PMHS Use as a Surrogate for Living Populations in Lower Extremity Research

Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University

By

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Abstract

Objective: The purpose of this thesis was to determine the degree of difference between anthropometric and heel pad tissue characteristics of the lower extremities of PMHS compared to living populations as well as to establish a wholistic procedure for extensive measurements of the foot using methodology previously used in lower limb anthropometry, x-ray imaging, and ultrasound imaging studies.

Methods: Thirty-seven PMHS were included in the anthropometry analysis, 21 PMHS were included in the x-ray analysis, and 32 PMHS were included in the ultrasound analysis. For the anthropometry, measurements were taken in seated and standing positions and included bimalleolar breadth, heel breadth, navicular height (medial prominence), navicular height (inferior medial border), talar head height, plantar curvature height, lateral malleolar height, medial malleolar height, acropodion foot length, hallux foot length, horizontal foot breadth, ball of foot length, and dorsum height. Comparisons were then made between left and right feet, seated and standing positions, males and females, and PMHS and living populations. For the x-ray analysis, two of the anthropometry measurements, navicular height (inferior medial border) and talar head height, had values for anthropometry compared against measurements determined through x-ray imaging. For the ultrasound analysis, ultrasound images were taken of the plantar foot at the calcaneus at loadings of 0, 5, 10, 15, 20, and 30 Newtons. Thicknesses, stiffnesses, and compressibility indexes were determined using the images, and these values were then compared against values seen in living populations.

Results: Left and right feet were found to have no significant differences in anthropometry. Seated and standing positions were found to be significantly different in 12 of the 13 measurements. Male values were found to be significantly different from female values in both seated and standing positions for all measurements except for plantar curvature height. By determining percent difference values between seated and standing positions for both males and females, no significant difference was found between sexes in their respective measurement changes from seated to standing positions except in plantar curvature height and lateral malleolus height. Eleven of the 13 measurements showed agreement between PMHS and living populations, with talar head height and plantar curvature height showing greater than 10% difference. In the x-ray analysis, navicular height was significantly different between anthropometry and x-ray values, and talar height was not significantly different. In the ultrasound analysis PMHS were found to have thinner and stiffer heel pads with lower compressibility than living populations.

Conclusions: A wholistic procedure for foot measurements and analysis was developed which incorporates methodology from previous literature. For foot measurement, x-ray imaging was shown to be necessary for certain landmarks but not for others. Results from this study have provided quantification of posture and sex differences as well as quantification for differences between PMHS and living populations for foot anthropometry. Differences were also quantified for the thickness, stiffness, and compressibility of PMHS compared to living populations. The results show that PMHS anthropometry sufficiently represents that of living people's anthropometry when sex and postural differences are accounted for, but PMHS is not representative of living populations regarding heel pad thickness, stiffness, or compressibility, and these differences must be considered in lower extremity testing.

Dedication

I dedicate this thesis to my family, FASBAD, for always being there for me and showing support in everything I do.

Acknowledgments

I'd like to start by thanking Dr. John Bolte IV and Dr. Randee Hunter for providing guidance throughout my time on the Boot project. Without my first involvement in Boot, I would certainly not be where I am today at the IBRC. I'd also like to especially thank the students of the Boot team: Zac Haverfield, Mukund Nadimpally, Ryan Lang, Jordan Reddington, and Nathan Kebede for helping throughout the long hours of Boot. I also want to thank Mike Tegtmeyer, Erika Matheis, and Kerry Danelson, other invaluable members of the Boot team, for their immense help in defining the what's and why's of the Boot project.

I'd also like to thank the rest of the IBRC for their support, laughs, and love shown to me throughout my time here so far. Thanks to you all, the IBRC is "the best injury biomechanics lab in the world" as our fearless leader says, and that's not just because of the work we put out but also because of the people who work here. I truly think we are making the world a better place with truly meaningful work, and I thank you all for joining me in being a part of it.

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Chapter 1: Introduction

In the field of injury biomechanics, post-mortem human subjects (PMHS) have been used for injury mechanism research as surrogates for living populations. For example, PMHS are often used in destructive tests such as frontal car crash testing or underbody blast tests in order to assess lower extremity injury in these real-world scenarios. In frontal crashes in car models from 2003-2010, 37% of moderate/severe injuries were lower extremity injuries (Austin (2012)). In underbody blasts, the second most frequent injury in soldiers that were wounded in action from 2010 to 2014 were lower extremity injuries (Loftis et al. (2019)). Despite the widespread use of PMHS as representatives for the living in these scenarios, there have been few if any studies aimed at validating PMHS use as surrogates for living subjects. There are known limitations to PMHS use that could affect how representative they are of living people including rigor mortis (causing the stiffening of soft tissues), health conditions prior to death (such as those of bedridden populations or those who have undergone extensive surgeries), and postmortem dehydration, all of which could affect the anatomy and physiology of the subject through changes in elastic and strength properties of tissues including muscles, tendons, and ligaments. These limitations in conjunction with the importance of using PMHS in injury research make it apparent that studies should be done to assess the similarity between PMHS and living populations. There have been a small number of studies which began to investigate differences between PMHS and living people, including a study from Cardoso et al. (2016) which found PMHS to have significantly greater values for stature than what is currently expected in the field when compared to living populations, indicating that at least for stature PMHS are not fully representative of living people. With little existing research on PMHS as surrogates in lower extremity testing, data for physical anatomical locations (anthropometry) in the foot and basic soft tissue characteristics such as thickness, stiffness, and compressibility of the heel pad could provide a foundation for better applying PMHS data to real-world lower extremity-related scenarios experienced by living people.

The data obtained from PMHS testing is invaluable to the field of injury prevention. More specifically, PMHS data are often used to develop safety tools in the field. Anthropomorphic test devices (ATDs) are an example which are often used to set the standards for car safety. In studies by Danelson et al. (2015) and Kang et al. (2012) which evaluated the biofidelity of ATD in underbody blasts and rear automotive impacts respectively, PMHS data were used to determine how well ATDs represent human response. Due to the nature of the ATDs being developed from PMHS data, it can be seen that as PMHS better represent living populations, the ATDs that are made from PMHS will therefore more closely align to the injury response of living people. This means ATDs could result in higher standards of safety due to their improved biofidelity. In addition to improving ATDs, items such as military footwear can be made safer as well. In a study done by McKay et al. (2010) which evaluated the effectiveness of military footwear in reducing forces on the tibia in underbody blasts, data were obtained from

ATD testing that would be used to improve the military footwear. Also, in the study by Danelson (2015), both the PMHS and ATD were equipped with military combat boots, showing they play a role in the biofidelic evaluation of ATDs in underbody blast scenarios. Through improving the accuracy of PMHS lower extremity data in representing living people for underbody blast and car crash scenarios, safety tools like ATDs and military footwear can be improved upon to make these scenarios safer.

This thesis investigates differences between the lower extremities of PMHS and living people and provides specific metrics that should be considered when using PMHS data to represent a target population. In accomplishing this, the primary objective of this thesis is to quantify differences between PMHS and living populations for lower extremity anthropometry and heel pad soft tissue characteristics. The anthropometric and heel pad characteristics were chosen for reasons including comparability to previous studies in living people the ease-of-use of these methods in measurement, and most importantly, the information these methods will provide on the characteristics of hard tissues in bony anatomy and soft tissues in heel pad properties in the lower extremity. In a scenario such as an underbody blast or a frontal car crash, the driving factors in lower extremity injury are the positioning of the extremity and materials under and around the extremity; thus, having a greater understanding of the above-mentioned characteristics of the lower extremity would aid in understanding injury mechanisms in these scenarios. Using these quantifications from anthropometry and heel pad properties, the bony anatomy and soft tissue characteristics determined from PMHS data can be more closely matched with living people because considerations can be made about PMHS data that have not been previously known in the field. When differences in the characteristics between groups are accounted for, the PMHS data can lead to improved safety tools in the area of injury prevention in the end. The approach for lower extremity analysis described in this thesis can serve as a guide for leg and foot measurement, analysis, and standardization in future lower extremity research in order to learn more about vital characteristics of bony anatomy and soft tissue qualities in PMHS and living populations. By providing a guide for this approach in future studies, these differences in characteristics can be obtained reliably and can be accounted for successfully.

This thesis will address a number of topics related to lower extremity measurement and comparisons between PMHS and living populations' lower extremities. This thesis is organized into three portions utilizing common methodologies for the foot: anthropometry, x-ray imaging, and ultrasound. The following are questions that this study aims to address with accompanying hypotheses about outcomes.

1. Chapter 2: Anthropometry
    a. Question: Are left and right feet significantly different in foot anthropometry in both seated and standing positions?
        i. Hypothesis: If right and left foot anthropometry are compared, there will be no significant difference between feet in landmark locations in both seated and standing positions.
    b. Question: Are there differences in foot anthropometry between seated and standing positions?
        i. Hypothesis: If foot measurements done in a seated position are compared against measurements done in a standing position, there will be significant differences in measurements between postures.
    c. Questions: Are there sex differences in foot anthropometry in seated and standing positions?

            i. Hypothesis: If male foot measurements are compared against female measurements, there will be significant differences between sexes in both seated and standing positions.
    d. Question: Are there sex differences in the change in foot anthropometry from the seated to the standing position?
        i. Hypothesis: If changes in male measurements from the seated to standing position are compared against the changes in female measurements between positions, there will be no significant differences between the sexes.
    e. Question: Do PMHS represent living populations in lower extremity characteristics of anthropometry?
        i. Hypothesis: If PMHS lower extremity anthropometry is compared against that of living people, foot dimensions will be significantly different between the groups
2. Chapter 3: X-ray Imaging
    a. Question: Are anthropometry and radiography significantly different in determining foot anthropometry, and is measurement using x-ray imaging necessary to supplement anthropometry in foot measurements for accurate landmark locations?
        i. Hypothesis: If anthropometric and radiographic measurements on the foot are compared, there will be no significant difference between values reported from each of the measurement methods.
3. Chapter 4: Ultrasound
    a. Question: Are left and right feet significantly different in heel pad thickness, stiffness, and compressibility?
        i. Hypothesis: If right and left heel pad properties are compared, there will be no significant difference between feet in thickness, stiffness, or compressibility.
    b. Questions: Are there sex differences in heel pad thickness, stiffness, and compressibility?
        i. Hypothesis: If male heel pad properties are compared against those in females, there will be a significant difference between sexes in heel pad thickness, stiffness, and compressibility.
    c. Question: Do PMHS represent living populations in heel pad properties of thickness, stiffness, and compressibility?
        i. Hypothesis: If PMHS lower extremity heel pad thickness, stiffness, and compressibility are compared against those of

living populations, heel pad properties will be significantly different between groups

Results for each of these questions illustrate differences in PMHS foot anthropometry and soft tissue properties of the heel that may need to be considered in injury biomechanics. Altogether, the aims of this study serve to shed light on what must be accounted for when using PMHS to represent living people in lower extremity testing.

Chapter 2: Anthropometry

2.1 Introduction

One method of characterizing the lower extremity of PMHS is anthropometric analysis. Anthropometry was chosen for this study because it provides the foundation for ATD design and development, so an anthropometric analysis should come first when comparing PMHS to target populations. There is existing literature for methodology and measurements of lower extremity anthropometry which use tools that are straightforward to obtain and use. Anthropometry has been widely used in analyzation of the feet of living populations and should be used in characterizing PMHS feet to compare back to those studies done on living people. This comparison is vital in addressing a primary objective of this study: quantifying potential differences in PMHS and living population's foot anthropometry. The relevant anatomical landmarks and measurement procedures for foot anthropometry have already been defined in the previous studies performed by Cobb et al. (2011), Cowan et al. (1993), Cowley et al. (2013), Gordon et al. (2014), Hotzman et al. (2011), Knapik et al. (2008), Larson et al. (2019), Saltzman et al. (1995), White (1982), and Williams et al. (2000).

A limitation of these mentioned studies is the lack of an all-inclusive list of foot measurements in consistent measurement scenarios. Thus, an objective of this thesis was to compile measurements from across the literature sources into one comprehensive list of measurements for a wholistic anthropometric analysis of PMHS feet. Also, due to the various measurement conditions, this portion aims to determine the significance of postural position (seated versus standing positions), laterality, and sex differences for consideration in lower limb testing scenarios.

Previous literature showed that for the anthropometry of living population's feet, there are no significant differences in left and right feet (Hisham et al. (2012)), but there are in seated versus standing positions (Cashmere et al. (1999) and Oladipo et al. (2008)). Previous studies also found that there were sex differences in foot anthropometry, commonly with males have larger values for all dimensions (Wunderlich et al. (2001) and Hong et al. (2011)). However, one study did not fully agree, with females having larger values for several heights such as for malleolar height (Luo et al. (2009)).

Considering the contrasting results for males versus females and a lack of data on PMHS populations to compare living populations against, the results from the previously mentioned anthropometric studies were used to determine the consistency of the results mentioned above and to compare the living data against PMHS values, therefore addressing the primary objective of quantifying the differences between PMHS and living population foot anthropometry.

2.2 Methods

2.2.1 Population

Thirty-seven post-mortem human subjects (PMHS) were included in this study, of which there were 25 males and 12 females. The average age was 71 years old, with a range of 47 to 100 years old and a standard deviation of ±13 years. All PMHS were obtained through The Ohio State Body Donor Program.

2.2.2 Exclusion Criteria

Subjects were excluded from this study if they exhibited characteristics that could have affected weight bearing or general range of motion, such as hip, knee, or ankle replacements and severe edema/swelling, ischemic tissue, or foot ulcers. Effects on weight bearing and range of motion from surgical procedures or lower limb deformities could have influenced the anthropometric measurements taken by preventing a sufficiently neutral posture of the PMHS in either standing or seated positions. Due to these potential inaccuracies in measurements, PMHS were excluded in these cases.

2.2.3 Pre-Measurement Preparation Procedure

With the subject on a gurney, the mass of the subject was determined by using a floor scale with the gurney's weight being removed. The stature was determined by using a tape measure to measure from the top of the head to the base of the heel with the subject supine on the gurney. The subject was cleaned and prepped for testing by applying a diaper, using gauze secured with duct tape to pack the mouth and nose as well as to cover the eyes, and finally cleaning the subject with ethanol and wipes.

A noninvasive observational assessment was done to determine presence of any lower limb surgical procedures or lower limb deformities such as arthritis, toe deformities, hallux rigidus, hallux valgus, ischemic tissue, or foot ulcers. If any observations were determined to be severe, it was decided whether the subject would undergo all measurements or only seated or standing measurements. For the purpose of this thesis, only the procedure for the subjects undergoing all measurements will be discussed. The subject was placed in a supine position for overall pictures. Shown in Figure 1, pictures were taken of the overall lower extremities, anterior and lateral knee, anterior and lateral leg, and the dorsal and plantar aspects of both feet.

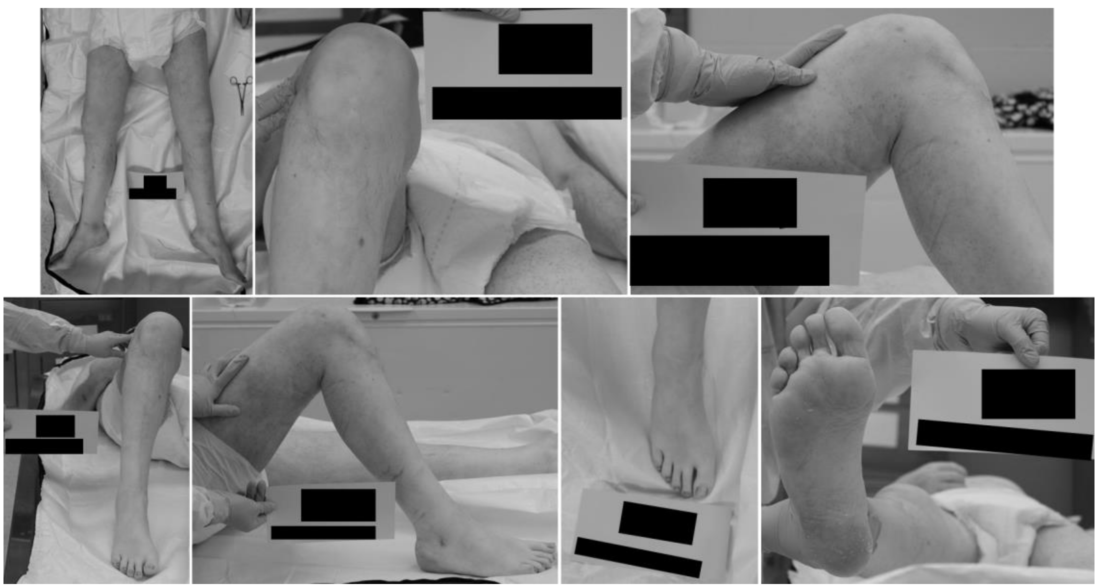


Figure 1: Overall Photographs

Lower limb anatomical landmarks were palpated and marked on the lower extremities based on defined protocols used in The Measurer's Handbook for the US Army and Marine Corps (Hotzman, et al., 2011). The landmarks consisted of the lateral and medial malleoli, dorsal juncture of the foot and leg, first and fifth metatarsophalangeal protrusion, medial prominence and inferior medial border of the navicular tuberosity, head of the talus, plantar curvature, and calcaneal line (Figure 2). Detailed images and descriptions of landmarks are defined in Appendix A.

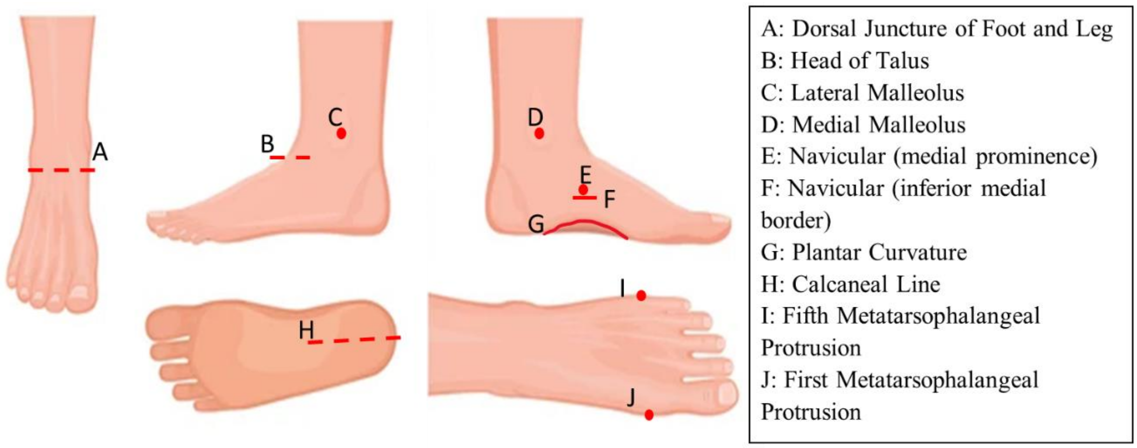


Figure 2: Foot Landmarks

Using techniques adapted from range of motions exercises from ALS Worldwide (2004), the lower limbs were exercised in order to remove rigor and maximize range of motion. Preconditioning movements included hip and knee flexion, hip rotation, hip abduction, hamstring stretch, subtalar joint inversion and eversion, ankle dorsiflexion and plantarflexion, metatarsophalangeal joint (MTPJ) exercising, and a test of lateral stability.

2.2.4 Seated Measurements

The seated fixture, shown in

Figure 3, was prepared for the PMHS to be moved and positioned in a seated posture. The subject was moved and secured in place using ratchet straps placed under the axillae and over the pelvis. The head was duct taped into place so that the posterior head was in contact with the back of the seat. The seated fixture was raised or lowered to obtain a 90-degree angle between the thigh and leg of the PMHS with feet flat on the ground. If necessary, duct tape was placed across both knees to ensure the thighs and legs of the PMHS remained parallel to each other. A bathroom scale was placed under each foot to record weights for both sides and to ensure equal weight distribution during the measurement process.

Figure 3: Seated Fixture

Seated measurements were then taken following defined protocols used in the previously mentioned studies from Cobb et al. (2011), Cowan et al. (1993), Cowley et al. (2013), Gordon et al. (2014), Hotzman et al. (2011), Knapik et al. (2008), Larson et al. (2019), Saltzman et al. (1995), White (1982), and Williams et al. (2000). Table 1 shows the comparative living population studies that were compared with this study's PMHS data. Table 1 also shows which measurements were included in each study's procedure as well as information on the procedures. The required equipment, shown in Figure 4 included an anthropometer, calipers, a height gauge, and an Arch Height Index Measurement System™. In the seated position, measurements were taken for bimalleolar breadth, heel breadth, navicular height (medial prominence), navicular height (inferior medial border), talar head height, plantar curvature height, lateral malleolar height, medial malleolar height, acropodion foot length, hallux foot length, horizontal foot breadth, ball of foot length, and dorsum height (Figure 5). Detailed images and descriptions of the measurements are given in Appendix B.

Table 1: Living Population Study Information

Source	Subject Description	Measurement Description	Relevant Measurements
Gordon n = 6068	4082 M and 1986 F soldiers separately measured	Right foot, standing	bimalleolar breadth heel breadth lateral malleolus height acropodion foot length horizontal foot breadth ball of foot length
Menz n = 95	31 M and 64 F (elderly) averaged	Right foot, standing	medial prominence of navicular
Saltzman n = 100	31 M and 69 F (middle-aged) averaged	Mixture of right and left feet, standing	inferior medial border of navicular talar head height plantar curvature
White n = 9792	8947 M and 845 F soldiers separately	Right and left averaged, posture not specified	medial malleolus height
Knapick n = 3952	2689 M and 1263 F soldiers separately measured	Right and left averaged, standing	hallux foot length
Williams n = 51	28 M and 23 F (university-aged) averaged	Right and left averaged, 90% weight (standing)	inferior medial border of navicular
Cowan n = 246	246 M soldiers	Right foot, standing	dorsum height
Cobb n = 111	42 M and 69 F (young adults) averaged	Right and left averaged, 90% weight (standing)	medial prominence of the navicular
Larson n = 25	13 M and 12 F Division III athletes averaged	Right and left averaged, standing	medial prominence of the navicular
Cowley n = 30	18 M and 12 F (young/middle aged) averaged	Right and left feet separately, standing	medial prominence of the navicular

Figure 4: Measurement Equipment

Figure 5: Measurements

2.2.5 Standing Measurements

A medical tilt table was prepared in order to place the PMHS into a standing posture. The subject was put in a supine position on the tilt table and strapped to the table using straps located inferior to the knees, on the upper thigh, on the middle of the abdomen, and under the axillae. A Tekscan™ Pressure Mapping Sensor (model 3150, Tekscan, Inc., Norwood, MA) was also placed on the tilt table's foot platform under the feet of the PMHS. The tilt table was cranked first to 45 degrees from vertical in order to tape the head in place and then into a vertical position so that the PMHS was positioned in an upright standing posture, as shown in Figure 6. The Tekscan™ mat was used to record the standing weight of the subject and ensure equal weight distribution between the two lower extremities during the measurement process. Real-time readings from the Tekscan™ mat were used to observe the subject's applied weight to the sensor while adjusting the straps in order to obtain at least 80% of the subject's pre-measured body weight. Standing measurements were taken once again following previously defined protocols. The measurement equipment used in the seated position was used again in the standing posture to acquire the same measurements.

Figure 6: Subject in a Standing Position

2.2.6 Statistical Analysis

For all statistical tests, an alpha level of 0.05 was used to determine significance. Normality was checked using a Shapiro-Wilk normality test on the whole sample, left and right subgroups, and male and female subgroups, and outliers were removed where applicable and valid. A description of the removed outliers and reasoning behind removal can be found in the results section. A matched pairs t-test was done on left versus right feet for seated and standing separately. Left and right values were averaged for all following analyses when found to be not significantly different. A matched pairs t-test was done on seated versus standing values, and percent differences were determined between the two positions as well. A two-sample t-test was done comparing male seated values with female seated values and male standing values with female standing values. A two-sample t-test was also done on percent differences of male seated and standing values compared against percent differences of female seated and standing values.

In a separate analysis, subsets of the PMHS measurements were compared against measurements recorded for living populations from previous research. Subsets were used in order to match the PMHS populations with the living populations as closely as possible (for example, if a study used all male, seated right foot measurements, then that is the subset of PMHS measurements used for the analysis). This was the case because no study has taken all the same measurements recorded in this study, so it was necessary to use a combination of various studies each with differing populations in order to compare against all the measurements included in this study. Information regarding the specific subsets used in comparisons for each measurement are shown in Table 1. Percent difference was determined in the comparison to quantify likeness between the two.

2.3 Results

2.3.1 Outlier Analysis

Table 2 shows which subjects were removed and the reasoning behind the removal. For the comparison between right and left standing heel breadth, a logarithmic transformation was done to ensure normality because although there was no documented reasoning to remove any subjects for this comparison, the data was not normally distributed and therefore required a transformation to ensure normality. This was the only transformation necessary in the analysis. These cases showed where specific feet were outliers among the rest of the data, and so these outlier feet were kept out of all subsequent analyses (wherever lefts and rights were averaged, the non-outlier foot was used in place of an average). For cases where both left and right seated values were outliers, such as for subjects 8486, 8655, and 8164, the subjects were removed from seated analyses (such as the seated male vs seated female measurements analysis) as well as seated versus standing comparisons (for the whole population as well as for seated to standing percent differences for males vs females).

Table 2: Outlier Analysis

Measurement (mm)	Outliers
Bimalleolar breadth	8615 (R excessive foot inversion)
Heel Breadth	N/A
Navicular height (medial prominence)	N/A
Navicular height (inferior medial border)	8239 (L excessive foot inversion)
Talar head height	N/A
Plantar curvature height	8239 (L excessive foot inversion)
Lateral malleolus height	8164 (no seated data); 8171 (no seated data); 8423 (R rolling/lack of stability in ankle)
Medial malleolus height	8164 (no seated data); 8171 (no seated data)
Acropodion foot length	8423 (R hallux significantly shorter from surgery); 8256 (R, surgery hallux included)
Hallux foot length	8423 (R hallux significantly shorter from surgery); 8256 (R, surgery hallux included)
Horizontal foot breadth	N/A
Ball of foot length	8486 (L and R seated recording error); 8655 (L and R seated recording error)
Dorsum height	8164 (heavy swelling of both feet); 8339 (L standing, no recording)

The complete set of raw measurements is shown in Appendix C. Overall statistical results can be found in Table 3. In Table 3, pluses (+) next to measurements indicate an increase from the seated to standing position, and minuses (-) indicate a decrease from seated to standing position. PMHS measurements were found to agree with 11 of the 13 literature studies. Exceptions to the above statements are marked with a red box in Table 3 and will be discussed further in the following sections.

Table 3: Overall Statistical Results

Measurement	Left vs Right (Seated) (p-value)	Left vs Right (Standing) (p-value)	Male vs Female (Seated) (p-value)	Male vs Female (Standing) (p-value)	Seated vs Standing (p-value)	PMHS vs Living Measurements (percent difference)
Bimalleolar breadth	0.091	0.266	<0.001*	<0.001*	0.219	-3.42
Heel Breadth+	0.842	0.572	0.001*	0.015*	<0.001*	-4.28
Navicular height (medial prominence) -	0.824	0.455	0.013*	0.006*	<0.001*	-9.59
Navicular height (inferior medial border) -	0.968	0.483	0.008*	0.007*	<0.001*	-8.25
Talar head height -	0.160	0.168	<0.001*	<0.001*	<0.001*	50.98
Plantar curvature height -	0.474	0.905	0.962	0.161	<0.001*	28.09
Lateral malleolus height -	0.541	0.393	<0.001*	0.002*	<0.001*	-2.38
Medial malleolus height -	0.342	0.654	<0.001*	<0.001*	0.006*	8.93
Acropodion foot length+	0.129	0.207	<0.001*	<0.001*	<0.001*	-3.53
Hallux foot length+	0.096	0.205	<0.001*	<0.001*	<0.001*	0.05
Horizontal foot breadth+	0.538	0.841	<0.001*	<0.001*	<0.001*	-6.73
Ball of foot length+	0.239	0.217	<0.001*	<0.001*	<0.001*	-3.81
Dorsum height -	0.319	0.438	<0.001*	<0.001*	<0.001*	-7.97

*Indicates significant statistical difference ($p < 0.05$)

+ Indicates an increase from seated to standing

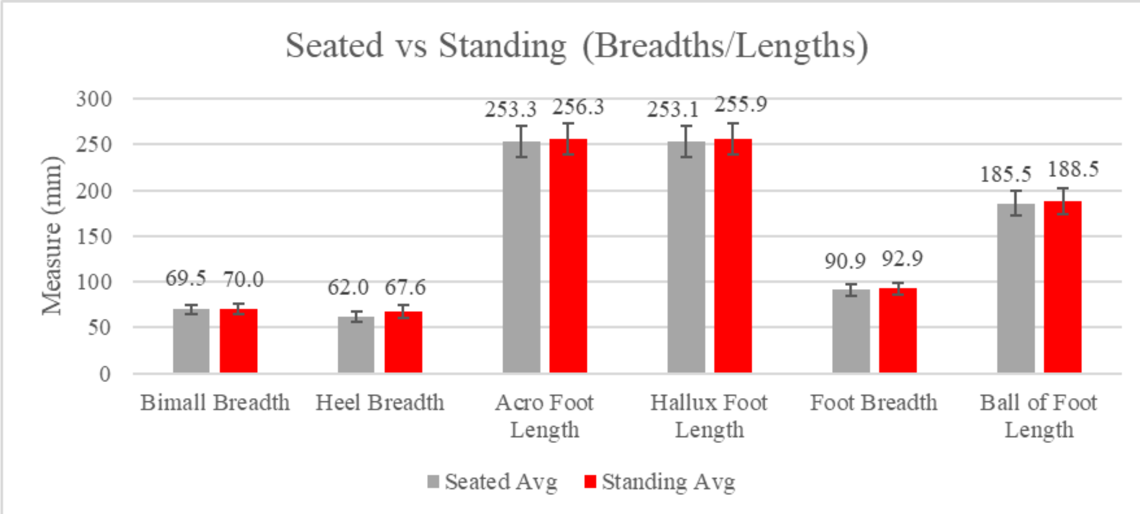
- Indicates a decrease from seated to standing

2.3.1 Left versus Right

None of the 13 measurements in Table 3 showed significant differences in left and right feet in either the seated or the standing positions as supported by the study from Hisham et al. (2018). Therefore, with no significant difference between feet in both positions, left and right values were averaged for all following statistical analyses where possible.

2.3.2 Seated versus Standing

Only one of the 13 measurements, bimalleolar breadth, showed no significant difference between seated and standing measurements (Table 3). The rest showed significant differences between postural positions (92% of measurements with significant differences), indicating that there is a statistically significant difference between measurements in the two positions. Figure 7 shows mean breadths and lengths on one graph and heights on the other for seated and standing measurements. Although all measures look close in value, all but bimalleolar breadth were found to be significantly different due to the nature of a matched pairs t-test.



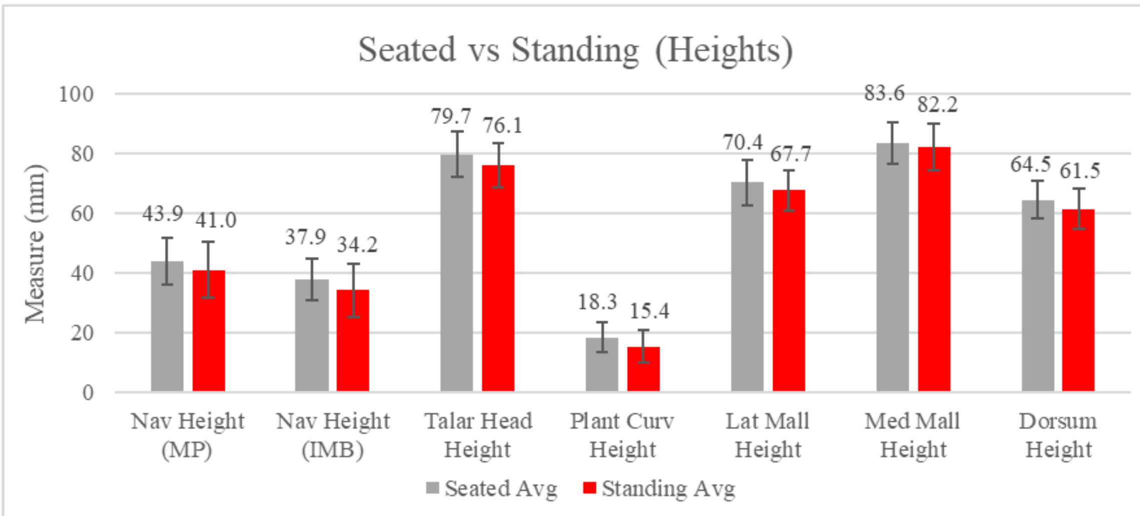
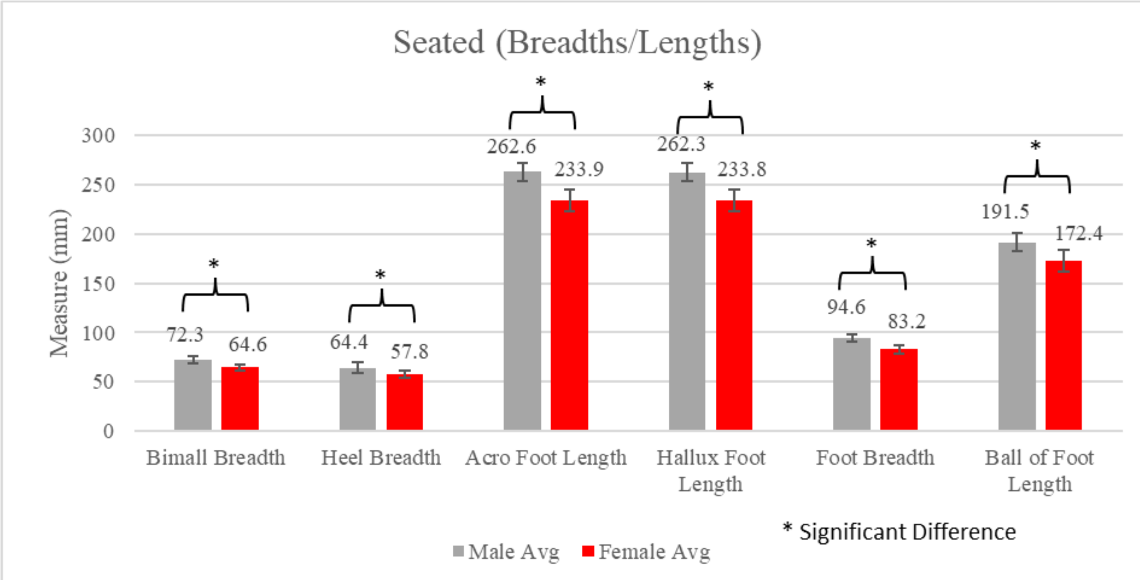


Figure 7: Seated vs Standing Measurements

Of the 12 measurements showing significant statistical differences, five measurements had percent differences indicating increases from seated to standing positions while the percent differences of the remaining seven showed decreases. All five measurements with increases were breadth or length measurements, and the remaining seven with decreases were height measurements.

2.3.3 Male versus Female

In both the seated and standing positions, only one measurement, plantar curvature height, was found to be the same between males and females. The rest of the measurements had significant differences between male and female measurements in both positions. So, for all lengths, breadths, and heights except for plantar curvature height, males were found to have significantly larger values than females (Figure 8).



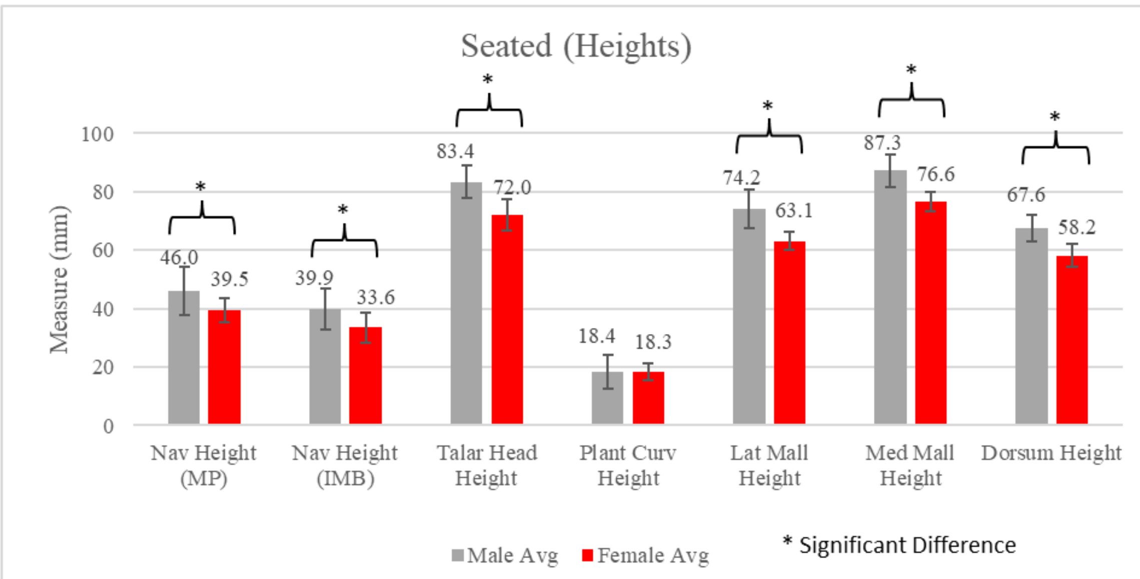


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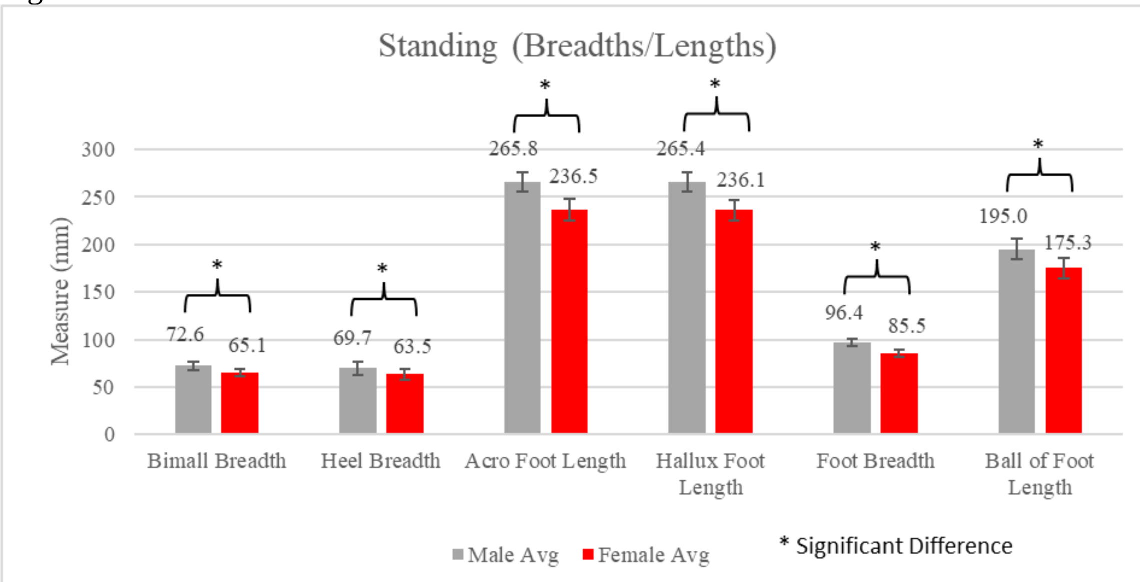
Figure 8: Male vs Female Measurements

Figure 8 continued



In the analysis comparing the male seated versus standing percent differences and the female seated versus standing percent differences, the percent differences of two measurements, plantar curvature height and lateral malleolar height, were found to be significantly different between males and females. The percent differences of the other 11 measurements (85%) showed no significant differences between males and females, which indicates similarity between male and female measurements regarding increases or decreases from the seated to standing positions. Figure 9 shows seated vs standing percent differences of males compared against females.

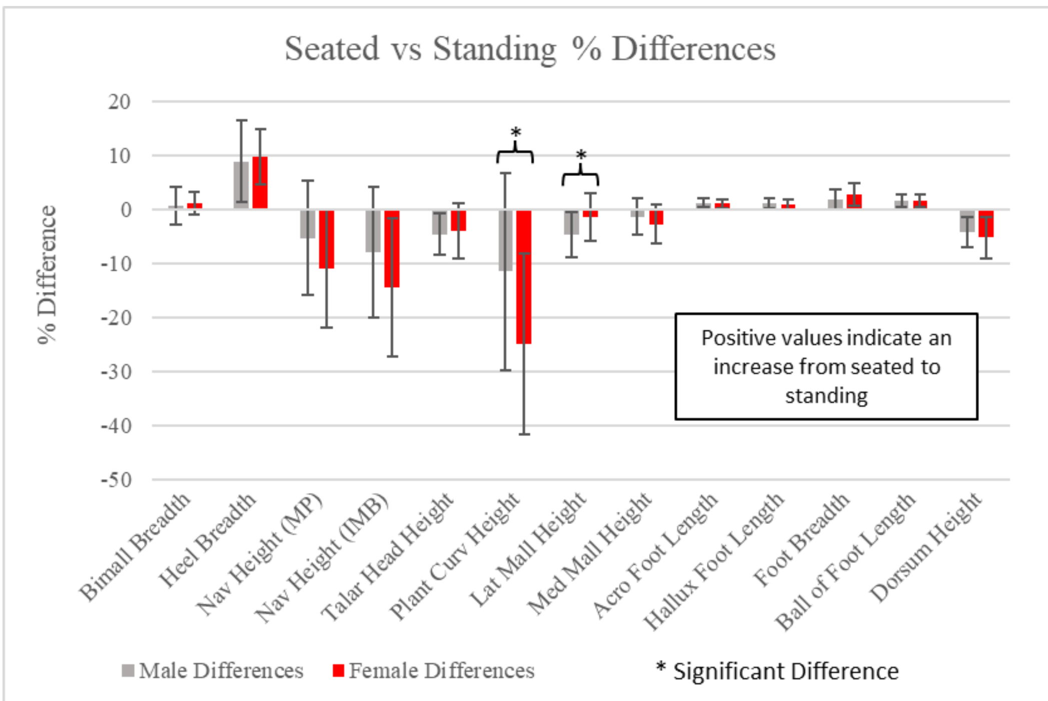


Figure 9: Male vs Female Seated to Standing Percent Differences

2.3.4 PMHS versus Living Populations

Using percent difference and a value of 10% or less to indicate relative agreement due to most results falling within that range and the exceptions falling far outside of it, eleven of the 13 measurements (85%) showed agreement between PMHS measurements and the living populations they were compared against. Measurements with a high percent difference (greater than 10%) between the two groups included talar head height and plantar curvature height. In both of these cases, the numerical values were larger for the PMHS than they were for the living populations, meaning the PMHS measurements had a greater height off the ground for these anatomical landmarks than the living populations. Figure 10 shows these comparisons between PMHS values and living population values.

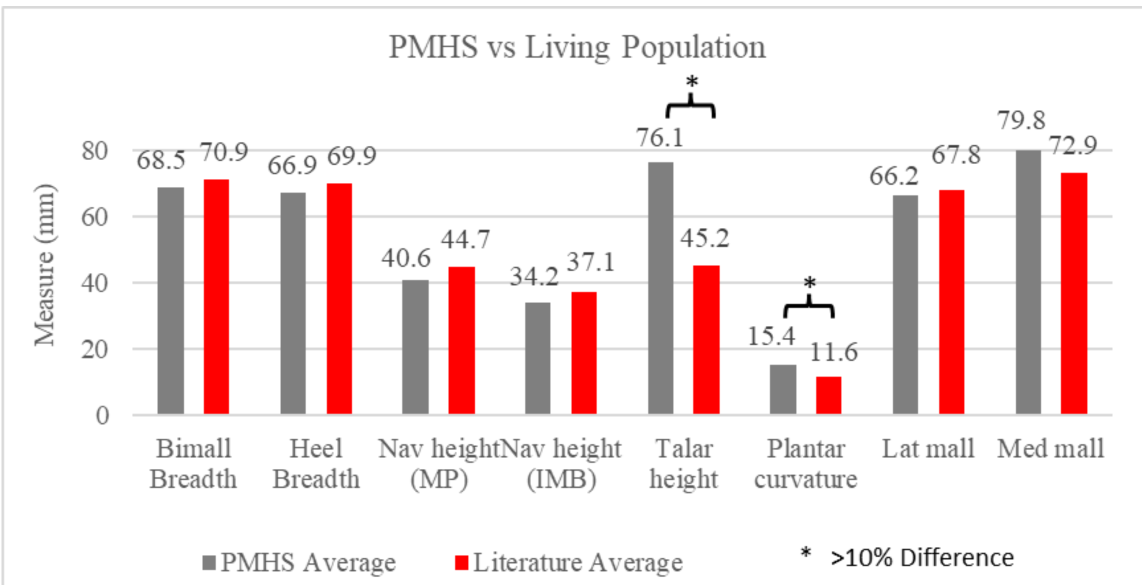


Figure 10: PMHS vs. Living Measurements

2.4 Discussion

2.4.1 Seated versus Standing

With 92% of measurements having significant differences between postural positions, it is apparent that seated measurements are not interchangeable with standing measurements. Similarly, Cashmere et al. (1999) which focused on the plantar arch of the foot and found height differences between conditions. Additionally, Oladipo et al. (2008), which found foot length and breadth increases from lower weight bearing to higher weight bearing positions. To compensate for differences in lower extremity anatomical locations due to different weight bearing conditions, it is recommended that weight either be added to or removed from the lower extremity or sufficient weight is added to the testing apparatus when testing pertains to seated or standing scenarios. A study that could benefit from these results is one from McKay et al. (2010), which tested the lower extremities of PMHS to evaluate underbody blast response. In this study, the lower extremity of a number of PMHS were instrumented with a load cell replacing a section of the tibia. Tissue was also removed from the samples, and while the authors did acknowledge changes in mass due to the addition of instrumentation and the removal of tissue, there was no analysis done to ensure a proper seated lower extremity mass was replicated. Therefore, this study could benefit from the seated versus standing data obtained for this thesis, as it could inform the addition or reduction of further mass to the lower extremity.

The one exception in this comparison was bimalleolar breadth, which did not change between seated and standing positions. This is most likely due to the highly bony nature of this measurement: this dimension is measured as the distance between the lateral and medial malleolus, which are both surrounded by very little soft tissue, so as joints and soft tissues shift from seated to standing positions, this landmark will not move much due to being relatively less affected by shifting of landmarks relative to each other.

2.4.2 Male versus Female

The results showed a majority of measurements had significant differences between male and female anatomical landmarks of the foot. The results in Figure 8 indicate that male measurements for all breadths, heights, and lengths were larger compared to females. These results agree with the studies from Luo et al. (2009), Wunderlich et al. (2001), and Hong et al. (2011) which compared between male and female foot geometry and showed male breadths, lengths, and heights to consistently be larger than female values. The only exception between the agreement with the literature is that the Luo (2009) study found that females had higher measurements (such as for the malleolar heights) than males. The Wunderlich study (2001) reported mean values in males and females for a number of measurements which overlapped with this study’s measurements of PMHS. Table 4 compares these percent differences between male and female to the PMHS percent differences found in this study (in the standing condition to match the Wunderlich study). The relatively high percent differences in the Wunderlich study were similar in value to this study’s results, which further supports the significant differences in both studies between males and females.

Table 4: Male versus Female Percent Differences

Measurement	Wunderlich (2001) Differences (%)	MvF		PMHS Differences (%)	MvF
Med Mall Height	12.37	M>F		12.90	M>F
Lat Mall Height	9.76	M>F		11.51	M>F
Plant Curv Height	5.01	M>F		18.08	M>F
Heel Breadth	10.27	M>F		9.35	M>F
Ball of Foot Length	10.20	M>F		10.63	M>F
Bimall Breadth	11.47	M>F		10.90	M>F
Foot Length	10.12	M>F		11.68	M>F

The lack of significant difference between males and females for plantar curvature height in both seated and standing positions may be due to the landmark’s position being relatively close to the ground, as differences are harder to detect between sexes with such a small measurement value.

Regarding the seated versus standing percent differences for males versus females, the drop in plantar curvature height from seated to standing for females was much larger than it was for males. This could be due to a greater amount of tissue stiffness in the plantar foot of males compared to females as supported by Zifchock et al. (2006), which would lead to greater movement in the plantar curvature of women with increased weight bearing. With the lateral malleolar height, the males had a larger decrease in height than the females. This could be due to an increased pronation in the feet of females. Considering increased pronation in females, a slight raising of the lateral malleolus with dropping of the medial malleolus would be caused by the distal tibiofibular joint. Increased foot pronation in females is supported by a study from Frey (2000), which investigated the foot structure and biomechanics of females compared to males.

Considering that percent differences of most measurements where not significantly different, males and females generally had similar changes in landmark location when moving from seated to standing positions. This could be due to a maximum amount of movement in the landmarks that is similar across sexes. In other words, although males tend to weigh more and therefore often have more weight applied to their feet, it could be the case that regardless of sex landmarks can only exhibit a certain amount of relative motion when changing positions due to mechanical limitations of joints in between bones.

Based on results for both the seated versus standing comparison and the seated versus standing percent difference comparison, males and females have significantly different averages for anatomical locations with males having larger values for all measurements, but males and females do not differ in their changes in measurements from the seated to standing position. This means that male data is not interchangeable with female. Also, changes in measurements from seated to standing were the same for males and females, so accounting for this change with PMHS testing, such as the previously mentioned underbody blast study done by McKay et al. (2010), could be done using the same methodology for males and females but with sex-specific values.

2.4.3 PMHS versus Living Populations

An agreement of 85% indicated that PMHS anthropometry exemplifies that of living populations. The disagreement in plantar curvature between PMHS and living populations could have been due to difficulty in obtaining the full body weight of the PMHS when measuring in the standing position. In a scenario where full body weight is not obtained, as was the case in this study due to the necessity of maintaining a secure PMHS standing position outweighing the goal of full body weight, one might not see as large of a drop in the soft tissues of the plantar foot. This would lead to a higher-up plantar curvature height, which could help to explain why the PMHS group had a larger value for plantar curvature height (15.51 mm) than the living population value (11.60 mm). The same could be the case for talar head height: with decreased dropping of the foot due to an inability to obtain full body weight, the height of the head of the talus could be higher up. Although the Tekscan™ sensor was used to help ensure equal weight distribution and to obtain a much weight as possible, full body weight was not always obtainable and the recorded body weight of subjects often settled in the 80-95% range of body weight.

2.4.4 Limitations

Positioning PMHS in a standing position was difficult due to the balance of maintaining proper support and stability of the PMHS while also maximizing the subject’s weight in order to properly replicate a full weight-bearing scenario as closely as possible. As the straps were loosened to allow for more weight applied to the feet, the subject had less equal weight distribution with shifting side to side.

Another challenge was obtaining and maintaining a 90-degree angle both at the knees and at the ankles when doing seated measurements. The knees tended to move outwards in the seated position, so in order to counter this, the knees were often held in place using either duct tape or surgical string. However, small movements were still common even after these securing measures were taken.

With multiple measurers in this portion, this study did not include an inter-observer error analysis. Error could have been present across measurers which may have led to slight differences in measurements in both seated and standing positions. For future studies, this limitation should be addressed with documentation of measurer along with an inter-observer analysis or with one assigned measurer along with an intra-observer analysis.

2.4.5 Conclusions

A holistic procedure for lower limb anthropometry of PMHS was developed that encompasses several studies on living populations and illustrates the differences between seated and standing positions as well as between male and female measurements, which should be accounted for in lower extremity experimental studies. Regarding the PMHS and living population comparison, an 85% agreement between 11 of the 13 PMHS and living population measurements indicates that anthropometry for the lower extremities of PMHS is applicable to living populations assuming that sex and postural position are accounted for in testing scenarios. These data which quantify the differences between PMHS and living population lower extremity anthropometry allows for an improved ability to adapt PMHS data to safety tools which will in turn increase safety in real-world scenarios.

Chapter 3: X-ray Imaging

3.1 Introduction

In contrast to measuring bony landmarks through palpation and including soft tissue thicknesses when doing anthropometric measurements, x-ray imaging provides direct measurements of the bone. As an alternative option to anthropometry, radiographic measurement has previously been used in foot measurement studies such as Gwani et al. (2017) and Shakoor et al. (2021). Both studies show applications of x-ray imaging to foot measurements: The study by Gwani focused on utilizing x-ray imaging to measure the medial, lateral, and transverse arches of the foot in a weight-bearing scenario, and the study by Shakoor investigated the use of radiographs in flat foot deformity and compared radiographic capabilities against those of CT imaging. These studies both provide examples of foot measurement using radiographs as opposed to anthropometry.

X-ray imaging was chosen to compare to anthropometry because of previous studies using x-ray measurement alongside anthropometry for anatomical measurements as well as the x-ray generators being relatively easy to operate with the proper training. In a study by Hameed et al. (2020) which investigated the diagnosing of flat footedness in children based on anthropometry vs radiography, it was shown that radiography had a higher accuracy in determining flat footedness than anthropometry with both a higher sensitivity (success in diagnosing the condition) and a higher specificity (success in determining the absence of the condition). In another study by Farkas et al. (2002) which investigated the difference between x-rays and anthropometry in measurements of the skull, significant differences were found between modalities in 16 of the 19 reported measurements, indicating differences between anthropometry and radiography. The Farkas study suggested the difference found between methods were most likely due to possible distortion on two-dimensional radiographic film. So, considering these differences across modalities found in these studies, a comparison with radiographic landmark locations and the values obtained from anthropometry serve to evaluate the potential differences between anthropometry and radiography in the context of the foot.

In order to evaluate differences in anthropometric measurement and radiographic measurement and to determine the potential necessity of x-ray measurements alongside anthropometry, the objective of this portion of the thesis aimed to determine differences in anthropometry and radiography by comparing two measurements, navicular height (inferior medial border) and talar head height, between the measurement methods. These two measurements were chosen because both are visible and easily measurable in the 2D plane of a lateral weight bearing x-ray and both were already taken for the anthropometry portion of the study. If it is shown that there is no difference between modalities, then anthropometry would be preferred due to the ability to measure bony anatomy easily with minimal equipment. If there is shown to be a difference, then both anthropometry and x-ray imaging should be considered to determine anatomical locations of the foot.

3.2 Methods

This analysis included all subjects which had lateral x-ray images taken and which had anthropometric measurements taken for the navicular height and talar head height. Due to excluding subjects that did not have lateral x-rays taken, this amounts to 21 subjects. Only the left foot was analyzed because there was a greater number of lateral weight bearing x-ray images for left feet than right and because a left versus right side comparison was not a focus of this portion of the study. The lateral x-rays were taken during the procedure for the anthropometry analysis once the PMHS was secured in the standing position on the tilt table with at least 80% of their mass obtained. While the subject was in the standing position, x-ray images were taken in the lateral orientation using a DRE Wireless Portable x-ray System (Georgian Anesthesia and Medical Corp, Tiny, ON). For the lateral x-rays, the x-ray detector was placed in between the feet of the subject parallel to the sagittal plane. The generator was positioned at an angle of 90° from vertical (with x-ray emitting perpendicularly into the sagittal plane). The generator was set at 55-60 kVp and 4-6 mAs, settings corresponding with those of previous studies such as Gwani et al. (2017), and the generator was centered on the base of the metatarsals (mid-foot) at a distance of 40 inches from the generator to the detector. An example of a left, lateral, weight-bearing x-ray image is shown in Figure 11.

Figure 11: Exemplar left lateral weight-bearing x-ray image

Measurements were taken by one measurer using OsiriX (Pixmeo SARL, Bernex, Switzerland) and Matlab (MathWorks, Natick, MA) (Figure 12). For height of the inferior medial border of the navicular, the distance between the most inferior portion of the navicular and the supporting surface was measured. For talar head height, the distance between the most superior surface of the talar head and the supporting surface was measured. For the statistical analysis of this portion, an alpha level of 0.05 was used. A Shapiro-Wilk test was used to check normality on the whole sample and outliers were removed where applicable and valid (more information can be found in results). After normality was ensured, matched pairs t-test was done on x-ray values versus anthropometric values.

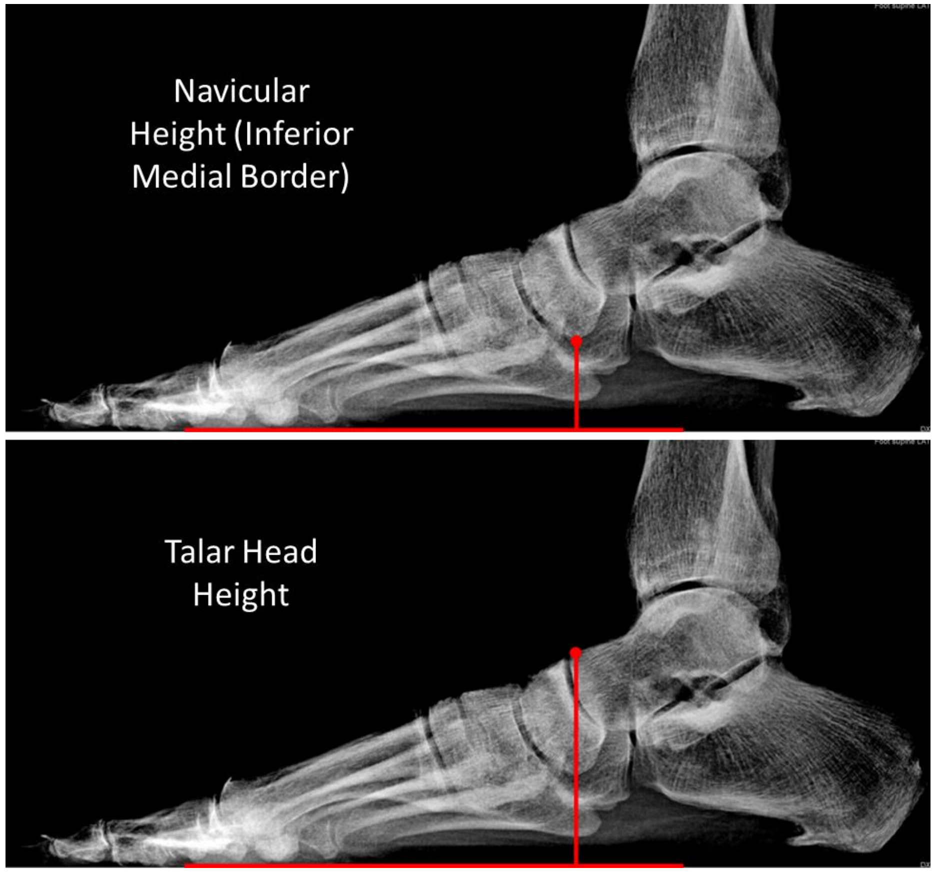


Figure 12: Radiographic Measurements

3.3 Results

The full dataset for the x-ray versus anthropometry analysis can be found in Table 5. One outlier, subject 8239, was removed from the navicular height analysis due to inability to invert the foot in the standing position (which affected the height of the navicular through rotation of the foot). The navicular height (inferior medial border) was found to be significantly different between anthropometry and x-ray imaging methods, while talar head height was found to be not significantly different between methods. Table 6 shows statistical results of the two measurements' comparisons. For navicular height, the anthropometric average (32.84 mm) was found to be lower than the x-ray average (36.20 mm).

Table 5: X-ray versus Anthropometry Data

Anthropometric and Radiographic Measurements (mm)				
PMHS	**Left Nav Height Xray**	**Left Nav Height Anthro**	**Left Talar Height Xray**	**Left Talar Height Anthro**
8239	59.14	63.87	91.28	83.39
8367	39.26	38.37	77.07	77.67
8371	41.78	43.64	79.68	78.58
8379	29.23	30.57	66.45	65.75
8402	30.53	28.77	68.53	73.89
8409	31.28	30.88	74.09	73.83
8458	37.92	33.89	79.45	81.99
8464	37.68	36.23	77.28	74.06
8470	24.19	21.64	60.89	51.79
8481	42.44	32.40	82.17	77.23
8483	41.12	37.58	82.22	82.83
8518	39.58	47.63	72.96	71.02
8520	40.07	32.00	79.07	76.01
8533	44.02	42.57	83.10	85.48
8545	39.54	34.41	80.74	81.00
8577	44.71	35.29	83.08	82.34
8580	26.25	21.53	65.08	64.10
8615	25.51	23.40	64.23	66.85
8620	43.99	28.44	75.49	71.38
8631	29.65	24.91	71.70	73.02
8655	35.18	32.70	79.03	77.09

*8239 excluded from Navicular Height due to inability to invert foot during standing (outlier)

Table 6: X-ray Summary Statistics

Measurement	**Anthro Mean**	**Anthro SD (±)**	**X-Ray Mean**	**X-Ray SD (±)**	**P-Value**
Navicular Height (Inferior Medial Border)	32.84	7.09	36.20	6.68	0.007*
Talar Head Height	74.73	7.92	75.89	7.56	0.141

*Indicates significant statistical difference

3.4 Discussion

Of the two measurements included in this analysis, navicular height (inferior medial border) showed significant differences between measurements obtained from anthropometry and x-ray imaging. The anthropometric average showing a lower height than the x-ray average could be due to the soft tissue in between the height gage and the bony surface of the navicular when taking this anthropometric measurement, shown in Figure 13. The soft tissue would cause the anthropometric measurement to be taken below the true location of the navicular.

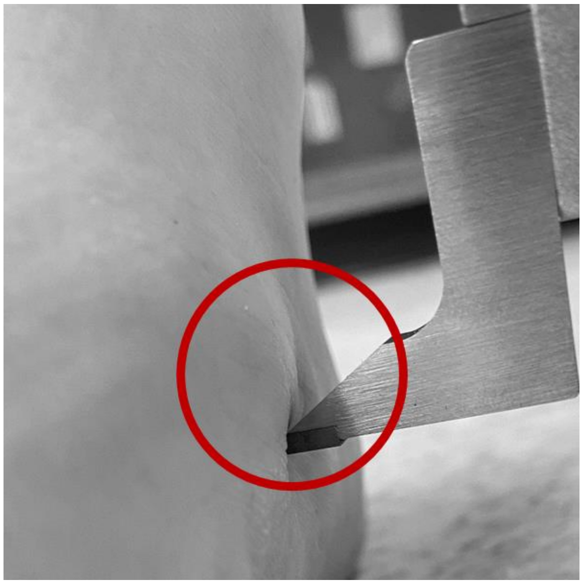


Figure 13: Soft Tissue Inclusion in Navicular Height (IMB) Measurement

In contrast, there is no soft tissue impeding measurement for the x-ray imaging, and so navicular measurement from the x-ray imaging is higher than the anthropometric measurement. This indicates that for the measurement of this landmark, x-ray imaging would yield more accurate results than anthropometry in locating the anatomical location of the inferior medial border of the navicular This difference in measurement methodologies is supported by the results of the previously mentioned studies from Hameed (2020) and Farkas (2002), which found differences between anthropometry and radiography regarding measures of flat footedness (determined from various foot landmarks) and skull anatomy respectively. As mentioned, the Hameed (2020) study found differences which they claimed were due to the higher success of radiography in identifying flat-footedness, and the Farkas study found differences in method which they said were most likely due to an inability of the two dimensional nature of radiography to detect landmarks in uneven positions on different planes of the face, as opposed to anthropometry, which can account for these uneven and multiplane landmark locations.

Talar head height showed no significant difference between anthropometric measurement and x-ray imaging. This indicates that for talar head height, anthropometry suffices in obtaining the accurate location of this landmark. Although three of the 19 reported measurements in the study by Farkas on skull measurements were found to be not significantly different, this 16% agreement between anthropometry and radiography does not provide a strong support of likeness between the methods. Nevertheless, the Farkas study did have measurements with no difference between anthropometry and radiography, which agrees with the result of talar head height being not significantly different across modalities. The Farkas study was done on the skull, so results might not directly apply, but at the very least the results from the Farkas study do show that anthropometry can agree with measurements obtained using radiography. These talar head height results combined with results for the navicular height indicate that for some landmarks the two methods provide values that are not significantly different but for other landmarks the two methods provide differing values.

Limitations of this portion of the study include the small sample size for this portion of the study. As opposed to the other parts which had at least 30 subjects, this part only had 21 subjects included due to the necessity of the subjects having both the anthropometry measurements as well as lateral weight bearing x-rays taken. Another limitation was the inclusion of only two measurements. The focus of this portion was to determine the necessity of x-ray imaging in locating anatomical landmarks, and in order to accomplish this only two measurements were utilized. However, with contrasting results from the navicular and talar head heights, it was shown that results may vary across foot landmarks. Therefore, for a more holistic investigation of whether x-ray imaging is necessary for all foot landmarks, this same comparison between methods will need to be made for more landmarks in the future. Lastly, this study also did not include an analysis on intra-observer error that may have been seen from the one measurer in this portion of the study. In order to quantify this potential error in the future, this analysis should be done in future studies.

Ideally, anthropometry can be used instead of radiography to determine landmark locations and foot dimensions in order to eliminate the need for radiation due to x-ray imaging. Thus, anthropometry is preferred for reasons of safety and simplicity. The study done by Saltzman et al. (1995) reported intraclass correlation coefficient (ICC) values for inter-observer reliability in both anthropometric and radiographic measurements and found that radiographic measurements had higher values for ICC in radiographic measurements (range of 0.90-0.99) compared to those for anthropometric measurements (0.74-0.79), but both had moderately reliable results. Since radiographic measurements were shown to have less inter-observer error than anthropometric measurements, but both had relatively high reliability between measurers, one must consider weighing the lower reliability seen in anthropometry against the negatives of both accessibility to the technology as well as radiation exposure when using radiography. Considering the adequate reliability of both methods and the lack of radiation in anthropometry, it still seems to be the better overall option. However, anthropometry is not always sufficient, as shown by the results for navicular height as well as the previously mentioned studies from Hameed and Farkas, which both found differences between methods as discussed. So, the results suggest that x-ray imaging may be necessary to provide additional measurement values to anthropometry for accurately locating certain landmarks measurements. The Hameed study suggests that x-ray measurement is more effective in determining anatomical locations in regard to several foot measurements such as arch index (total area of the plantar foot divided by area of the midfoot) due to radiography more accurately detecting flat footedness, but those results do not fully evaluate whether radiography more accurately determines landmarks throughout the entire foot. For future research, more landmarks should be measured and radiographically imaged in order to determine which landmarks or measurements may require x-ray imaging and which can utilize just anthropometry for accurate anatomical locations.

Chapter 4: Calcaneal Soft Tissue

4.1 Introduction

The components involved in anatomical human analysis can be divided into two categories: hard tissue and soft tissue. Among other components, hard tissue includes bone and soft tissue includes skin, muscle, fat, ligament, tendon, and other supporting tissues. The anthropometric analysis portion of this study was focused on determining locations of PMHS foot landmarks for comparison to living populations, which aids in quantifying bony anatomy and characterizing the hard tissues of the PMHS lower extremity. In an effort to begin characterizing the soft tissue of PMHS for comparisons to living populations, this ultrasound analysis focused on thicknesses, stiffnesses, and compressibility of the heel pad in PMHS. There are various mechanical properties of heel pads which can be analyzed and compared back to living populations, but the focus of this study lies on the three mentioned properties. Studies from Belhan et al. (2019), Chatzistergos et al. (2014), Gooding et al. (1985), Hall et al. (2015), Hsu et al. (1998), Hsu et al. (2009), Nass et al. (1999), Rome et al. (1998), Rome et al. (2002), Tong et al. (2003), and Uzel et al. (2006) all have investigated the heel pads of living people. Table 7 shows information about the populations and measurement protocols used in each of the above-mentioned studies which utilized ultrasound imaging for heel pad properties.

Several of these above-mentioned studies as well as several studies which did not use ultrasound did left versus right and male versus female analyses. Generally, left and right feet were found to have similarity in thickness and compressibility (Belhan et al. (2019), Uzel et al. (2006), and Hall et al. (2015)) but differences in stiffness (Ugbolue et al. (2019)). In male versus female comparisons, previous studies found that males had greater thicknesses than females (Hall et al. (2015), Uzel et al. (2006), and Prichasuk et al. (1994)), but no sex differences were found in stiffness (Ugbolue et al. (2019)). Compressibility had contrasting results, with some results showing no significant sex differences (Prichasuk et al. (1994) and Uzel et al. (2006)) but other results showing sex differences (Nass et al. (1999)).

With contrasting results for sex differences in compressibility, an abundance of literature on living comparisons, and a lack of data on PMHS heel pads, procedures from the studies which used ultrasound imaging were adapted for measurement of PMHS heels, and with comparable methodology both data sets could be compared to determine potential post-death changes in the heel pad of the foot for determination of laterality differences, sex differences, and potential differences between PMHS and living people.

Table 7: Ultrasound Study Information

Source	Population	Measurement Description	Reported Stiffness	Reported Compressibility Index
Belhan et al. 2019	n = 50 (21M, 29F) mean age = 46.5 yrs	control vs plantar fasciitis unloaded, still probe mixture of right and left feet	-	-
Chatzistergos et al. 2014	n(control) = 17 mean age = 35 yrs	control vs type II diabetes 0-30 N, probe speed: 1.25 mm/s right feet	Yes	-
Gooding et al. 1985	n(control) = 10 (5M, 5F) mean age = 28 yrs	control vs diabetic unloaded, still probe averaged right and left feet	-	-
Hall et al. 2015	n = 39 (20M, 19F) mean age = 39.3 yrs	runners unloaded and loaded, still probe mixture of right and left feet	-	Yes
Hsu et al. 1998	n(old) = 13 mean age = 68	young vs old 0-3kg (~30N), probe speed 0.6 mm/s mixture of right and left feet	Yes	Yes
Hsu et al. 2009	n(control) = 16 (9M, 7F) mean age = 55.2 yrs	control vs type II diabetes 0 to 98N, probe speed: 6 mm/s mixture of right and left feet	-	-
Nass et al. 1999	n(control) = 31(20M, 11F) mean age = 60.9 yrs	normal vs overweight 0,10,25,50,75, and 100% of BW, still probe mixture of right and left feet	-	Yes

Continued

Table 7 continued

Rome et al. 1998	n = 15 (4M, 11F) mean age = 25.4	healthy volunteers unloaded and loaded (standing), still probe right feet	-	-
Rome et al. 2002	n(control) = 64 mean age = 23.9 yrs	control vs plantar heel pain loaded (standing), still probe foot side not reported	-	-
Tong et al. 200	n(control) = 14 (6M, 8F) mean age = 43.2	control vs plantar heel pain 0-30N (by 5N), still probe mixture of right and left feet	-	Yes
Uzel et al. 2006	n(control) = 42 (7M, 35F) mean age = 45	people with plantar heel pain unloaded and loaded (standing), still probe mixture of right and left feet	-	Yes
Uzel et al. 2006	n(sedentary) = 50 (25M, 25F) mean age = 23	athletic activity unloaded and loaded (standing), still probe both right and left feet	-	Yes

After death, the properties of soft tissues sometimes change due to factors such as rigor mortis, physical activity prior to death, or dehydration. Rigor mortis was explored in studies by Clark et al. (1997), Krompecher (1981), and Shuck et al. (1979). The study by Clark which investigated literature on soft tissue changes after death found that although rigor can indeed have effects on the stiffness of soft tissues, muscles relax by about 48 hours after death on average. The study by Krompecher explored the relationship between temperature and how long rigor was active for following death. That study found that at colder temperatures (6 °C) rigor fully develops between 48 and 60 hours after death and is fully resolved by 168 hours, and at close to room temperature (24 °C) it fully develops 5 hours after death and is resolved at 16 hours. The study by Shuck investigated the relationship between torque required to overcome rigor and the amount of time passed after death and found that required torque decreased as time passed with a flattening out of torque past around 12 hours. All of these studies concluded that while rigor is present and active in the soft tissues of PMHS in the time soon after death, it does lose its effect within hours to days after death depending on temperatures, but it is unknown how this affects quantifying mechanical properties of soft tissue.

Also, factors such as physical activity (as investigated by studies such as Ikezoe et al. (2011) and Uzel et al. (2006)) and dehydration (as investigated by studies such as Huff-Lonergan et al. (2005) and Matamala et al. (2008)) could influence the characteristics of the soft tissues in the heel pad. The Ikezoe study investigated the relationship between age-related loss of muscle thickness and daily physical activity and found that as daily physical activity decreased, tissue thickness decreased as well for most of the analyzed muscle groups. Also focused on physical activity, the Uzel study compared the heel pad thickness and compressibility of a control population with a highly active population and found that with decreased physical activity there was no significant loss of heel pad thickness or compressibility, indicating physical activity may not be a large factor in heel pad properties. In term of dehydration, the Huff-Lonergan study investigated the decrease in ability of meat to retain water after death due to postmortem changes related to degradation of cells and the forcing of water into extracellular space where it can be lost to the soft tissue. The Matamala study found that PMHS that were not treated with conservation methods had less thickness in the soft tissues of the face when compared to PMHS that were treated with conservation methods. The authors of this study indicated the loss in thickness was from dehydration of the facial soft tissues.

In an effort to explore the potential effects of the factors discussed above, an analysis on heel pad stiffness can begin to describe post death calcaneal pad characteristics. The living population values of the previously mentioned studies found in Table 7 can be compared against this study's PMHS values to gain a better understanding of potential changes after death and quantify the differences between the two groups. So, the objective of this portion of the study was to investigate variation in heel pad characteristics within PMHS and to compare PMHS heel pad thicknesses, stiffnesses, and compressibility with living people to determine changes that may occur in the heel pad after death.

4.2 Methods

Thirty-two subjects (15 males and 17 females) were included in this study. The average age was 75 years old, with a range of 53 to 100 years old and a standard deviation of ±11 years. All PMHS were obtained through The Ohio State Body Donation Program.

Shown in Figure 14 and Figure 15, a custom-built ultrasound imaging fixture was built based on the fixture used in the study from Chatzistergos. The newly built fixture was used for recording ultrasound images of the plantar surface of the foot in this portion of the study. The fixture was equipped with a Lumify ultrasound sensor (Koninklijke Philips NV, Amsterdam, Netherlands), a load cell, and hand cranks to adjust movement of the sensor. The probe could be rotated about all axes in 3 dimensions to ensure the probe was as perpendicular as possible to the plantar surface of the heel pad. The large crank in the back of the fixture allowed for force application to the plantar surface of the foot with inward and outward motion of the probe in relation to the foot. A small gel standoff pad, shown in Figure 16 was placed between the ultrasound probe and the plantar surface of the subject's foot, and a layer of ultrasound gel was also applied to the contacting surface of the standoff pad. The standoff pad may have had effects on the distribution of loading on the foot due to the elastic property of the pad. In other words, it is possible that some magnitude of the force was being applied towards the expansion of the standoff pad as opposed to directly to the foot. However, this redistribution of loading into the pad was not analyzed for this study, and for simplicity, forces as close as possible to the target levels (mentioned later) were obtained. The ultrasound sensor was plugged into an accessory Android™ tablet to view and save the images using the Philips Lumify Ultrasound App (Koninklijke Philips NV, Amsterdam, Netherlands), and the load cell was plugged into a Slice Pro (Diversified Technical System, Inc., Seal Beach, CA) data acquisition system to view real time values for force application in newtons.

Figure 14: Ultrasound Fixture

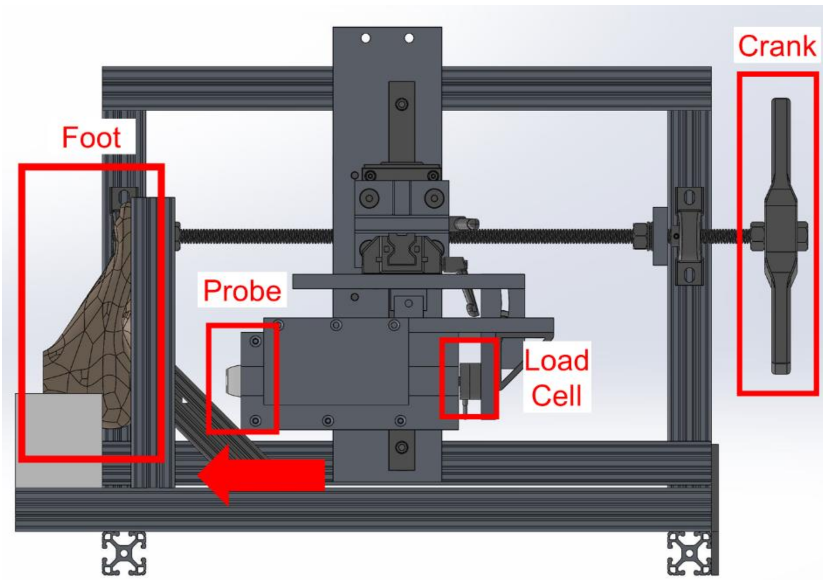


Figure 15: Simplified View of the Ultrasound Fixture

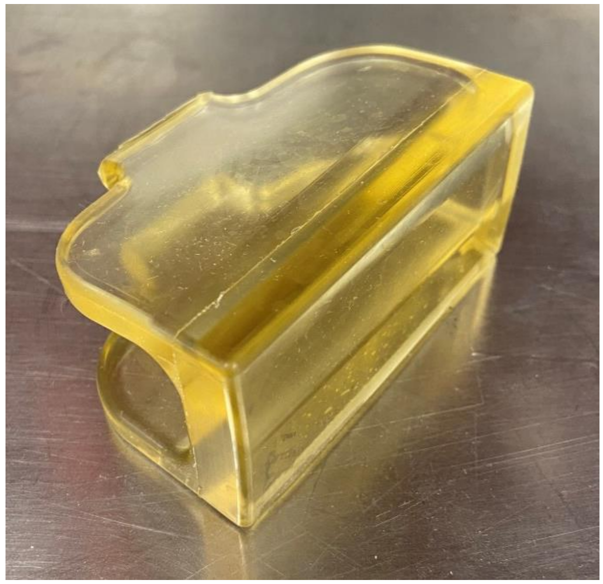


Figure 16: Ultrasound Standoff Pad

In a supine position on a table, the subject was moved so that the feet hung off the of the table. Then one foot was placed so that the heel of the subject hung off the end of the orange piece on the ultrasound fixture shown in Figure 14 with the bottom of the foot facing the ultrasound probe. The black strap shown and silver horizontal bars above the orange piece in Figure 14 were then used to secure the foot in place with the plantar surface as perpendicular as possible to the ultrasound probe and with the full surface of the heel pad unobstructed. Once the subject's foot was in position, static B-mode ultrasound images were taken of each foot's calcaneus at 0, 5, 10, 15, 20, and 30 Newtons. For the 0 N image, the probe was cranked inward to the point where a measurable image of the calcaneus was observed on the tablet as shown on the left in Figure 17.

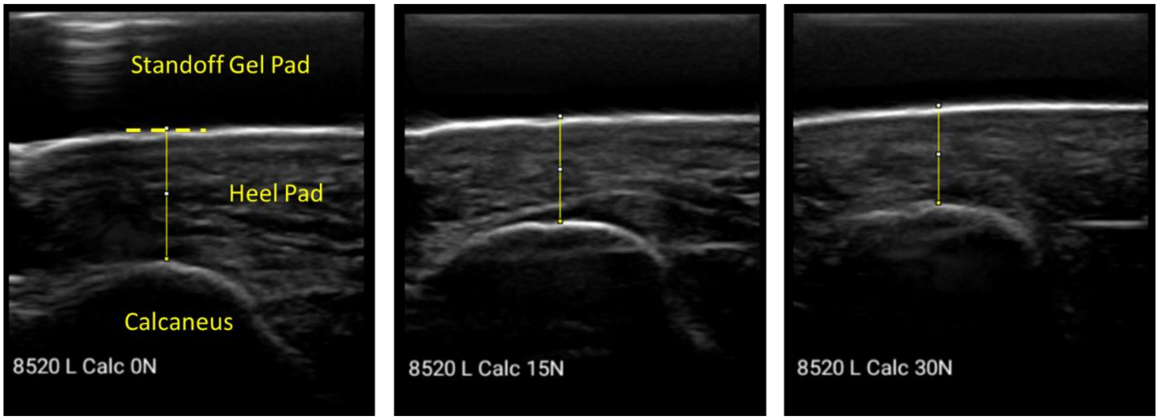


Figure 17: Example Ultrasound Measurements of Left Calcaneus: 0 N (left), 15 N (middle), and 30 N (right). The dotted line shows the outermost layer of the skin.

After saving all images, the smallest distance between the calcaneus and the outermost layer of the skin of the heel was determined using ImageJ (National Institute of Mental Health (Research Services Branch), Bethesda, MD) (Figure 17). The thickness of the soft tissue at 0 N was considered the baseline heel measurement used for comparing PMHS thicknesses with living population thicknesses due to most of the studies having reported unloaded thicknesses of the heel. For each load, five measurements were taken, and then an average was taken of the three middle measures (the maximum and minimum values were excluded). Displacement was then calculated by subtracting the baseline thickness from the thickness at each force level. The displacement at each level of force was plotted with force magnitudes to produce a force-displacement curve, and the slope of the curve represented the stiffness of the heel pad (Figure 18). Similar methodology for determining stiffness from the slope of a force-displacement plot was used in the studies which reported values for stiffness (Chatzistergos et al (2014) and Hsu et al. (1998)). The compressibility index (CI) was calculated using the following equation:

$$Compressibility\ index\ (CI) = \frac{thickness_{30\ N}}{thickness_{0\ N}}$$

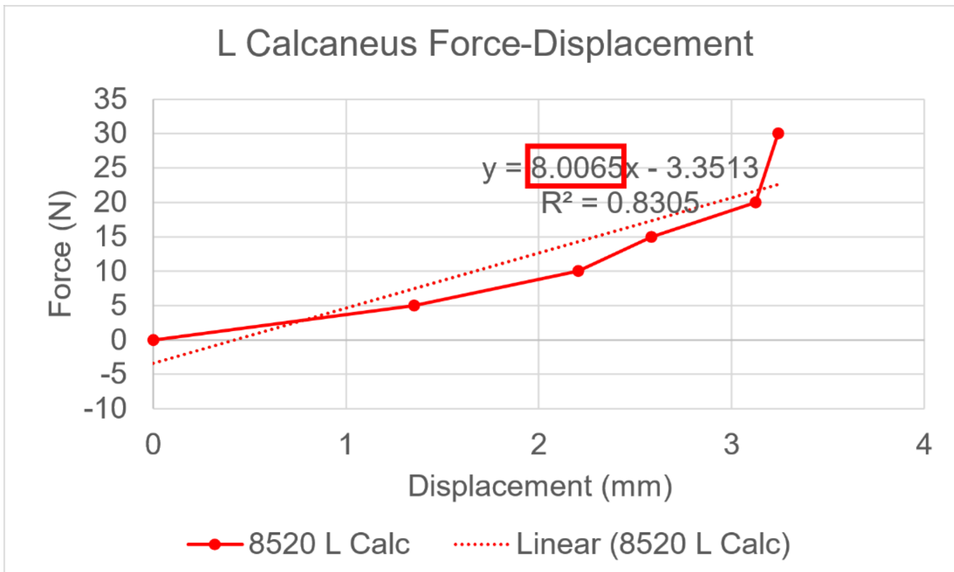


Figure 18: Stiffness Value (shown in the red box) from Exemplar Force-Displacement Curve

For the statistical analysis, normality was checked on the whole sample, outliers were identified, and a square transformation was done on the CI data to ensure normality. A matched pairs t-test was done on left versus right feet for thickness, stiffness, and CI, and a two-sample t-test was done on males versus females for the same variables. When left and right feet were found to have no significant difference, they were averaged when comparing to literature. To compare with literature values for living people for thicknesses, stiffnesses, and CI, a one-sample t-test was used when the literature study did not report a value for population variance, and a one-sample z-test was done when variance was reported.

4.3 Results

Overall results can be found in Appendix D. Appendix D contains tables for raw thickness measurements at each level of force (Table 19-Table 24) as well as a tables for average thicknesses at each level of force (Table 25). It also shows a table for stiffness and compressibility index values for each subject in Table 26 and Table 27 respectively. Subject 8464 was removed from all analyses due to excessive swelling in both feet

4.3.1 Left versus Right

For this analysis, males and females were combined in both left and right groups. The results of the comparison between left and right thicknesses are shown in Table 8. Left and right feet were found to be not significantly different in their thicknesses. The results of the comparison between left and right stiffnesses are shown in Table 9. Stiffness was found to be significantly different across feet. The results of the comparison between left and right CI's are shown in Table 10. Left and right feet were found to be not significantly different in their CI's.

Table 8: Left vs Right Thickness

Thickness (mm)				
Left Mean	Right Mean	Left SD (±)	Right SD (±)	P-Value
13.31	13.02	2.88	2.71	0.484

*8464 removed for excessive swelling in both feet

Table 9: Left vs Right Stiffness

Stiffness (N/mm)				
Left Mean	Right Mean	Left SD (±)	Right SD (±)	P-Value
8.55	10.32	2.88	3.06	0.006*

*8464 removed for excessive swelling in both feet

Table 10: Left vs Right Compressibility Index

Compressibility Index								
Left Mean	Right Mean	Left SD (±)	Right SD (±)	Left Squared Mean	Right Squared Mean	Left Squared SD (±)	Right Squared SD (±)	P-Value
0.75	0.77	0.06	0.05	0.56	0.60	0.09	0.08	0.111

*8464 removed for excessive swelling in both feet
*A square transformation was done to ensure normality of the data

4.3.2 Male versus Female

The results of the comparison between male and female thicknesses, stiffnesses, and CI’s are shown in Table 11, Table 12, and Table 13 respectively. Male and female heel pads were not significantly different in their thicknesses, stiffnesses, or CI’s.

Table 11: Male vs Female Thickness

Thickness (mm)				
Male Mean	Female Mean	Male SD (±)	Female SD (±)	P-Value
13.17	13.26	2.34	3.15	0.901

*8464 removed for excessive swelling in both feet

Table 12: Male vs Female Stiffness

Stiffness (N/mm)					
Foot	Male Mean	Female Mean	Male SD (±)	Female SD (±)	P-Value
Left	9.24	7.97	3.12	2.62	0.230
Right	10.26	10.36	2.86	3.30	0.934

*8464 removed for excessive swelling in both feet

Table 13: Male vs Female Compressibility Index

Compressibility Index								
Male Mean	Female Mean	Male SD (±)	Female SD (±)	Male Squared Mean	Female Squared Mean	Male Squared SD (±)	Female Squared SD (±)	P-Value
0.77	0.75	0.05	0.06	0.59	0.57	0.08	0.09	0.458

*8464 removed for excessive swelling in both feet

*A square transformation was done to ensure normality of the data

4.3.3 Thickness Analysis

The whole dataset for thicknesses can be found in Appendix D. For comparison to literature, the results for the t and z-tests done on thickness are shown in Table 14. Nine of the 11 sources (82%) reported calcaneal thicknesses of living populations, which were found to be significantly different from this study's PMHS calcaneal thicknesses. All of these nine sources had thicknesses larger than PMHS calcaneal thicknesses.

Table 14: Statistical Results for PMHS vs Living Population Unloaded Thickness (PMHS value averaged L to R)

Thickness (mm)					
Literature Source	**Lit Mean**	**PMHS Mean**	**Lit SD (±)**	**PMHS SD (±)**	**P-Value**
Belhan et al. 2019	19.94	13.16	-	2.77	<0.001*
Chatzistergos et al. 2014	19.50		4.70		<0.001*
Gooding et al. 1985	16.60		-		<0.001*
Hall et al. 2015	13.80		-		0.076
Hsu et al. 1998	20.10		2.40		<0.001*
Hsu et al. 2009	18.40		1.20		<0.001*
Nass et al. 1999	15.00		2.60		<0.001*
Rome et al. 1998	12.47		4.20		0.193
Tong et al. 2003	15.50		2.40		<0.001*
Uzel et al. 2006	19.80		2.90		<0.001*
Uzel et al. 2006	18.60		2.50		<0.001*

*8464 removed for excessive swelling in both feet

4.3.4 Stiffness Analysis

The whole dataset for stiffnesses can be found in Appendix D for stiffnesses. For the stiffness analysis (Table 15), only two studies, Chatzistergos et al. (2014) and Hsu et al. (1998), reported values for stiffnesses of the calcaneus. Both studies had values for stiffness that were significantly different from PMHS values. Chatzistergos et al. (2014) had a larger value for stiffness while Hsu et al. (1998) had a smaller value compared to PMHS calcaneal stiffness.

Table 15: Statistical Results for PMHS vs Living Population Stiffness

Stiffness (N/mm)					
Literature Source	**Lit Mean**	**PMHS Mean**	**Lit SD (±)**	**PMHS SD (±)**	**P-Value**
Chatzistergos et al. 2014	17.10	10.32	6.00	3.06	<0.001*
Hsu et al. 1998	3.89	L 8.55	0.67	L 2.88	<0.001*
		R 10.32		R 3.06	<0.001*

*8464 removed for excessive swelling in both feet
*Right foot only used for Chatzistergos study

4.3.5 Compressibility Index Analysis

The whole dataset for compressibility index can be found in Appendix D for CI's. For this analysis (Table 16), all of the six studies done on living populations had CI's of the heel pad which were significantly different from PMHS values. All studies had lower values than PMHS CI’s, which indicates that PMHS had a greater change in thickness when loaded.

Table 16: Statistical Results for PMHS vs Living Population Compressibility Index

<table>
<tr><th colspan="6">Compressibility Index</th></tr>
<tr><th>Literature Source</th><th>Lit Mean</th><th>PMHS Mean</th><th>Lit SD (±)</th><th>PMHS SD (±)</th><th>P-Value</th></tr>
<tr><td>Hall et al. 2015</td><td>0.513</td><td rowspan="6">0.760</td><td></td><td rowspan="6">0.057</td><td><0.001*</td></tr>
<tr><td>Hsu et al. 1998</td><td>0.613</td><td>0.055</td><td><0.001*</td></tr>
<tr><td>Nass et al. 1999</td><td>0.355</td><td>0.067</td><td><0.001*</td></tr>
<tr><td>Tong et al. 2003</td><td>0.654</td><td>0.077</td><td><0.001*</td></tr>
<tr><td>Uzel et al. 2006</td><td>0.600</td><td>0.090</td><td><0.001*</td></tr>
<tr><td>Uzel et al. 2006</td><td>0.610</td><td>0.060</td><td><0.001*</td></tr>
</table>

*8464 removed for excessive swelling in both feet

4.4 Discussion

4.4.1 Postmortem Effects on PMHS

With the results of the studies from Clark (1997), Krompecher (1981), and Shuck (1979) indicating little to no effects of rigor on soft tissues and muscles after a time scale of hours or a few days, it was concluded that the PMHS used in this study were not adversely affected by rigor. All subjects were measured days after death to the extent where rigor would no longer be heavily active, so based on the results of these mentioned studies, it can be concluded that rigor did not play a large part in soft tissue changes within the heel pad.

Regarding physical activity, the level of activity or mobility of subjects prior to death was unable to be determined. However, the results from the Uzel study (2006) showed that heel pads were not affected by physical activity in terms of thickness or stiffness, so an understanding of physical activity prior to death was not necessary to understanding potential changes in the heel pad.

Dehydration of soft tissues, as explored in the previously mentioned studies from Huff-Lonergan (2005) and Matamala (2008) seemed to be the most influential factor in possible changes in the heel pad due to the lasting effects and consistent changes to soft tissue properties as shown in these studies. The potential effects of postmortem dehydration regarding heel pad thickness, stiffness, and compressibility individually will be further discussed in the following sections for each property of the heel pad.

4.4.2 Left versus Right

Left and right feet were found to be interchangeable for thickness and CI but not for stiffness. However, for the stiffness analysis, procedures were matched for the respective stiffness comparisons. So, for the study performed by Chatzistergos et al. (2014) which analyzed the right heel, only the right foot of PMHS heel pad measurements were included in the comparison with this study, but for the study by Hsu (1998) which included both right and left foot data, both feet of the PMHS were used. The Hsu study (1998) did not report values for left and right feet separately, so left and right feet of the PMHS were separately compared to the value from the Hsu (1998) study. For thickness, the studies by Belhan (2019), Hall (2015), and Uzel (2006) found no significant difference between left and right feet, which supports the findings of this study. For stiffness, the study from Ugbolue (2019) which used a motion analysis on reflective markers placed on the heel pads during loading and found that stiffness was significantly different between left and right feet for females which they hypothesized was due to foot dominance, which supports results shown in PMHS from this study. For CI, the studies by Hall (2015) and Uzel (2006) both found no significant difference between left and right feet, which also supports the findings of this study.

Stiffness and compressibility are similar properties but are determined through different calculations, so a difference between the two in terms of asymmetry across feet seems unexpected but still possible. The property of stiffness is more focused on how the heel pad reacts to loading, while compressibility is focused on how much total compression the tissue undergoes. In terms of this study, a subject could have had different stiffness but similar compressibility across feet if the thickness values at 5, 10, 15, and 20 N were significantly different across feet but the difference between the baseline thickness (at 0 N) and the maximum compression thickness (at 30 N) were similar in the left and right foot. The viscoelastic nature of the heel pad can explain this potential occurrence in that the heel pad may react differently to forces in the intermediate range of loading (5, 10, 15, and 20 N) compared to the minimum (0 N) and maximum (30 N) forces.

The lack of differences in left and right feet for thickness and CI in PMHS indicate that differences across feet are negligible when studying PMHS heel pad thickness and compressibility for applications focused on the soft tissue of the heel pad.

However, if investigating the stiffness of the lower extremity using PMHS, one must consider which foot is being used for testing and must account for differences in heel pad stiffness across feet when using the data. feet.

4.4.3 Male versus Female

Males and females were found to have no significant differences in thicknesses, stiffnesses, or CI's, meaning for all analyses comparing to literature the males and females were averaged together. The thickness results are in contrast to finding in the studies by Hall (2015), Uzel (2006), and Prichasuk (1994), all of which found males to have thicker heel pads than females. The study from Prichasuk (1994) used x-rays of unloaded and loaded (standing) heel pad thicknesses to determine differences from age, sex, and body weight and also found that males had thicker heel pads, which they claimed was due to the generally larger size of males compared to females. This discrepancy between male and females seen in living populations versus what was seen in the PMHS population could be due to the degree of postmortem dehydration that occurs in the heel pads of both sexes. The data from the Huff-Lonergan (2005) and Matamala (2008) studies showed that after death fluids leave soft tissues due to a decreased ability of those tissues to retain water. As fluids leave the heel pads of both males and females after death, heel pad thicknesses decrease in both groups. As thicknesses decrease, differences between males and females would lessen as well, which could explain the lack of significant difference in heel thickness observed after death. Regarding stiffness, the study from Ugbolue (2019) found that there were no significant sex differences in heel pad stiffness, which supports the results found for PMHS heel pad stiffness. Regarding CI of the heel pads, the study from Prichasuk (1994) found that there was no significant difference between males and females in CI of heel pad. The study by Uzel (2006) also found no sex differences in compressibility which supports the findings in this study as well. In contrast, the study from Nass (1999) showed significant differences in CI between males and females, which could be due to the use of an overweight population in their comparison of CI between sexes. With overweight people in the dataset, it is possible that CI's were affected in the male and/or female population when comparing the two, as opposed to the control groups used in the other two mentioned studies which addressed sex differences in CI.

Considering the lack of difference in males and females in all three heel pad properties of thickness, stiffness, and compressibility, sex differences were not found to be significant in this analysis of PMHS. With no sex differences found, further investigation should be done as to whether heels pads in male PMHS can be used to represent females when using PMHS in lower extremity testing focused on heel pads. With certain literature sources such as Hall (2015), Uzel (2006), and Prichasuk (1994) finding sex differences in thickness, PMHS results indicate that they do not fully represent the differences between male and female heel pads at least for the property of thickness.

4.4.4 Thickness Analysis

With 82% of sources showing living populations having thicker heel pads than PMHS, the results indicate that after death, thickness of the heel pad decreases. This could be due to dehydration after death which decreases fluids in soft tissues, as investigated by the Huff-Lonergan (2005) and Matamala (2008) studies. One study from Rome (1998) reviewed literature on the properties of heel pads and stated that fluid flow within the fat layers of the heel pad would affect its mechanical and material behaviors. This lack of fluid normally in the heel pad would cause a decrease in the overall thickness of the tissue and would therefore lead to smaller thickness values when compared against living population values.

As soft tissues are exposed to less loading from less physical activity, they atrophy and decrease in size. The Ikezoe (2011) study found that as people age, their muscles become smaller due to lack of physical activity, and this occurrence could help to explain the decreased thickness in heel pads after death. However, Uzel at al. (2006) found no difference in heel pad thickness with differences in physical activity, which could be because the heel pad consists mostly of adipose tissues and fat compartments as opposed to muscles and so would not show decreases in size with less physical activity. Due to the Uzel (2006) study being more relevant to the results shown in this thesis, it seems that physical activity can be eliminated as a large factor in determining heel pad thickness.

The study from Uzel et al. (1998) investigated heel pad thickness in a comparison between young and old people, and the study showed that there was a significant difference between the two groups in heel pad thickness. However, the Uzel (1998) study found that thickness increased from younger to older population which they said was most likely due to increases in BMI and body fat with age. The results of this thesis suggest that there is a reversal in differences as PMHS show thinner heel pad than living (younger) populations, which is most likely due to the degree of postmortem dehydration.

With the results showing decreases in heel pad thickness after death, measures will need to be taken to ensure this difference is accounted for when using data from the soft tissue of the lower extremity of PMHS. For example, if a study such as the underbody blast study done by McKay et al. (2010) wanted to analyze soft tissue properties for applying to ATD material standards, thickness differences between PMHS and living populations of the heel pad would need to be considered.

4.4.5 Stiffness Analysis

One study reported a stiffness larger than the PMHS value and the other reported a lower value, which indicates that more stiffness data is needed on living population heel pads. Regarding the procedures used for stiffness in the two included studies, both had methods similar to this thesis' methodology in terms of force magnitude and application. The Chatzistergos (2014) study included a loading of the heel pad up to 30 N while moving the ultrasound probe at a constant speed of 1.25 mm/s, while the study by Hsu (1998) loaded the heel up to 3 kg (29.42 N) at a probe velocity of 0.6 mm/s. This thesis' procedure took images with the probe stationary and went up to 30 N, so the methodologies of both studies closely align with the methods of this thesis. One important difference in the two mentioned studies is that the Hsu (1998) study analyzed an older population (mean age of 68) while the Chatzistergos (2014) study had a younger population (mean age of 35). This indicates that the stiffness values from Hsu (1998) may be more relevant to this study in comparing living population stiffness with PMHS stiffness. The Hsu (1998) study found a stiffness much smaller than the PMHS value, meaning there was less force required to decrease the thickness of living people's heel pads.

As with the decreased heel pad thickness in PMHS, this increase in stiffness after death could be due to the dehydration of the heel pad (supported by the Huff-Lonergan (2005) and Matamala (2008) studies). As there is less water and fluids to saturate the heel pad in a PMHS as compared to a living person, the tissues of the heel pad could show less total deformation without water filling the fatty compartments of the heel pad and deforming within its soft tissues.

Along with thickness, the Hsu (1998) study also investigated the stiffness of young vs old heel pads and found that there was no significant difference between the two. Although there was not a significant difference found, the elderly population did have a slightly stiffer heel pad, which the researchers in this study claimed was most likely due to a loss of elasticity and increased heel pad fat as people get older. Although they found no significant difference, these changes the Uzel study mentioned could have played a role in the finding of significant difference between PMHS and living populations along with the factor of postmortem dehydration. As elasticity is lost in old age and as water leaves the heel pad after death causing the adipose tissues within it shrink, there is less ability to deform when loaded, which would lead to a stiffer heel pad after death as shown by the results of this study.

When comparing the stiffness results with the thickness results, the Chatzistergos (2014) study showed the living people having thicker and stiffer heel pads, while the Hsu (1998) study showed living people having thicker but less stiff heel pads. Seeing as how the Hsu (1998) study more closely aligns to the results of this study, the thicker and less stiff heel pads in living population is supported by the observation of dehydration after death.

4.4.6 Compressibility Index

The results show PMHS having a smaller change in heel pad thickness when loaded, indicating that there is a change in the compressibility of the heel pad after death. Once again dehydration could be responsible for this change in the soft tissue of the heel pad after death. As there is less water saturating and deforming in the heel pad of PMHS, the ability to compress will decrease. The Uzel (1998) study also looked at young versus old CI's of the heel pad and found that the older group had less compressibility than the younger group. Considering the compressibility goes down with age, and the fact that this study's PMHS population had an average age of 75 years old compared to lower average ages in all six studies which reported compressibility values (refer to Table 7), the results of the Uzel study support a decrease in compressibility in the PMHS population. The later study by Uzel (2006) found that there was no difference in heel pad compressibility at varying levels of physical activity, so that can be eliminated as a factor for changes in CI after death as it was for heel pad thickness.

4.4.7 Limitations

One challenge in this portion of the study was in maintaining stability of the PMHS foot within the ultrasound fixture. Without active muscles of the PMHS to hold the foot in place as you would see in a living person, the foot tended to move from its initial position when applying loads. While this would not affect the thickness results due to thickness values being used from the initial ultrasound image taken at 0 N, this issue could affect stiffness values as the foot potentially shifted as load was increased and the corresponding thicknesses at each load were potentially skewed. In order to address this in a future PMHS study, measures should be taken to better secure the PMHS foot in the fixture without compromising the calcaneal surface of the foot.

Another limitation was the image quality of the ultrasound images. In some cases, the peak of the calcaneus was difficult to locate when measuring to the outermost surface of the skin, and so exact thicknesses were difficult to determine in these cases. In order to lessen the effect of this challenge, multiple measurements were taken for each loading magnitude, and averages were taken of these measurements excluding the maximum and minimum values.

4.4.8 Conclusions

Comparing to the thickness and stiffness results, it was shown that after death the heel pad becomes less thick, stiffer, and less compressible overall, indicating changes in all properties after death and suggesting that PMHS are not exact surrogates for living populations in regard to soft tissue characteristics. These changes in the soft tissues of the heel pad are most likely due to dehydration that occurs in the soft tissues of PMHS after death. Considering these postmortem changes, in lower extremity studies involving soft tissue analysis, these differences in heel pad characteristics between PMHS and living populations should be considered when selecting and modifying materials in the process of developing safety devices such as ATDs and military footwear.

Chapter 5: Conclusions

Using methods from existing anthropometric studies done on the feet of living people, a holistic procedure for anthropometric foot measurement was developed which encompasses measurements across literature. It was found that PMHS foot anthropometry agreed with living populations in most cases, and there were found to be significant differences between seated and standing positions as well as between males and females for foot anthropometry. This means that as long as sex differences (for example, refraining from using males to represent females) and positional differences (for example, adding weight to the lower extremity of a PMHS to test for a standing scenario) are accounted for, PMHS can be used as accurate representation of living people in foot anthropometry.

Differences between anthropometric and radiographic measurements were found for the measurement of the height of the navicular's inferior medial border, but there were no significant differences found for the measurement of talar head height. This indicates that anthropometry alone is sufficient for some landmarks, but for others x-ray imaging might be necessary. Further measurement of other foot landmarks will need to be investigated using both anthropometry and radiography to determine whether both methods are necessary for complete measurement of landmarks.

No sex differences were found in heel pad thickness, stiffness, or compressibility. Differences were not found between left and right heel pad thicknesses and compressibility, but there was a significant difference between left and right stiffness. Regarding PMHS heel properties compared to those of living populations, thickness, stiffness, and compressibility were all found to be significantly different between PMHS and living population values. PMHS were found to have thinner, stiffer, and less compressible heel pads than those of living people.

In total, PMHS serve well as surrogates for living people in regard to foot anthropometry given that position and sex differences are accounted for. In determining foot anthropometry for PMHS feet in lower extremity testing, anthropometry may sometimes need to be supplemented with radiographic measurement depending on the landmarks of interest. For heel pad properties, PMHS are not fully representative of living populations regarding thickness, stiffness, or compressibility, and differences between the two, as quantified in this thesis, must be considered for lower extremity testing of PMHS.

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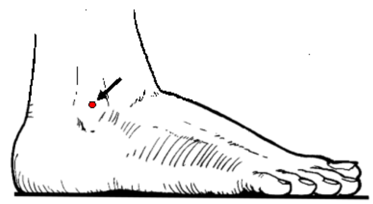
Appendix A: Anatomical Landmarks of the Foot

Adapted from Hotzman et al. (2011)

<table>
<tr><td>LATERAL MALLEOLUS</td><td></td></tr>
<tr><td>DESCRIPTION: The most lateral point of the lateral malleolus (the ankle bone on the outside of the foot).

PROCEDURE: Subject stands on the tilt table with the weight distributed equally on both feet. Use a marking block to locate the protruding point on the lateral malleolus. Draw a cross (+) through the point.

REQUIRED INSTRUMENTS: Marking block

CAUTION: This landmark can be on a vein.</td><td></td></tr>
</table>

<table>
<tr><td>MEDIAL MALLEOLUS</td><td></td></tr>
<tr><td>DESCRIPTION: The most prominent point of the medial malleolus (the ankle bone on the inside of the foot).

PROCEDURE: Subject stands on the tilt table with the weight distributed equally on both feet. Use a marking block to locate the protruding point on the medial malleolus. Draw a cross (+) through the point.

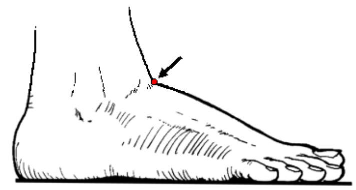
REQUIRED INSTRUMENTS: Marking block

NOTE: The medial and lateral malleoli are rarely at the same height above the floor and should be landmarked independently with no regard to the height of the other.</td><td></td></tr>
</table>

DORSAL JUNCTURE OF THE FOOT AND LEG

DESCRIPTION: The top of a skin crease between the foot and the front of the ankle when the knees and ankles are flexed about 30°

PROCEDURE: Preform flexion and extension on the subject's foot so that a distinct skin crease is visible at the top of the foot at its juncture with the ankle. Locate the top of the deepest and longest crease by inspection. Draw a short horizontal line through the point.



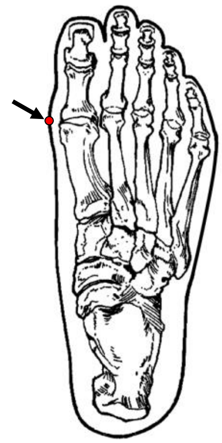
FIRST METATARSOPHALANGEAL PROTRUSION

DESCRIPTION: The most medial protrusion of the right foot in the region of the first metatarsophalangeal joint.

PROCEDURE: Subject stands on the tilt table with the weight distributed equally on both feet. Stand in front of the subject and, by inspection, locate the maximum protrusion of the inside of the foot near the big toe. If the maximum protrusion covers an area larger than a point, use a marking block. The landmark is at the midpoint of the surface that is in contact with the block. Draw a short vertical line through the landmark.

REQUIRED INSTRUMENTS: Marking block

CAUTION: On some subjects the big toe will splay out. This should be ignored. Be sure the mark is placed on or near the joint on the end of the foot and not on the toe.

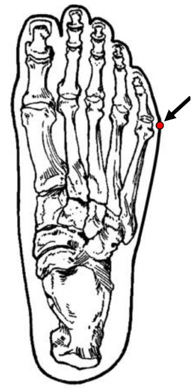


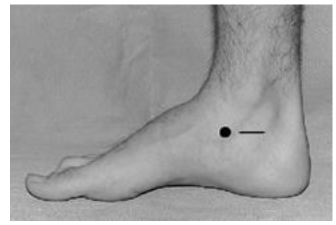
FIFTH METATARSOPHALANGEAL PROTRUSION

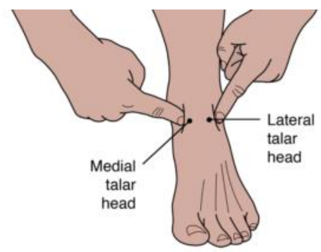
DESCRIPTION: The most lateral protrusion of the right foot in the region of the fifth metatarsophalangeal joint.

PROCEDURE: Subject stands on the tilt table with the weight distributed equally on both feet. Stand in front of the participant and, by inspection, locate the maximum protrusion on the outside of the foot near the little toe. If the maximum protrusion is not clearly defined, use a marking block. The landmark is at the midpoint of the surface that is in contact with the block. Draw a short vertical line through the landmark.

REQUIRED INSTRUMENTS: Marking block



NAVICULAR TUBEROSITY	
DESCRIPTION: The most prominent point of the medial navicular tuberosity. PROCEDURE: Foot is in an unladen posture. Locate the inferior margin of the medial malleolus. Palpate inferior/anterior approximately 2.5 cm to locate the raised bony prominence of the navicular. Draw a cross (+) through the point. Draw a circle delineating the navicular from the surrounding structures. From: https://youtu.be/jjeOx7rYz4Q NOTE: The navicular extends laterally as far as the 3rd metatarsals. CAUTION: The navicular tuberosity may be difficult to locate in some subjects.	

HEAD OF TALUS	
DESCRIPTION: The lowest palpable medial projection of the head of the talus. PROCEDURE: Foot is in an unladen posture. Locate your thumb on the medial and your finger on the lateral malleolus move anterior until you can feel a dip under your finger. Slightly plantarflex the foot until you can palpate the head of the talus. Draw a cross (+) through the point. From: https://youtu.be/LQKv7X6keko NOTE: The navicular tuberosity may be difficult to locate in some subjects.	

Appendix B: Lower Extremity Measurements

BIMALLEOLAR BREADTH

Elderly:	*General (cm):*	*Soldier (cm):*
	7.5 +/- 0.4 6.7 +/- 0.3	7.5 +/- 0.4 6.7 +/- 0.3

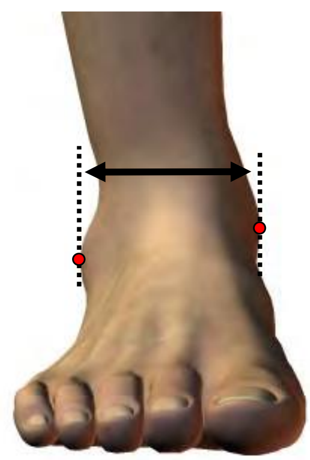
DESCRIPTION: The horizontal distance between the maximum protrusions of the ankle bones (lateral and medial malleoli) on the right foot.

DRAWN LANDMARK: Lateral malleolus, right.

UNDRAWN LANDMARK: Medial malleolus.

PROCEDURE: Attach the slide on blocked to the calipers and zero the calipers. The feet are about 10 cm apart with the toes pointing forward. Stand behind the subject and use a caliper to measure the horizontal distance between the maximum protrusions of the ankle bones (lateral and medial malleoli) of the right foot. Make sure that the calipers are level and not angled when measuring. Holding the fixed blade of the caliper parallel to the long axis of the foot, place it on the medial malleolus. Hold the beam of the caliper parallel to the floor. Both blades of the instrument should just touch the skin.

INSTRUMENT: Calipers/Caliper attachments.



HEEL BREADTH

Elderly:	General (cm):	Soldier (cm):
	7.3 +/- 0.5 M 6.7 +/- 0.5 F	7.2 +/- 0.5 M 6.7 +/- 0.5 F

DESCRIPTION: The maximum horizontal distance between the medial and lateral points on the inside and outside of the right heel, at or posterior to the lateral malleolus landmark.

UNDRAWN LANDMARKS: Heel point, lateral and medial.

PROCEDURE: The feet are spread apart about 10 cm and are parallel. Slide the caliper attachments down to increase the length of the blades and zero the caliper once the desired length is reached. Measure from behind the subject and use a caliper to measure the maximum horizontal distance between the medial and lateral points on the inside and outside of the heel. The measurement is taken just above the level of the table at the most protruding points of the curvature of the heel. Hold the caliper so that the fixed blade is on the medial heel point on the inside of the heel and parallel to the medial side of the foot. Exert only enough pressure to ensure that the caliper blades are on the heel points.

INSTRUMENT: Caliper. Caliper Attachments

CAUTION: Some subjects will not exhibit medial and lateral heel points. For these participants, measure the breadth of the heel at the level of the most protruding point of the lateral malleolus.

LATERAL MALLEOLUS HEIGHT

Elderly:	*General (cm):*	*Soldier (cm):*
	34.3 +/- 1.7 M 31.0 +/- 1.5 F	34.2 +/- 1.3 M 31.0 +/- 1.5 F

DESCRIPTION: The vertical distance between a standing surface and the lateral malleolus landmark.

DRAWN LANDMARK: Lateral malleolus, right

PROCEDURE: Subject is sitting in the seat fixture with the weight distributed equally on both feet. Stand at the right of the subject and use a height gauge to measure the vertical distance between the standing surface and the drawn lateral malleolus landmark on the outside of the right ankle.

INSTRUMENT: Height gauge

CAUTION: The measurer's eyes must be at the level of the blade or the gauge.

MEDIAL MALLEOLUS HEIGHT		
Elderly:	*General (cm):* 34.3 +/- 1.7 M 31.0 +/- 1.5 F	*Soldier (cm):* 34.2 +/- 1.3 M 31.0 +/- 1.5 F

DESCRIPTION: The vertical distance between a standing surface and the medial malleolus landmark.

DRAWN LANDMARK: Medial malleolus, right

PROCEDURE: Subject is sitting in the seat fixture with weight distributed equally on both feet. Stand at the right of the subject and use a height gauge to measure the vertical distance between the standing surface and the drawn medial malleolus landmark on the inside of the right ankle.

INSTRUMENT: Height gauge

CAUTION: The measurer's eyes must be at the level of the blade or the gauge.

NAVICULAR HEIGHT, MEDIAL PROMINENCE		
Elderly (cm): 26.5 +/- 9.1	*General:*	*Soldier:*

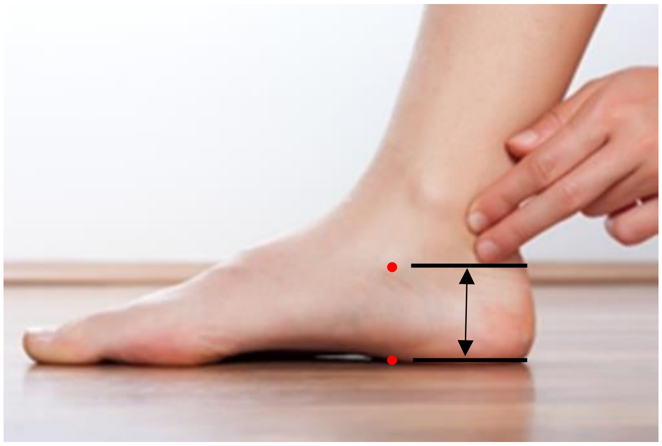
DESCRIPTION: The height from the most medial prominence of the unloaded navicular to the standing surface.

DRAWN LANDMARK: Navicular tuberosity.

PROCEDURE: Subject is seated in the seat fixture. Measure the vertical distance between the standing surface and the most medial prominence of the palpated navicular bone.

INSTRUMENT: Height gauge

CAUTION: Ensure the foot and ankle maintain a neutral posture prior to taking measurements.



NAVICULAR HEIGHT, INFERIOR-MEDIAL BORDER		
Elderly:	*General (cm):* 39.7 +/- 5.6	*Soldier (cm):* 1.6 +/- 7.7 M 36.4 +/- 7.3 F

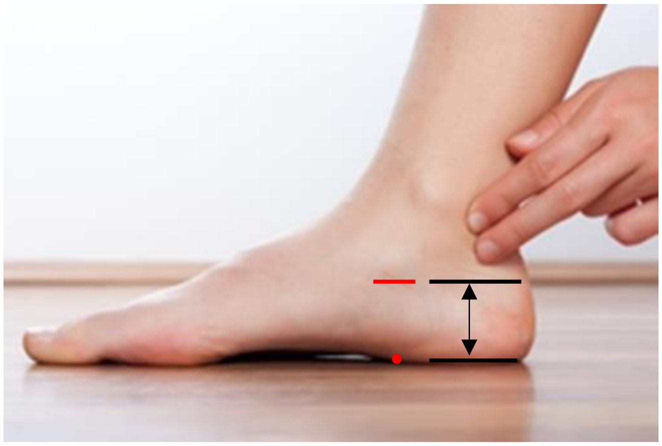
DESCRIPTION: The height from the most inferior-medial border of the unloaded navicular to the standing surface.

DRAWN LANDMARK: Navicular tuberosity.

PROCEDURE: Subject is seated in the seat fixture. Measure the vertical distance between the standing surface and the most inferior-medial border of the palpated navicular.

INSTRUMENT: Height gauge

CAUTION: Ensure the foot and ankle maintain a neutral posture prior to taking measurements.



TALAR HEAD HEIGHT,		
Elderly:	*General:*	*Soldier:*
DESCRIPTION: The height from the lowest palpable medial projection of the unloaded talar head to the standing surface. DRAWN LANDMARK: Head of talus. PROCEDURE: Subject is seated in the seat fixture. Measure the vertical distance between the standing surface and the lowest palpable midline protrusion of the head of the talus when palpated anteriorly. INSTRUMENT: Height gauge CAUTION: Ensure the foot and ankle maintain a neutral posture prior to taking measurements.		

PLANTAR CURVATURE HEIGHT,		
Elderly:	*General (cm):* 11.6 +/- 3.5 (loaded)	*Soldier:*

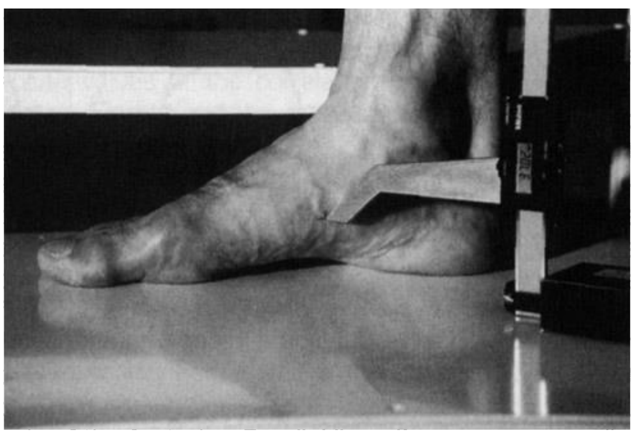
DESCRIPTION: The height from the highest point along the soft tissue margin of the unloaded medial plantar curvature to the standing surface.

UNDRAWN LANDMARK: Soft tissue margin of medial plantar curvature.

PROCEDURE: Subject is seated in the seat fixture. Using the height gauge, determine the highest point along the soft tissue margin of the medial plantar curvature. Measure the vertical distance between this point using light contact of the caliper branch on the skin to the standing surface.

INSTRUMENT: Height gauge

CAUTION: Ensure the foot and ankle maintain a neutral posture prior to taking measurements.



FOOT LENGTH, ACROPODION

Elderly (cm):	*General (cm):*	*Soldier (cm):*
24.2-27.3	25.0 +/- 2.3 M 23.5 +/- 1.2 F	28.4-25.6 M 26.4-22.4 F

DESCRIPTION: The maximum length of the foot.

UNDRAWN LANDMARKS: Acropodion.

PROCEDURE: Subject is seated in the seat fixture. Place the heel of the foot into the appropriate JAKTool heel slot. Take the 1st MET Block and align the silver marking to the 1st metatarsal joint. Slide the foot length bar until it gently touches the longest toe. If necessary, cut toenails if the Jaktool is not flush with the skin of the toe. Record the value from the silver indicating line.

INSTRUMENTS: Jaktool

CAUTION: Be sure the foot is correctly positioned before taking the measurement.

FOOT LENGTH, HALLUX

Elderly (cm):	*General (cm):*	*Soldier (cm):*
24.2-27.3	26.4 +/- 1.7 M 23.7 +/- 1.5 F	26.8 +/- 1.4 M 24.4 +/- 1.4 F

DESCRIPTION: The length of the foot from the heel to the first toe.

UNDRAWN LANDMARKS: Hallux.

PROCEDURE: Subject is seated in the seat fixture. Place the heel of the foot into the appropriate JAKTool heel slot. Take the 1st MET Block and align the silver marking to the 1st metatarsal joint. Slide the foot length bar until it gently touches the first toe. Move the longest toe out of the way if needed. If necessary, cut toenails if the Jaktool is not flush with the skin of the toe. Record the value from the silver indicating line.

INSTRUMENTS: Jaktool

CAUTION: Be sure the foot is correctly positioned before taking the measurement.

NOTE: This measurement may be the same as FOOT LENGTH, ACROPODION if the first toe is also the longest toe.

BALL OF FOOT LENGTH/ TRUNCATED FOOT LENGTH		
Elderly:	*General (cm):* 20.1 +/- 1.0 M 18.2 +/- 1.0 F (Brannock)	*Soldier (cm):* 19.7-21.2 M 16.8-19.2 F (Brannock)

DESCRIPTION: The distance from the back of the heel (pterion) to the landmark at the first metatarsophalangeal protrusion on the ball of the right foot.

DRAWN LANDMARK: First metatarsophalangeal protrusion, right.

PROCEDURE: Subject is seated in the seat fixture. Slide the heel into the heel slot of the JAKTool. Slide the 1st MET Block until the silver marking aligns with 1st metatarsal joint and the first metatarsophalangeal protrusion landmark. Record the value.

INSTRUMENT: JAKTool

FOOT BREADTH, HORIZONTAL

Elderly:	*General (cm):*	*Soldier (cm):*
	10.2 +/- 0.5M 9.3 +/- 0.5 F	10.2 +/- 0.5 M 9.3 +/- 0.5 F

DESCRIPTION: The maximum breadth of the right foot.

DRAWN LANDMARKS: First metatarsophalangeal protrusion, right; fifth metatarsophalangeal protrusion, right.

PROCEDURE: Subject is seated in the seat fixture. Place the heel of the foot into the appropriate JAKTool heel slot. Take the 1st MET Block and align the silver marking to the 1st metatarsal joint. Slide the foot length bar until it gently touches the longest toe. Finally slide the foot breadth bar to the widest point or the 5th metatarsophalangeal protrusion and record the value at the gold indicator line of that bar.

INSTRUMENTS: JAKTool

CAUTION: Be sure the foot is correctly positioned before taking the measurement

DORSUM HEIGHT, SEATED

Elderly:	*Genera (cm)l:* 7.91 +/ 0.53 M 7.17 +/- 0.52 F	*Soldier:*

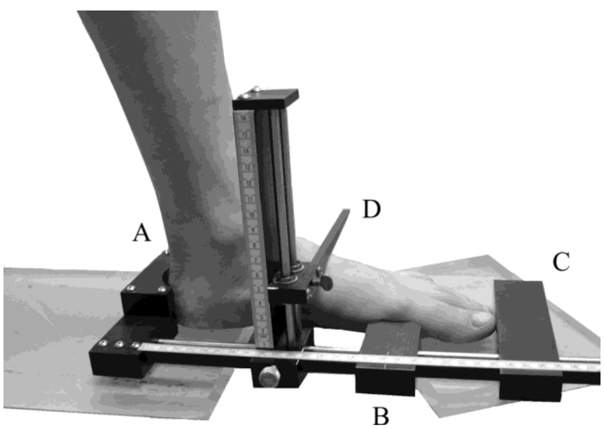
DESCRIPTION: The vertical distance from the standing surface to the unloaded top of the foot at 50% total (acropodion) foot length.

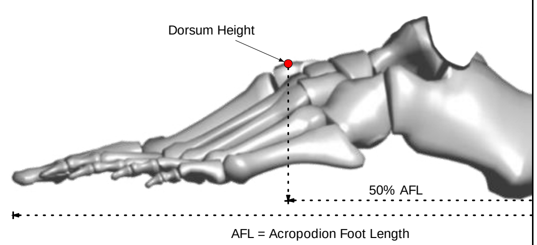
UNDRAWN LANDMARK: 50% total (acropodion) foot length.

PROCEDURE: Subject is seated in the seat fixture. Slide the heel into the heel slot of the JAKTool. Calculate 1/2 of the Total Foot Length. Slide the Arch Height Tower until the silver line reaches half of the calculated Total Foot Length. Release the Dorsum Bar and all is to slide downward and gently rest on the superior surface of the subject’s foot. Record the value of the silver indicating line.

INSTRUMENT: Jaktool.

CAUTION: Ensure the foot and ankle maintain a neutral posture prior to taking measurements.





Appendix C: Anthropometry Measurements

Table 17: Seated Anthropometric Data

Seated Measurements (mm)														
Subject	**Sex**	**Se vs St**	**L BiMall Breadth**	**R BiMall Breadth**	**L Heel Breadth**	**R Heel Breadth**	**L Nav Height MP**	**R Nav Height MP**	**L Nav Height IB**	**R Nav Height IB**	**L Talar**	**R Talar**	**L Plant Curv**	**R Plant Curv**
8164	M	Seated	80.64	79.19	73.68	72.72	35.65	34.93	44.52	39.99	80.92	75.54	9.17	10.90
8171	M	Seated	69.95	69.78	69.28	67.22	52.49	63.98	46.23	57.39	92.68	98.06	27.77	30.32
8177	M	Seated	68.03	66.19	62.01	63.54	47.79	49.33	45.31	44.58	79.69	82.56	30.49	28.52
8186	F	Seated	63.12	63.40	50.43	53.09	43.15	45.96	35.97	39.71	76.27	77.70	20.46	18.41
8217	F	Seated	61.46	64.01	57.17	57.68	33.92	30.34	29.10	29.75	73.91	73.31	20.47	21.54
8239	M	Seated	69.20	66.75	67.88	67.50	55.53	50.48	49.67	47.51	85.62	84.95	25.90	26.70
8251	F	Seated	60.52	58.98	53.82	55.32	32.40	40.92	30.26	34.95	73.57	76.61	17.55	19.97
8256	M	Seated	74.50	77.74	64.90	65.66	42.44	42.82	36.74	37.75	82.76	84.16	12.60	19.43
8270	M	Seated	72.51	72.74	65.47	65.97	46.77	43.25	42.90	38.83	82.63	84.77	12.30	10.36
8311	F	Seated	72.84	73.23	64.24	64.28	45.31	40.23	41.62	36.70	79.44	76.92	17.80	17.36
8323	M	Seated	72.96	74.70	52.46	55.43	37.62	18.79	32.91	16.34	81.90	81.96	14.99	7.11

Continued

Table 17 continued

8339	M	Seated	78.92	72.55	82.21	82.49	32.50	26.74	29.19	24.50	73.95	71.90	12.49	8.54
8344	M	Seated	74.49	71.13	57.79	58.72	45.09	43.51	39.85	37.78	82.10	83.12	14.92	16.12
8367	M	Seated	70.98	68.16	58.57	57.75	45.91	44.31	42.17	40.67	84.02	84.41	19.60	20.34
8371	M	Seated	70.45	69.94	62.53	63.48	48.82	52.96	45.29	46.99	77.15	83.10	18.85	25.63
8379	F	Seated	62.78	61.37	56.68	52.58	40.19	40.09	36.13	34.86	71.87	72.53	20.79	21.15
8402	M	Seated	73.97	71.46	68.18	60.57	36.78	39.37	30.64	35.00	73.64	76.36	12.73	11.90
8409	M	Seated	66.23	66.03	65.69	66.81	36.17	36.65	31.29	31.91	74.07	77.87	14.07	13.66
8423	M	Seated	74.08	71.42	71.86	73.58	52.13	59.91	45.61	54.04	96.47	93.46	17.50	21.09
8425	F	Seated	68.50	64.12	63.20	60.04	46.50	44.23	44.39	40.62	76.71	75.86	13.98	12.78
8427	M	Seated	64.75	65.45	61.34	60.47	50.95	44.17	46.43	40.62	82.63	77.57	20.18	16.55
8458	M	Seated	70.15	73.41	63.24	64.35	49.69	58.01	38.80	46.36	91.93	95.34	23.61	24.01
8464	M	Seated	78.19	77.70	65.06	67.49	48.35	52.36	40.85	42.09	82.49	88.09	20.75	21.16
8470	F	Seated	67.89	65.74	67.01	58.60	33.28	36.71	25.26	26.17	58.01	64.04	13.74	19.62
8483	M	Seated	77.58	77.86	60.88	60.77	49.74	53.91	43.22	46.00	84.54	84.59	19.24	25.85
8486	F	Seated	64.39	64.14	55.64	55.31	41.39	38.28	32.74	31.39	73.91	76.08	21.17	16.41
8518	M	Seated	67.44	67.29	61.53	63.62	56.85	56.92	48.36	46.65	79.30	83.50	21.44	25.79
8520	M	Seated	69.47	68.33	57.47	59.33	48.47	44.52	41.37	38.01	84.98	86.82	19.29	19.39
8533	M	Seated	71.17	73.08	56.64	58.85	58.31	47.61	45.94	38.39	93.09	87.18	22.91	14.19
8545	M	Seated	70.77	71.11	61.15	63.01	47.78	47.33	37.59	39.33	85.69	84.34	20.25	18.48
8577	M	Seated	74.92	73.89	59.91	63.65	49.53	49.63	39.02	39.13	83.97	83.33	17.95	19.67
8580	F	Seated	62.13	62.83	62.64	58.05	34.29	51.01	29.96	43.77	60.73	73.14	20.81	26.39
8582	F	Seated	64.77	62.23	59.17	59.43	42.13	37.92	39.56	29.81	73.43	70.61	18.95	17.63
8615	F	Seated	67.09	59.82	59.82	57.06	33.70	42.92	24.68	28.79	68.22	61.03	8.62	18.79
8620	F	Seated	65.48	62.73	52.25	53.78	33.29	38.94	26.71	32.37	70.06	74.64	16.62	17.45
8631	M	Seated	73.45	74.45	62.86	64.16	34.02	39.48	26.72	29.87	75.21	80.63	13.97	10.55

Continued

Table 17 continued

8655	M	Seated	79.29	82.44	71.13	70.14	49.86	39.41	36.57	31.38	83.23	79.65	14.50	13.07
Averages			**70.14**	**69.33**	**62.32**	**62.23**	**43.75**	**44.00**	**37.93**	**37.84**	**79.21**	**80.15**	**18.07**	**18.56**
Averages (L&R)			**69.74**		**62.27**		**43.87**		**37.89**		**79.68**		**18.31**	

Table 17 continued

Subject	Sex	Se vs St	L Lat Mall Height	R Lat Mall Height	L Med Mall	R Med Mall	L Acro Length	R Acro Length	L Hallux Length	R Hallux Length	L Foot Breadth	R Foot Breadth	L Ball Length	R Ball Length
8164	M	Seated					278.50	273.50	278.50	270.00	97.00	96.00	207.00	210.00
8171	M	Seated					255.50	245.50	255.50	245.50	92.00	98.00	189.50	186.00
8177	M	Seated	72.00	69.95	86.82	79.32	256.60	261.50	256.50	261.50	91.00	89.00	193.00	198.00
8186	F	Seated	66.45	62.87	80.24	79.96	234.50	234.00	234.50	234.00	80.00	79.00	179.00	173.00
8217	F	Seated	63.48	57.23	74.96	71.08	246.00	236.00	246.00	236.00	80.50	83.00	183.50	176.50
8239	M	Seated	79.07	84.24	87.98	91.74	265.00	264.00	265.00	264.00	89.00	91.50	184.00	200.00
8251	F	Seated	65.11	61.88	83.08	80.43	226.00	224.50	226.00	224.50	81.00	88.00	165.00	162.00
8256	M	Seated	72.72	72.16	91.81	89.74	276.50	260.00	276.50	249.90	99.00	95.00	210.00	182.00
8270	M	Seated	63.42	67.12	86.32	85.90	251.00	250.00	251.00	250.00	94.50	97.00	178.00	183.00
8311	F	Seated	64.46	66.25	79.99	79.03	226.00	230.00	226.00	230.00	91.00	90.00	161.00	162.00
8323	M	Seated	70.96	70.55	86.00	76.67	260.50	265.00	260.50	265.00	98.00	96.00	197.00	198.00
8339	M	Seated	72.51	74.84	81.94	80.94	261.00	263.00	261.00	263.00	103.00	106.00	191.00	187.00
8344	M	Seated	72.82	86.37	94.17	101.38	263.00	267.00	263.00	267.00	97.00	99.00	187.00	191.00
8367	M	Seated	73.86	77.41	92.51	90.20	270.00	267.00	270.00	267.00	92.00	95.00	198.00	201.00
8371	M	Seated	73.15	75.32	89.38	85.27	250.00	244.00	250.00	244.00	93.00	93.00	185.00	176.00
8379	F	Seated	62.82	62.05	74.13	74.93	253.00	249.00	253.00	246.00	85.00	84.00	192.00	184.00
8402	M	Seated	64.54	63.90	75.52	76.29	252.00	249.00	252.00	249.00	92.00	94.00	177.00	179.00
8409	M	Seated	67.69	67.42	78.07	80.94	266.00	267.00	263.00	265.00	94.00	94.00	195.00	194.00
8423	M	Seated	92.20	93.45	96.24	98.88	272.00	244.00	272.00	244.00	97.00	96.00	196.00	184.00

Continued

Table 17 continued

8425	F	Seated	63.09	65.52	79.74	78.65	248.00	244.00	248.00	244.00	91.00	83.00	182.00	183.00
8427	M	Seated	70.24	69.86	83.84	79.06	253.00	261.00	253.00	261.00	91.00	93.00	182.00	186.00
8458	M	Seated	82.14	84.10	87.39	88.01	272.00	275.00	272.00	275.00	93.00	93.00	202.00	201.00
8464	M	Seated	70.60	75.47	81.09	92.76	257.00	253.00	257.00	253.00	98.00	97.00	190.00	187.00
8470	F	Seated	57.33	58.17	76.24	70.88	220.00	221.00	220.00	221.00	82.00	87.00	163.00	165.00
8483	M	Seated	79.87	80.19	93.36	89.38	264.00	262.00	264.00	262.00	92.00	94.00	199.00	196.00
8486	F	Seated	61.18	64.97	78.64	79.84	241.00	238.00	241.00	238.00	90.00	87.00	138.00	137.00
8518	M	Seated	76.92	74.83	90.38	79.73	256.00	251.00	256.00	251.00	107.00	96.00	173.00	171.00
8520	M	Seated	69.41	71.53	86.83	87.47	252.00	253.00	252.00	249.00	93.00	93.00	184.00	185.00
8533	M	Seated	77.51	66.44	98.75	85.58	255.00	255.00	255.00	255.00	93.00	91.00	184.00	183.00
8545	M	Seated	76.86	79.43	95.87	91.23	269.00	269.00	269.00	269.00	95.00	95.00	195.00	198.00
8577	M	Seated	70.85	69.89	87.47	89.59	265.00	263.00	262.00	263.00	89.00	90.00	200.00	198.00
8580	F	Seated	69.91	70.02	74.57	80.86	227.00	221.00	227.00	221.00	79.00	82.00	163.00	157.00
8582	F	Seated	63.39	65.23	80.01	73.33	250.00	245.00	250.00	245.00	79.00	78.00	187.00	188.00
8615	F	Seated	59.34	60.77	65.28	75.79	224.00	222.00	224.00	222.00	79.00	82.00	166.00	164.00
8620	F	Seated	61.59	61.46	73.48	74.08	226.00	228.00	226.00	228.00	77.00	78.50	167.00	170.00
8631	M	Seated	76.06	80.80	83.38	83.77	278.00	276.00	278.00	276.00	91.00	95.00	212.00	210.00
8655	M	Seated	71.77	60.83	86.15	88.48	272.00	278.00	272.00	278.00	92.00	92.00	21.00	22.00
Averages			**70.15**	**70.64**	**84.05**	**83.18**	**253.84**	**251.59**	**253.68**	**250.98**	**90.73**	**91.08**	**180.43**	**179.12**
Averages (L&R)			**70.40**		**83.61**		**252.72**		**252.33**		**90.91**		**179.78**	

Continued

Table 17 continued

Subject	Sex	Se vs St	L Dorsum Height	R Dorsum Height
8164	M	Seated	91.00	98.00
8171	M	Seated	69.00	74.00
8177	M	Seated	71.00	68.50
8186	F	Seated	58.50	59.00
8217	F	Seated	55.50	59.50
8239	M	Seated	79.00	77.00
8251	F	Seated	59.00	61.00
8256	M	Seated	64.00	67.00
8270	M	Seated	68.00	66.00
8311	F	Seated	64.00	67.00
8323	M	Seated	60.00	56.00
8339	M	Seated	59.00	63.00
8344	M	Seated	67.00	69.00
8367	M	Seated	68.00	61.00
8371	M	Seated	68.00	71.00
8379	F	Seated	57.00	57.00
8402	M	Seated	61.00	64.00
8409	M	Seated	64.00	63.00
8423	M	Seated	69.00	83.00

Continued

Table 17 continued

8425	F	Seated	62.00	64.00
8427	M	Seated	68.00	65.00
8458	M	Seated	68.00	69.00
8464	M	Seated	73.00	72.00
8470	F	Seated	55.00	51.00
8483	M	Seated	68.00	71.00
8486	F	Seated	59.00	57.00
8518	M	Seated	65.00	74.00
8520	M	Seated	69.00	68.00
8533	M	Seated	74.00	71.00
8545	M	Seated	68.00	64.00
8577	M	Seated	65.50	64.00
8580	F	Seated	58.00	65.00
8582	F	Seated	58.00	53.50
8615	F	Seated	54.00	51.00
8620	F	Seated	52.00	59.00
8631	M	Seated	61.00	62.00
8655	M	Seated	69.00	67.00
Averages			**64.82**	**65.72**
Averages (L&R)			**65.27**	

Table 18: Standing Anthropometric Measurements

Standing Measurements (mm)														
Subject	**Sex**	**Se vs St**	**L BiMall Breadth**	**R BiMall Breadth**	**L Heel Breadth**	**R Heel Breadth**	**L Nav Height MP**	**R Nav Height MP**	**L Nav Height IB**	**R Nav Height IB**	**L Talar**	**R Talar**	**L Plant Curv**	**R Plant Curv**
8164	M	Standing					39.59	44.71	28.67	32.24	80.26	78.07	10.20	9.49
8171	M	Standing			70.56	75.17	52.55	62.08	45.85	57.78	92.22	89.41	29.57	29.76
8177	M	Standing	66.78	68.47	67.10	65.55	46.76	49.01	35.43	45.25	76.33	75.47	23.98	25.04
8186	F	Standing	64.72	64.08	57.31	57.09	33.73	37.91	26.38	30.24	71.84	72.32	13.90	15.41
8217	F	Standing	63.13	64.33	61.19	74.46	30.02	24.99	25.50	21.46	68.28	67.03	12.16	10.74
8239	M	Standing	69.62	68.29	79.33	69.76	65.61	48.13	63.87	45.70	83.39	78.46	35.26	26.69
8251	F	Standing	60.13	57.93	63.27	58.05	39.64	45.56	34.77	40.50	72.60	74.19	21.44	18.34
8256	M	Standing	78.16	75.59	73.88	68.80	38.17	41.79	34.83	37.54	79.70	81.51	13.40	18.58
8270	M	Standing	69.40	69.58	57.77	56.83	43.28	36.67	40.35	35.58	81.82	78.29	11.54	10.25
8311	F	Standing	69.72	73.92	66.67	66.66	42.96	36.52	36.24	30.74	79.52	72.95	14.44	11.19
8323	M	Standing	73.51	72.68	63.47	63.70	27.63	7.94	22.24	6.95	74.14	69.54	6.88	1.22
8339	M	Standing	82.09	81.17	92.77	94.52	26.95	22.89	23.10	19.77	64.67	70.77	6.37	7.29
8344	M	Standing	69.74	66.82	68.93	66.35	43.83	41.75	38.86	37.38	80.93	81.37	14.37	14.97
8367	M	Standing	71.89	73.23	68.11	70.82	42.05	38.83	38.37	35.68	77.67	79.24	14.45	15.96
8371	M	Standing	68.03	70.01	74.96	71.27	46.44	51.25	43.64	46.63	78.58	80.55	19.40	25.00
8379	F	Standing	64.99	62.97	60.02	56.15	34.36	32.41	30.57	28.85	65.75	67.69	15.16	14.40
8402	M	Standing	71.44	72.39	67.44	64.49	34.89	36.12	28.77	33.93	73.89	75.80	10.84	11.91
8409	M	Standing	66.76	68.06	70.99	72.70	35.45	36.48	30.88	31.70	73.83	78.01	13.76	13.25
8423	M	Standing	71.21	71.01	80.69	72.31	54.37	65.69	49.96	62.11	87.36	92.82	20.66	21.49
8425	F	Standing	69.60	65.32	67.04	69.24	41.56	35.88	38.47	32.16	75.51	73.51	9.29	9.63

Continued

Table 18 continued

8427	M	Standing	66.34	67.54	63.12	63.10	50.42	45.00	43.57	39.58	80.13	84.81	16.44	18.28
8458	M	Standing	75.17	74.51	83.28	79.00	44.71	40.35	33.89	30.11	81.99	86.38	15.71	8.63
8464	M	Standing	81.80	79.06	66.99	76.41	45.13	44.79	36.23	34.86	74.06	80.42	19.54	14.35
8470	F	Standing	72.09	68.28	68.17	68.57	30.22	24.35	21.64	19.46	51.79	51.64	8.45	8.46
8483	M	Standing	74.93	77.41	63.07	67.02	49.19	47.86	37.58	42.32	82.83	84.08	14.69	16.96
8486	F	Standing	65.50	63.24	54.92	57.65	34.27	38.62	29.21	32.52	71.29	74.82	15.50	13.40
8518	M	Standing	71.36	66.92	68.50	68.12	55.33	65.67	47.63	55.27	71.02	82.11	18.69	28.90
8520	M	Standing	70.67	72.26	61.20	60.50	43.80	40.90	32.00	35.42	76.01	81.16	17.15	16.97
8533	M	Standing	70.89	74.57	63.59	67.12	52.75	52.36	42.57	41.41	85.48	82.50	17.86	17.36
8545	M	Standing	77.18	75.17	65.25	64.66	46.82	45.01	34.41	36.78	81.00	79.16	18.76	15.10
8577	M	Standing	69.37	72.83	65.31	67.38	44.18	47.69	35.29	38.46	82.34	82.31	19.10	21.62
8580	F	Standing	63.83	65.43	72.79	70.55	28.13	36.22	21.53	28.24	64.10	68.66	13.45	12.97
8582	F	Standing	62.98	63.77	63.35	68.45	38.06	32.52	27.89	23.26	71.06	68.02	18.03	14.41
8615	F	Standing	63.18	61.29	63.09	66.24	33.52	41.51	23.40	27.27	66.85	70.12	10.49	15.83
8620	F	Standing	65.89	64.40	55.27	57.33	35.78	32.07	28.44	26.17	71.38	69.53	15.37	13.18
8631	M	Standing	73.84	71.52	66.81	67.31	35.29	35.62	24.91	29.65	73.02	78.81	11.35	11.66
8655	M	Standing	83.88	77.22	71.55	78.50	45.27	33.75	32.70	23.34	77.09	71.86	11.56	9.54
Averages			**70.28**	**69.75**	**67.44**	**67.83**	**41.42**	**40.56**	**34.31**	**34.49**	**75.67**	**76.58**	**15.65**	**15.36**
Averages (L&R)			**70.02**		**67.63**		**40.99**		**34.40**		**76.12**		**15.51**	

Continued

Table 18 continued

Subject	Sex	Se vs St	L Lat Mall Height	R Lat Mall Height	L Med Mall	R Med Mall	L Acro Length	R Acro Length	L Hallux Length	R Hallux Length	L Foot Breadth	R Foot Breadth	L Ball Length	R Ball Length
8164	M	Standing	47.37	47.90	56.62	66.64	283.00	279.50	283.00	279.50	101.00	100.00	216.00	217.00
8171	M	Standing	71.47	68.75	76.03	84.62	259.50	241.00	259.50	241.00	94.00	98.00	194.00	182.00
8177	M	Standing	70.96	63.38	84.05	80.22	259.50	263.00	259.50	263.00	93.00	93.00	196.00	200.00
8186	F	Standing	60.93	61.31	76.01	74.35	232.50	239.00	232.50	239.00	84.50	82.00	185.00	180.50
8217	F	Standing	59.56	62.63	74.22	67.44	247.00	238.00	247.00	238.00	85.50	84.00	187.50	182.00
8239	M	Standing	68.64	69.45	92.03	85.92	259.50	269.00	259.50	269.00	86.00	94.00	188.00	198.00
8251	F	Standing	64.37	63.21	82.48	85.22	226.00	222.00	226.00	222.00	87.00	84.50	164.50	161.00
8256	M	Standing	66.09	70.67	92.36	93.40	277.00	261.00	277.00	250.00	101.50	97.00	211.00	177.00
8270	M	Standing	61.69	66.17	83.40	81.97	251.00	252.00	251.00	252.00	96.50	97.00	177.00	186.00
8311	F	Standing	67.73	66.37	83.22	78.10	230.00	233.00	230.00	233.00	92.00	92.00	167.00	163.00
8323	M	Standing	65.56	63.40	78.17	70.71	266.00	265.00	266.00	265.00	98.00	101.00	202.00	203.00
8339	M	Standing	68.78	70.32	76.42	80.78	263.00	269.00	263.00	269.00	105.00	107.00	189.00	192.00
8344	M	Standing	69.59	81.20	93.90	98.60	266.00	269.00	266.00	269.00	100.00	103.00	191.00	197.00
8367	M	Standing	70.28	72.15	84.06	84.43	273.00	270.50	273.00	270.50	96.00	97.00	201.00	201.00
8371	M	Standing	71.23	74.55	89.44	86.88	254.00	249.00	254.00	249.00	95.00	92.00	189.00	183.50
8379	F	Standing	61.45	62.66	70.94	70.89	257.00	256.00	257.00	253.00	90.50	90.00	191.00	190.00
8402	M	Standing	63.22	63.09	74.38	76.32	253.00	250.00	253.00	250.00	94.00	94.00	178.00	182.00
8409	M	Standing	67.14	67.25	79.11	80.82	271.00	271.00	267.00	270.00	96.00	99.00	201.00	200.00
8423	M	Standing	93.70	94.05	98.80	99.51	270.00	249.00	270.00	249.00	96.00	98.00	196.00	187.00
8425	F	Standing	61.00	65.36	79.15	78.60	252.00	248.00	252.00	242.00	90.00	85.00	186.00	184.00
8427	M	Standing	72.94	70.78	86.43	87.05	259.00	264.00	259.00	264.00	91.00	92.00	186.00	187.00

Continued

Table 18 continued

8458	M	Standing	75.16	69.67	83.42	81.67	282.00	284.00	282.00	284.00	92.00	93.00	208.00	207.00
8464	M	Standing	68.54	74.17	89.34	82.44	261.00	260.00	261.00	260.00	100.00	100.00	191.00	196.00
8470	F	Standing	54.39	60.15	75.48	69.32	224.00	222.00	224.00	222.00	85.00	88.00	170.00	166.00
8483	M	Standing	73.10	72.63	92.84	90.42	269.00	265.00	269.00	265.00	95.00	97.00	203.00	198.00
8486	F	Standing	65.05	65.34	76.08	81.02	245.00	238.00	245.00	238.00	90.00	88.00	178.00	175.00
8518	M	Standing	72.37	74.99	86.93	83.65	260.00	250.00	260.00	246.00	112.00	91.00	176.00	172.00
8520	M	Standing	65.85	68.31	84.53	87.72	258.00	258.00	258.00	258.00	93.00	94.00	187.00	189.00
8533	M	Standing	72.28	69.90	92.51	91.38	255.00	255.00	255.00	255.00	95.00	93.00	185.00	187.00
8545	M	Standing	70.99	74.25	84.05	91.06	273.00	273.00	273.00	273.00	97.00	98.00	199.50	204.00
8577	M	Standing	69.93	64.34	85.94	90.53	272.00	269.00	262.00	265.00	90.00	90.00	200.00	199.00
8580	F	Standing	63.39	63.47	70.08	71.73	230.50	228.00	230.50	228.00	82.00	82.00	165.00	160.00
8582	F	Standing	62.58	57.04	71.60	70.12	252.00	248.00	252.00	248.00	79.00	79.00	189.00	192.50
8615	F	Standing	58.76	55.00	63.53	71.95	230.00	224.00	230.00	224.00	83.00	88.00	169.00	166.00
8620	F	Standing	62.67	66.72	75.16	73.92	223.00	231.00	223.00	231.00	78.50	82.00	165.00	171.00
8631	M	Standing	75.77	75.43	82.22	83.33	282.00	280.00	282.00	280.00	91.00	96.00	220.00	213.00
8655	M	Standing	64.04	62.67	86.55	91.14	279.00	283.00	279.00	283.00	98.00	100.00	206.00	203.00
Averages			**66.99**	**67.53**	**81.39**	**81.73**	**256.88**	**254.76**	**256.50**	**253.97**	**92.78**	**92.93**	**189.39**	**187.88**
Averages (L&R)			**67.26**		**81.56**		**255.82**		**255.24**		**92.86**		**188.64**	

Continued

Table 18 continued

Subject	Sex	Se vs St	L Dorsum Height	R Dorsum Height
8164	M	Standing		
8171	M	Standing	64.50	74.00
8177	M	Standing	66.00	64.50
8186	F	Standing	53.00	54.00
8217	F	Standing	54.00	54.50
8239	M	Standing	79.50	73.00
8251	F	Standing	56.00	61.00
8256	M	Standing	60.00	64.00
8270	M	Standing	65.50	64.00
8311	F	Standing	65.00	66.00
8323	M	Standing	56.00	52.00
8339	M	Standing		56.00
8344	M	Standing	65.00	67.00
8367	M	Standing	64.00	60.00
8371	M	Standing	66.00	65.00
8379	F	Standing	54.00	52.00
8402	M	Standing	62.00	63.00
8409	M	Standing	59.00	59.00
8423	M	Standing	73.00	79.00
8425	F	Standing	58.00	56.00
8427	M	Standing	67.00	64.00

Continued

Table 18 continued

8458	M	Standing	62.00	59.00
8464	M	Standing	66.00	68.00
8470	F	Standing	51.00	46.00
8483	M	Standing	67.00	73.00
8486	F	Standing	56.00	57.00
8518	M	Standing	57.00	76.00
8520	M	Standing	66.00	66.00
8533	M	Standing	71.00	69.00
8545	M	Standing	64.00	62.00
8577	M	Standing	62.00	61.00
8580	F	Standing	53.00	58.00
8582	F	Standing	54.00	50.00
8615	F	Standing	48.00	54.00
8620	F	Standing	57.00	56.00
8631	M	Standing	59.00	60.00
8655	M	Standing	66.00	62.00
Averages			**61.33**	**61.81**
Averages (L&R)			**61.57**	

Appendix D: Ultrasound Data

Table 19: Raw Thickness Measurements at 0 N (cm)

PMHS	Image:	Calc 0N						
	Measurement:	1st	2nd	3rd	4th	5th	Minimum	Maximum
8285	L	1.621	1.612	1.612	1.612	1.606	1.606	1.621
8285	R	1.247	1.241	1.244	1.236	1.25	1.236	1.25
8295	L	2.039	2.043	2.048	2.039	2.043	2.039	2.048
8295	R	1.72	1.724	1.707	1.72	1.72	1.707	1.724
8299	L	1.127	1.123	1.136	1.123	1.123	1.123	1.136
8299	R	1.374	1.371	1.371	1.368	1.377	1.368	1.377
8390	L	1.175	1.178	1.178	1.178	1.175	1.175	1.178
8390	R	1.353	1.358	1.351	1.347	1.353	1.347	1.358
8409	L	1.517	1.526	1.517	1.534	1.517	1.517	1.534
8409	R	1.517	1.517	1.517	1.513	1.517	1.513	1.517
8423	L	1.431	1.422	1.440	1.440	1.435	1.422	1.44
8423	R	1.316	1.302	1.310	1.313	1.310	1.302	1.316
8425	L	1.048	1.034	1.055	1.055	1.055	1.034	1.055
8425	R	0.972	0.966	0.966	0.966	0.959	0.959	0.972
8427	L	1.013	1.022	1.022	1.022	1.013	1.013	1.022
8427	R	1.026	1.019	1.024	1.024	1.022	1.019	1.026
8435	L	1.302	1.296	1.290	1.293	1.293	1.29	1.302
8435	R	1.463	1.474	1.471	1.468	1.463	1.463	1.474
8451	L	1.408	1.417	1.422	1.422	1.417	1.408	1.422
8451	R	1.338	1.342	1.345	1.333	1.345	1.333	1.345
8458	L	1.339	1.351	1.353	1.342	1.345	1.339	1.353
8458	R	1.188	1.192	1.196	1.192	1.190	1.188	1.196
8464	L	1.256	1.253	1.256	1.259	1.261	1.253	1.261
8464	R	1.678	1.672	1.684	1.678	1.678	1.672	1.684
8470	L	1.779	1.773	1.779	1.776	1.782	1.773	1.782
8470	R	1.193	1.184	1.190	1.178	1.193	1.178	1.193
8477	L	1.388	1.397	1.392	1.39	1.394	1.388	1.397
8477	R	1.402	1.405	1.402	1.405	1.414	1.402	1.414
8483	L	1.203	1.203	1.203	1.198	1.198	1.198	1.203
8483	R	1.374	1.368	1.374	1.371	1.376	1.368	1.376

Continued

Table 19 continued

8486	L	1.002	1.011	1.011	1.004	1.007	1.002	1.011
8486	R	0.976	0.974	0.976	0.981	0.978	0.974	0.981
8493	L	1.537	1.549	1.54	1.537	1.543	1.537	1.549
8493	R	1.642	1.634	1.634	1.638	1.634	1.634	1.642
8494	L	1.177	1.164	1.172	1.173	1.168	1.164	1.177
8494	R	1.388	1.394	1.391	1.391	1.394	1.388	1.394
8507	L	1.402	1.400	1.402	1.394	1.388	1.388	1.402
8507	R	1.184	1.190	1.187	1.178	1.184	1.178	1.19
8518	L	1.767	1.779	1.776	1.759	1.776	1.759	1.779
8518	R	1.267	1.254	1.263	1.267	1.254	1.254	1.267
8520	L	1.259	1.256	1.259	1.25	1.256	1.25	1.259
8520	R	1.599	1.603	1.612	1.608	1.599	1.599	1.612
8531	L	0.892	0.882	0.881	0.892	0.884	0.881	0.892
8531	R	0.902	0.902	0.899	0.882	0.905	0.882	0.905
8545	L	1.155	1.157	1.155	1.159	1.155	1.155	1.159
8545	R	1.158	1.141	1.138	1.132	1.138	1.132	1.158
8577	L	0.845	0.848	0.845	0.851	0.848	0.845	0.851
8577	R	0.833	0.830	0.839	0.831	0.819	0.819	0.839
8580	L	1.282	1.282	1.290	1.287	1.284	1.282	1.29
8580	R	1.592	1.578	1.589	1.598	1.592	1.578	1.598
8582	L	1.41	1.405	1.417	1.411	1.405	1.405	1.417
8582	R	1.25	1.25	1.25	1.25	1.248	1.248	1.25
8615	L	1.922	1.917	1.92	1.92	1.92	1.917	1.922
8615	R	2.147	2.147	2.142	2.151	2.155	2.142	2.155
8620	L	1.224	1.233	1.241	1.227	1.224	1.224	1.241
8620	R	0.974	0.972	0.968	0.968	0.961	0.961	0.974
8631	L	1.172	1.172	1.178	1.172	1.178	1.172	1.178
8631	R	1.211	1.218	1.218	1.213	1.211	1.211	1.218
8646	L	1.043	1.043	1.041	1.039	1.041	1.039	1.043
8646	R	1.147	1.144	1.144	1.152	1.149	1.144	1.152
8654	L	1.201	1.198	1.198	1.195	1.193	1.193	1.201
8654	R	1.224	1.23	1.227	1.23	1.227	1.224	1.23
8655	L	1.552	1.552	1.549	1.546	1.552	1.546	1.552
8655	R	1.418	1.42	1.427	1.42	1.418	1.418	1.427

Table 20: Raw Thickness Measurements at 5 N (cm)

PMHS	Image:	Calc 5N						
	Measurement:	1st	2nd	3rd	4th	5th	Minimum	Maximum
8285	L	1.474	1.468	1.468	1.466	1.468	1.466	1.474
8285	R	1.086	1.095	1.095	1.095	1.086	1.086	1.095
8295	L	1.891	1.891	1.894	1.894	1.891	1.891	1.894
8295	R	1.543	1.549	1.543	1.535	1.555	1.535	1.555
8299	L	1.05	1.056	1.056	1.052	1.054	1.05	1.056
8299	R	1.293	1.29	1.287	1.293	1.287	1.287	1.293
8390	L	1.022	1.006	1.004	1.011	1.013	1.004	1.022
8390	R	1.239	1.23	1.23	1.239	1.241	1.23	1.241
8409	L	1.351	1.348	1.356	1.362	1.362	1.348	1.362
8409	R	1.365	1.365	1.371	1.371	1.368	1.365	1.371
8423	L	1.282	1.287	1.279	1.279	1.276	1.276	1.287
8423	R	1.184	1.187	1.190	1.198	1.198	1.184	1.198
8425	L	0.933	0.924	0.926	0.931	0.931	0.924	0.933
8425	R	0.903	0.901	0.901	0.901	0.901	0.901	0.903
8427	L	0.911	0.905	0.911	0.914	0.911	0.905	0.914
8427	R	0.942	0.933	0.942	0.940	0.944	0.933	0.944
8435	L	1.184	1.178	1.181	1.181	1.184	1.178	1.184
8435	R	1.414	1.392	1.409	1.392	1.392	1.392	1.414
8451	L	1.259	1.259	1.250	1.246	1.254	1.246	1.259
8451	R	1.250	1.250	1.250	1.250	1.250	1.25	1.25
8458	L	1.236	1.236	1.224	1.230	1.230	1.224	1.236
8458	R	1.095	1.098	1.106	1.106	1.106	1.095	1.106
8464	L	1.256	1.259	1.253	1.259	1.256	1.253	1.259
8464	R	1.466	1.454	1.460	1.457	1.457	1.454	1.466
8470	L	1.375	1.381	1.386	1.373	1.382	1.373	1.386
8470	R	1.158	1.158	1.158	1.158	1.155	1.155	1.158
8477	L	1.319	1.322	1.325	1.333	1.325	1.319	1.333
8477	R	1.204	1.195	1.198	1.198	1.207	1.195	1.207
8483	L	1.142	1.134	1.134	1.138	1.134	1.134	1.142
8483	R	1.218	1.213	1.213	1.201	1.213	1.201	1.218
8486	L	0.92	0.907	0.914	0.92	0.917	0.907	0.92
8486	R	0.859	0.859	0.868	0.859	0.862	0.859	0.868
8493	L	1.356	1.356	1.348	1.356	1.353	1.348	1.356
8493	R	1.480	1.474	1.477	1.471	1.477	1.471	1.48
8494	L	1.017	1.013	1.009	1.022	1.024	1.009	1.024
8494	R	1.280	1.284	1.276	1.284	1.284	1.276	1.284
8507	L	1.345	1.336	1.342	1.342	1.342	1.336	1.345
8507	R	1.072	1.066	1.060	1.066	1.060	1.06	1.072

Continued

Table 20 continued

8518	L	1.603	1.603	1.592	1.601	1.592	1.592	1.603
8518	R	1.126	1.132	1.118	1.132	1.129	1.118	1.132
8520	L	1.125	1.119	1.116	1.129	1.121	1.116	1.129
8520	R	1.454	1.463	1.460	1.460	1.466	1.454	1.466
8531	L	0.841	0.823	0.819	0.817	0.815	0.815	0.841
8531	R	0.830	0.838	0.843	0.838	0.836	0.83	0.843
8545	L	1.054	1.050	1.052	1.052	1.054	1.05	1.054
8545	R	1.032	1.029	1.032	1.034	1.023	1.023	1.034
8577	L	0.785	0.790	0.787	0.790	0.793	0.785	0.793
8577	R	0.713	0.713	0.716	0.713	0.707	0.707	0.716
8580	L	1.149	1.147	1.144	1.144	1.147	1.144	1.149
8580	R	1.434	1.437	1.440	1.434	1.437	1.434	1.44
8582	L	1.305	1.307	1.305	1.302	1.305	1.302	1.307
8582	R	1.135	1.141	1.141	1.132	1.147	1.132	1.147
8615	L	1.707	1.707	1.71	1.707	1.704	1.704	1.71
8615	R	2.065	2.069	2.073	2.069	2.078	2.065	2.078
8620	L	1.152	1.149	1.144	1.141	1.141	1.141	1.152
8620	R	0.879	0.886	0.884	0.888	0.886	0.879	0.888
8631	L	1.073	1.069	1.071	1.073	1.067	1.067	1.073
8631	R	1.177	1.157	1.149	1.157	1.17	1.149	1.177
8646	L	0.884	0.884	0.888	0.888	0.881	0.881	0.888
8646	R	1.052	1.049	1.043	1.046	1.049	1.043	1.052
8654	L	1.125	1.129	1.134	1.134	1.121	1.121	1.134
8654	R	1.141	1.147	1.141	1.141	1.144	1.141	1.147
8655	L	1.342	1.328	1.342	1.33	1.325	1.325	1.342
8655	R	1.285	1.282	1.276	1.284	1.276	1.276	1.285

Table 21: Raw Thickness Measurements at 10 N (cm)

PMHS	Image: Measurement:	Calc 10N						
		1st	2nd	3rd	4th	5th	Minimum	Maximum
8285	L	1.299	1.296	1.299	1.302	1.299	1.296	1.302
8285	R	1.054	1.067	1.062	1.065	1.069	1.054	1.069
8295	L	1.765	1.764	1.762	1.762	1.759	1.759	1.765
8295	R	1.483	1.483	1.48	1.477	1.489	1.477	1.489
8299	L	1.013	1.015	1.013	1.015	1.019	1.013	1.019
8299	R	1.216	1.213	1.218	1.216	1.218	1.213	1.218
8390	L	0.963	0.957	0.966	0.966	0.957	0.957	0.966
8390	R	1.185	1.19	1.188	1.19	1.183	1.183	1.19
8409	L	1.336	1.319	1.353	1.345	1.345	1.319	1.353
8409	R	1.302	1.302	1.302	1.310	1.316	1.302	1.316
8423	L	1.216	1.216	1.224	1.211	1.216	1.211	1.224
8423	R	1.126	1.121	1.129	1.135	1.126	1.121	1.135
8425	L	0.876	0.887	0.885	0.880	0.880	0.876	0.887
8425	R	0.862	0.866	0.855	0.862	0.862	0.855	0.866
8427	L	0.874	0.876	0.876	0.871	0.879	0.871	0.879
8427	R	0.905	0.894	0.894	0.897	0.888	0.888	0.905
8435	L	1.115	1.118	1.112	1.115	1.115	1.112	1.118
8435	R	1.366	1.362	1.371	1.362	1.366	1.362	1.371
8451	L	1.187	1.184	1.181	1.172	1.172	1.172	1.187
8451	R	1.195	1.201	1.195	1.204	1.207	1.195	1.207
8458	L	1.187	1.193	1.193	1.195	1.190	1.187	1.195
8458	R	1.098	1.095	1.095	1.089	1.095	1.089	1.098
8464	L	1.231	1.231	1.235	1.235	1.233	1.231	1.235
8464	R	1.379	1.376	1.382	1.385	1.379	1.376	1.385
8470	L	1.203	1.198	1.205	1.196	1.196	1.196	1.205
8470	R	1.093	1.093	1.095	1.084	1.091	1.084	1.095
8477	L	1.224	1.228	1.224	1.233	1.231	1.224	1.233
8477	R	1.134	1.140	1.132	1.140	1.140	1.132	1.14
8483	L	1.082	1.082	1.078	1.086	1.086	1.078	1.086
8483	R	1.152	1.149	1.158	1.161	1.161	1.149	1.161
8486	L	0.865	0.862	0.868	0.866	0.865	0.862	0.868
8486	R	0.810	0.807	0.805	0.808	0.808	0.805	0.81
8493	L	1.256	1.254	1.257	1.261	1.254	1.254	1.261
8493	R	1.388	1.388	1.379	1.374	1.382	1.374	1.388
8494	L	0.991	0.991	0.994	0.991	1.000	0.991	1.00
8494	R	1.213	1.200	1.211	1.220	1.216	1.2	1.22
8507	L	1.264	1.256	1.262	1.259	1.261	1.256	1.264
8507	R	1.065	1.060	1.065	1.063	1.063	1.06	1.065

Continued

Table 21 continued

8518	L	1.48	1.466	1.466	1.468	1.468	1.466	1.48
8518	R	1.069	1.066	1.072	1.069	1.066	1.066	1.072
8520	L	1.047	1.032	1.039	1.037	1.034	1.032	1.047
8520	R	1.328	1.336	1.328	1.325	1.325	1.325	1.336
8531	L	0.749	0.749	0.753	0.757	0.75	0.749	0.757
8531	R	0.793	0.806	0.804	0.802	0.804	0.793	0.806
8545	L	0.963	0.971	0.971	0.974	0.968	0.963	0.974
8545	R	0.966	0.968	0.968	0.970	0.974	0.966	0.974
8577	L	0.731	0.731	0.727	0.731	0.733	0.727	0.733
8577	R	0.67	0.675	0.674	0.677	0.677	0.67	0.677
8580	L	1.052	1.055	1.052	1.046	1.052	1.046	1.055
8580	R	1.336	1.336	1.339	1.342	1.330	1.33	1.342
8582	L	1.218	1.222	1.213	1.222	1.218	1.213	1.222
8582	R	1.063	1.072	1.072	1.063	1.052	1.052	1.072
8615	L	1.556	1.556	1.569	1.556	1.56	1.556	1.569
8615	R	1.918	1.927	1.94	1.935	1.927	1.918	1.940
8620	L	1.103	1.099	1.099	1.099	1.095	1.095	1.103
8620	R	0.819	0.819	0.823	0.819	0.819	0.819	0.823
8631	L	1.022	1.026	1.028	1.026	1.024	1.022	1.028
8631	R	1.112	1.116	1.114	1.108	1.114	1.108	1.116
8646	L	0.81	0.81	0.809	0.813	0.812	0.809	0.813
8646	R	0.955	0.953	0.957	0.948	0.95	0.948	0.957
8654	L	1.066	1.06	1.063	1.063	1.063	1.06	1.066
8654	R	1.093	1.086	1.091	1.091	1.088	1.086	1.093
8655	L	1.304	1.306	1.31	1.313	1.31	1.304	1.313
8655	R	1.213	1.211	1.211	1.211	1.207	1.207	1.213

Table 22: Raw Thickness Measurements at 15 N (cm)

PMHS	Image:	Calc 15N						
	Measurement:	1st	2nd	3rd	4th	5th	Minimum	Maximum
8285	L	1.259	1.261	1.262	1.262	1.267	1.259	1.267
8285	R	1.073	1.078	1.082	1.075	1.073	1.073	1.082
8295	L	1.677	1.681	1.677	1.677	1.672	1.672	1.681
8295	R	1.445	1.457	1.44	1.457	1.448	1.44	1.457
8299	L	0.97	0.957	0.966	0.968	0.966	0.957	0.97
8299	R	1.181	1.177	1.185	1.185	1.19	1.177	1.19
8390	L	0.911	0.908	0.911	0.914	0.905	0.905	0.914
8390	R	1.157	1.155	1.153	1.157	1.157	1.153	1.157
8409	L	1.229	1.237	1.228	1.224	1.233	1.224	1.237
8409	R	1.261	1.256	1.263	1.254	1.263	1.254	1.263
8423	L	1.124	1.118	1.132	1.118	1.121	1.118	1.132
8423	R	*	*	*	*	*	*	*
8425	L	0.823	0.825	0.823	0.830	0.828	0.823	0.83
8425	R	0.862	0.855	0.855	0.862	0.855	0.855	0.862
8427	L	0.830	0.833	0.833	0.842	0.833	0.83	0.842
8427	R	0.869	0.866	0.866	0.871	0.866	0.866	0.871
8435	L	1.046	1.052	1.052	1.052	1.057	1.046	1.057
8435	R	1.341	1.328	1.332	1.332	1.315	1.315	1.341
8451	L	1.121	1.112	1.112	1.112	1.118	1.112	1.121
8451	R	1.149	1.155	1.155	1.152	1.161	1.149	1.161
8458	L	1.168	1.162	1.164	1.164	1.166	1.162	1.168
8458	R	1.040	1.043	1.034	1.043	1.043	1.034	1.043
8464	L	1.205	1.209	1.218	1.222	1.224	1.205	1.224
8464	R	1.319	1.322	1.322	1.316	1.313	1.313	1.322
8470	L	1.116	1.119	1.108	1.112	1.106	1.106	1.119
8470	R	1.039	1.043	1.035	1.039	1.047	1.035	1.047
8477	L	1.192	1.192	1.185	1.188	1.185	1.185	1.192
8477	R	1.073	1.078	1.073	1.071	1.073	1.071	1.078
8483	L	1.052	1.060	1.043	1.047	1.056	1.043	1.06
8483	R	1.112	1.114	1.112	1.114	1.112	1.112	1.114
8486	L	0.851	0.838	0.838	0.845	0.849	0.838	0.851
8486	R	0.764	0.762	0.762	0.759	0.759	0.759	0.764
8493	L	1.2	1.203	1.205	1.198	1.2	1.198	1.205
8493	R	1.325	1.330	1.331	1.333	1.333	1.325	1.333
8494	L	0.952	0.945	0.940	0.940	0.940	0.94	0.952
8494	R	1.164	1.177	1.170	1.177	1.172	1.164	1.177
8507	L	1.207	1.213	1.207	1.207	1.216	1.207	1.216
8507	R	1.039	1.032	1.039	1.039	1.037	1.032	1.039

Continued

Table 22 continued

8518	L	1.391	1.397	1.394	1.399	1.388	1.388	1.399
8518	R	1.032	1.026	1.043	1.037	1.040	1.026	1.043
8520	L	0.998	0.998	1	1.004	0.989	0.989	1.004
8520	R	1.241	1.233	1.241	1.250	1.241	1.233	1.25
8531	L	0.734	0.731	0.736	0.733	0.736	0.731	0.736
8531	R	0.778	0.774	0.778	0.776	0.780	0.774	0.78
8545	L	0.922	0.907	0.920	0.912	0.922	0.907	0.922
8545	R	0.955	0.955	0.940	0.955	0.948	0.94	0.955
8577	L	0.71	0.714	0.707	0.708	0.708	0.707	0.714
8577	R	0.652	0.660	0.659	0.657	0.658	0.652	0.66
8580	L	1.012	1.012	1.014	1.014	1.014	1.012	1.014
8580	R	1.276	1.279	1.282	1.282	1.279	1.276	1.282
8582	L	1.166	1.164	1.16	1.162	1.159	1.159	1.166
8582	R	1.078	1.072	1.069	1.069	1.072	1.069	1.078
8615	L	1.47	1.474	1.483	1.474	1.457	1.457	1.483
8615	R	1.752	1.746	1.75	1.746	1.754	1.746	1.754
8620	L	1.039	1.043	1.043	1.043	1.043	1.039	1.043
8620	R	0.806	0.81	0.802	0.802	0.808	0.802	0.81
8631	L	0.961	0.968	0.972	0.963	0.968	0.961	0.972
8631	R	1.08	1.082	1.075	1.082	1.088	1.075	1.088
8646	L	0.728	0.728	0.727	0.73	0.726	0.726	0.73
8646	R	0.877	0.877	0.875	0.886	0.881	0.875	0.886
8654	L	1.012	1.014	1.009	1.006	1.02	1.006	1.02
8654	R	1.045	1.043	1.043	1.043	1.039	1.039	1.045
8655	L	1.25	1.254	1.254	1.246	1.25	1.246	1.254
8655	R	1.172	1.166	1.168	1.172	1.172	1.166	1.172

Table 23: Raw Thickness Measurements at 20 N (cm)

PMHS	**Image:**	Calc 20N						
	Measurement:	1st	2nd	3rd	4th	5th	Minimum	Maximum
8285	L	1.224	1.221	1.233	1.221	1.23	1.221	1.233
8285	R	1.017	1.015	1.011	1.009	1.013	1.009	1.017
8295	L	1.63	1.625	1.629	1.63	1.625	1.625	1.63
8295	R	1.417	1.422	1.42	1.417	1.417	1.417	1.422
8299	L	0.942	0.938	0.94	0.94	0.933	0.933	0.942
8299	R	1.134	1.125	1.121	1.125	1.125	1.121	1.134
8390	L	0.902	0.911	0.911	0.902	0.908	0.902	0.911
8390	R	1.129	1.121	1.119	1.123	1.123	1.119	1.129
8409	L	*	*	*	*	*	*	*
8409	R	1.220	1.228	1.220	1.224	1.224	1.22	1.228
8423	L	1.072	1.069	1.072	1.066	1.078	1.066	1.078
8423	R	1.037	1.037	1.043	1.034	1.035	1.034	1.043
8425	L	0.802	0.805	0.802	0.802	0.807	0.802	0.807
8425	R	0.831	0.826	0.824	0.829	0.829	0.824	0.831
8427	L	0.823	0.819	0.815	0.819	0.810	0.81	0.823
8427	R	0.836	0.845	0.851	0.842	0.848	0.836	0.851
8435	L	1.009	1.006	1.003	1.003	1.003	1.003	1.009
8435	R	1.293	1.297	1.293	1.293	1.293	1.293	1.297
8451	L	1.151	1.147	1.155	1.155	1.159	1.147	1.159
8451	R	1.132	1.129	1.135	1.129	1.126	1.126	1.135
8458	L	1.127	1.125	1.125	1.123	1.125	1.123	1.127
8458	R	1.011	1.014	1.011	1.017	1.014	1.011	1.017
8464	L	1.198	1.205	1.207	1.200	1.198	1.198	1.207
8464	R	1.273	1.279	1.279	1.273	1.276	1.273	1.279
8470	L	1.062	1.058	1.058	1.06	1.056	1.056	1.062
8470	R	1.006	1.002	0.988	1.009	1.015	0.988	1.015
8477	L	1.132	1.138	1.138	1.141	1.132	1.132	1.141
8477	R	1.041	1.054	1.045	1.045	1.043	1.041	1.054
8483	L	1.046	1.049	1.040	1.040	1.043	1.04	1.049
8483	R	1.075	1.069	1.080	1.075	1.075	1.069	1.08
8486	L	0.799	0.799	0.797	0.799	0.802	0.797	0.802
8486	R	0.730	0.736	0.724	0.727	0.733	0.724	0.736
8493	L	1.155	1.153	1.157	1.157	1.157	1.153	1.157
8493	R	1.270	1.273	1.273	1.276	1.276	1.27	1.276
8494	L	0.908	0.908	0.914	0.911	0.914	0.908	0.914
8494	R	1.127	1.127	1.123	1.134	1.129	1.123	1.134
8507	L	1.184	1.178	1.193	1.193	1.190	1.178	1.193
8507	R	0.985	0.989	0.991	0.987	0.985	0.985	0.991

Continued

Table 23 continued

8518	L	1.333	1.322	1.328	1.33	1.333	1.322	1.333
8518	R	1.009	1.009	1.006	1.003	1.009	1.003	1.009
8520	L	0.946	0.944	0.944	0.946	0.944	0.944	0.946
8520	R	1.193	1.198	1.195	1.195	1.198	1.193	1.198
8531	L	0.726	0.724	0.726	0.724	0.727	0.724	0.727
8531	R	0.752	0.752	0.752	0.750	0.754	0.75	0.754
8545	L	0.875	0.879	0.875	0.871	0.879	0.871	0.879
8545	R	0.894	0.894	0.894	0.894	0.890	0.89	0.894
8577	L	0.69	0.698	0.693	0.688	0.690	0.688	0.698
8577	R	0.639	0.634	0.635	0.639	0.639	0.634	0.639
8580	L	1	1.006	0.997	1.000	0.994	0.994	1.006
8580	R	1.224	1.230	1.230	1.233	1.230	1.224	1.233
8582	L	1.108	1.112	1.116	1.123	1.116	1.108	1.123
8582	R	1.02	1.017	1.017	1.026	1.014	1.014	1.026
8615	L	1.573	1.565	1.578	1.569	1.569	1.565	1.578
8615	R	1.724	1.724	1.733	1.724	1.733	1.724	1.733
8620	L	0.974	0.978	0.983	0.987	0.978	0.974	0.987
8620	R	0.782	0.782	0.782	0.78	0.789	0.78	0.789
8631	L	0.938	0.929	0.933	0.931	0.929	0.929	0.938
8631	R	1.047	1.05	1.054	1.058	1.054	1.047	1.058
8646	L	0.705	0.705	0.704	0.705	0.705	0.704	0.705
8646	R	0.823	0.82	0.819	0.819	0.82	0.819	0.823
8654	L	0.991	1	1	0.994	0.997	0.991	1
8654	R	1.006	1.004	1.006	1.004	1.004	1.004	1.006
8655	L	1.203	1.211	1.198	1.205	1.203	1.198	1.211
8655	R	1.129	1.132	1.129	1.129	1.129	1.129	1.132

Table 24: Raw Thickness Measurements at 30 N (cm)

PMHS	Image:	Calc 30N						
	Measurement:	1st	2nd	3rd	4th	5th	Minimum	Maximum
8285	L	1.129	1.129	1.129	1.124	1.129	1.124	1.129
8285	R	0.996	0.996	0.998	0.996	0.996	0.996	0.998
8295	L	1.543	1.552	1.539	1.543	1.547	1.539	1.552
8295	R	1.362	1.368	1.368	1.374	1.374	1.362	1.374
8299	L	0.654	0.657	0.659	0.654	0.655	0.654	0.659
8299	R	1.121	1.121	1.116	1.116	1.116	1.116	1.121
8390	L	0.885	0.885	0.885	0.891	0.885	0.885	0.891
8390	R	1.099	1.095	1.097	1.097	1.099	1.095	1.099
8409	L	*	*	*	*	*	*	*
8409	R	1.173	1.173	1.172	1.170	1.172	1.17	1.173
8423	L	1.043	1.043	1.040	1.055	1.052	1.04	1.055
8423	R	0.989	0.983	0.983	0.994	0.983	0.983	0.994
8425	L	*	*	*	*	*	*	*
8425	R	0.807	0.805	0.805	0.807	0.800	0.8	0.807
8427	L	0.778	0.784	0.780	0.776	0.776	0.776	0.784
8427	R	0.787	0.805	0.807	0.805	0.807	0.787	0.807
8435	L	0.928	0.922	0.925	0.931	0.922	0.922	0.931
8435	R	1.263	1.267	1.276	1.272	1.272	1.263	1.276
8451	L	0.983	0.974	0.983	0.966	0.957	0.957	0.983
8451	R	1.069	1.080	1.075	1.066	1.072	1.066	1.08
8458	L	1.103	1.108	1.108	1.108	1.101	1.101	1.108
8458	R	0.960	0.960	0.957	0.966	0.963	0.957	0.966
8464	L	1.147	1.147	1.141	1.138	1.141	1.138	1.147
8464	R	1.227	1.221	1.230	1.216	1.221	1.216	1.23
8470	L	0.972	0.968	0.976	0.981	0.972	0.968	0.981
8470	R	0.959	0.957	0.955	0.955	0.955	0.955	0.959
8477	L	1.067	1.067	1.067	1.06	1.06	1.06	1.067
8477	R	0.978	0.970	0.974	0.972	0.976	0.97	0.978
8483	L	1.034	1.039	1.035	1.039	1.043	1.034	1.043
8483	R	1.043	1.040	1.046	1.043	1.034	1.034	1.046
8486	L	0.783	0.783	0.78	0.78	0.78	0.78	0.783
8486	R	0.690	0.687	0.693	0.687	0.687	0.687	0.693
8493	L	1.086	1.091	1.086	1.086	1.095	1.086	1.095
8493	R	1.210	1.207	1.210	1.210	1.204	1.204	1.21
8494	L	0.922	0.914	0.917	0.908	0.908	0.908	0.922
8494	R	1.097	1.097	1.097	1.097	1.091	1.091	1.097
8507	L	1.170	1.170	1.172	1.172	1.170	1.17	1.172
8507	R	0.978	0.976	0.976	0.976	0.976	0.976	0.978

Continued

Table 24 continued

8518	L	1.256	1.259	1.25	1.248	1.25	1.248	1.259
8518	R	0.954	0.960	0.960	0.960	0.957	0.954	0.96
8520	L	0.933	0.933	0.933	0.931	0.938	0.931	0.938
8520	R	1.147	1.152	1.147	1.155	1.147	1.147	1.155
8531	L	0.662	0.658	0.657	0.652	0.655	0.652	0.662
8531	R	0.724	0.724	0.728	0.726	0.724	0.724	0.728
8545	L	0.905	0.892	0.888	0.897	0.897	0.888	0.905
8545	R	0.834	0.845	0.834	0.830	0.834	0.83	0.845
8577	L	0.639	0.638	0.637	0.644	0.639	0.637	0.644
8577	R	0.559	0.559	0.562	0.559	0.559	0.559	0.562
8580	L	0.954	0.954	0.954	0.946	0.954	0.946	0.954
8580	R	1.178	1.175	1.175	1.172	1.178	1.172	1.178
8582	L	1.067	1.065	1.06	1.06	1.056	1.056	1.067
8582	R	0.94	0.943	0.943	0.937	0.943	0.937	0.943
8615	L	1.47	1.466	1.466	1.466	1.47	1.466	1.47
8615	R	1.668	1.668	1.672	1.668	1.673	1.668	1.673
8620	L	0.985	0.978	0.976	0.983	0.974	0.974	0.985
8620	R	0.737	0.739	0.728	0.737	0.735	0.728	0.739
8631	L	0.925	0.925	0.92	0.922	0.918	0.918	0.925
8631	R	1.035	1.037	1.035	1.037	1.035	1.035	1.037
8646	L	0.767	0.767	0.77	0.772	0.769	0.767	0.772
8646	R	0.77	0.767	0.766	0.766	0.77	0.766	0.77
8654	L	0.96	0.96	0.96	0.954	0.954	0.954	0.96
8654	R	0.994	0.994	0.991	0.991	0.994	0.991	0.994
8655	L	1.144	1.147	1.149	1.149	1.149	1.144	1.149
8655	R	1.075	1.071	1.069	1.067	1.069	1.067	1.075

Table 25: Heel Pad Thicknesses

Thicknesses (mm)				
Subject				
8285	Left	16.120	Right	12.440
8295	Left	20.417	Right	17.200
8299	Left	11.243	Right	13.720
8390	Left	11.770	Right	13.523
8409	Left	15.200	Right	15.170
8423	Left	14.353	Right	13.110
8425	Left	10.527	Right	9.660
8427	Left	10.190	Right	10.233
8435	Left	12.940	Right	14.673
8451	Left	14.187	Right	13.417
8458	Left	13.460	Right	11.913
8464	Left	12.570	Right	16.780
8470	Left	17.780	Right	11.890
8477	Left	13.920	Right	14.040
8483	Left	12.013	Right	13.730
8486	Left	10.073	Right	9.767
8493	Left	15.400	Right	16.353
8494	Left	11.710	Right	13.920
8507	Left	13.987	Right	11.850
8518	Left	17.730	Right	12.613
8520	Left	12.570	Right	16.033
8531	Left	8.860	Right	9.010
8545	Left	11.557	Right	11.390
8577	Left	8.470	Right	8.313
8580	Left	12.843	Right	15.910
8582	Left	14.087	Right	12.500
8615	Left	19.200	Right	21.483
8620	Left	12.280	Right	9.693
8631	Left	11.740	Right	12.140
8646	Left	10.417	Right	11.467
8654	Left	11.970	Right	12.280
8655	Left	15.510	Right	14.193

Table 26: Heel Pad Stiffnesses

Stiffnesses (N/mm)				
Subject				
8285	Left	5.766	Right	10.531
8295	Left	5.656	Right	7.868
8299	Left	6.330	Right	10.244
8390	Left	8.459	Right	10.744
8409	Left	5.163	Right	8.217
8423	Left	6.836	Right	8.977
8425	Left	7.642	Right	17.695
8427	Left	11.770	Right	13.277
8435	Left	8.033	Right	14.353
8451	Left	6.841	Right	10.947
8458	Left	11.376	Right	13.057
8464	Left	24.621	Right	6.015
8470	Left	3.269	Right	11.821
8477	Left	8.796	Right	6.577
8483	Left	14.792	Right	8.224
8486	Left	12.117	Right	9.823
8493	Left	6.231	Right	6.704
8494	Left	9.453	Right	9.350
8507	Left	11.025	Right	12.910
8518	Left	5.406	Right	9.379
8520	Left	8.007	Right	5.835
8531	Left	12.930	Right	16.333
8545	Left	8.832	Right	9.778
8577	Left	14.144	Right	11.271
8580	Left	8.059	Right	6.710
8582	Left	8.126	Right	9.795
8615	Left	5.130	Right	5.154
8620	Left	10.378	Right	12.282
8631	Left	10.329	Right	15.130
8646	Left	5.596	Right	7.300
8654	Left	11.454	Right	11.234
8655	Left	6.986	Right	8.266
*8464 left (outlier) removed for normality				

Table 27: Heel Pad Compressibility Indexes

Compressibility Indexes (unitless)				
Subject				
8285	Left	0.700	Right	0.801
8295	Left	0.756	Right	0.797
8299	Left	0.583	Right	0.815
8390	Left	0.752	Right	0.812
8409	Left	0.809	Right	0.773
8423	Left	0.729	Right	0.751
8425	Left	0.763	Right	0.834
8427	Left	0.763	Right	0.787
8435	Left	0.715	Right	0.866
8451	Left	0.687	Right	0.799
8458	Left	0.822	Right	0.807
8464	Left	0.909	Right	0.729
8470	Left	0.547	Right	0.804
8477	Left	0.765	Right	0.694
8483	Left	0.864	Right	0.759
8486	Left	0.775	Right	0.704
8493	Left	0.706	Right	0.739
8494	Left	0.780	Right	0.788
8507	Left	0.837	Right	0.824
8518	Left	0.706	Right	0.760
8520	Left	0.742	Right	0.716
8531	Left	0.741	Right	0.804
8545	Left	0.775	Right	0.732
8577	Left	0.754	Right	0.672
8580	Left	0.743	Right	0.739
8582	Left	0.754	Right	0.754
8615	Left	0.764	Right	0.777
8620	Left	0.797	Right	0.760
8631	Left	0.786	Right	0.853
8646	Left	0.738	Right	0.669
8654	Left	0.800	Right	0.809
8655	Left	0.740	Right	0.754
*8470 left (outlier) removed for normality				