution to the current limited data in this area.

Conclusion

The findings of this investigation suggest that there may be an evolutionary component to high prevalence of ankle equinus we have previously reported in a modern day population of Aboriginal and Torres Strait Islander Peoples. In addition the evidence of a high arch foot type being prevalent in preserved foot prints from Lake Mungo suggest a predilection to a high arched foot in Aboriginal and Torres Strait Islander Peoples may also be an inherited trait. This raises the possibility of the development of these biomechanical characteristics to create physical advantage and increase chance of survival in combination with knowledge, endurance and resilience.

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