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DEPARTMENT OF BIOENGINEERING

PRELIMINARY INVESTIGATION OF THE EFFECTS OF ARCH HEIGHT ON SUBTALAR JOINT MECHANICS DURING WALKING

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A thesis submitted in partial fulfillment of the requirements for baccalaureate degrees in Bioengineering and International Studies with honors in Bioengineering

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ABSTRACT

The purpose of this honors thesis was to modify a method for locating the subtalar joint axis from measured foot motions. Once the axis is located with this subtalar axis locator (SAL II), then moments about this axis can be determined through a series of walking trials by utilizing a 6 camera motion analysis system and force plates. The location of and moments about the subtalar joint axis provide key insight into the mechanics of this crucial ankle joint. This study specifically sought to determine if arch height correlates with peak internal subtalar joint moments during walking. Further understanding of how arch height affects these subtalar joint mechanics could contribute to the improved treatment methods of such gait disorders as adult acquired flatfoot disorder.

Preliminary testing of a limited subject population indicated a possible correlation between low arches and large internal supination subtalar joint axis moments during early stance. The reliability of the Arch Height Measurement System was also determined, providing the Penn State Biomechanics Laboratory with a reliable way of measuring arch height. This thesis establishes the protocol for determining subtalar joint axis location and moments with the SAL II device, a protocol that can be used to definitively determine correlations between arch height and subtalar joint mechanics in a variety of future studies.

LIST OF FIGURES
LIST OF TABLES
ACKNOWLEDGEMENTS
Chapter 1 Introduction
1.1 Statement of the Problem
1.2 Objective of the Project
Chapter 2 Literature Review
2.1 Background on Subtalar Joint
2.2 Methods for Locating Subtalar Joint Axis
2.2.1 Cadaver Studies
2.2.2 In vivo Studies
2.3 Subtalar Joint Moments during Gait11
2.4 Subtalar Joint Function and Foot Type13
2.5 Methods of Assessing Arch Height
Chapter 3 Methods16
3.1 Changes to SAL II
3.2 Subtalar Joint Moments during Gait
3.2.1 Tibial Cluster
3.2.2 Calcaneus Cluster I
3.2.3 Calcaneus Cluster II
3.3 Creation of the Arch Height Measurement System
3.4 Establishment of the Protocol
3.4.1 Tipping of the SAL base
3.4.2 Common Speed Across Subjects
3.4.3 Appropriate Foot Placement on Force Plates
3.5 Post-Processing
Chapter 4 Results
Chapter 5 Discussion
5.1 Results Summary
5.2 Possible Implications
5.3 Limitations 41
5.4 Conclusion
Works Cited

TABLE OF CONTENTS

Appendix A	Final Protocol	48
Appendix B	Testing Data Sheet	51

LIST OF FIGURES

Figure 1.1	Anatomy of the ankle joint	
Figure 1.2	Location of the subtalar joint axis2	
Figure 2.1	Location of the subtalar joint axis	
Figure 2.2	Arch height index measurement system15	5
Figure 3.1	SAL I device	5
Figure 3.2	SAL II device before changes were made17	7
Figure 3.3	SAL II device after changes were made18	3
Figure 3.4	Tibial cluster after changes were made)
Figure 3.5	Wrapping of Coban to secure calcaneus cluster to foot	2
Figure 3.6	Calcaneus marker cluster II	3
Figure 3.7	Top view of AHMS	1
Figure 3.8	Location of anatomical landmark markers	7
Figure 3.9	The necessary values to calculate STJ moments)
Figure 4.1	Subject 1 STJ moments vs. Percent Stance (comfortable)	L
Figure 4.2	Subject 2 STJ moments vs. Percent Stance (comfortable)	L
Figure 4.3	Subject 3 STJ moments vs. Percent Stance (comfortable)	2
Figure 4.4	Subject 1 STJ moments vs. Percent Stance (1.5m/s)	2
Figure 4.5	Subject 2 STJ moments vs. Percent Stance (1.5m/s)	3
Figure 4.6	Subject 3 STJ moments vs. Percent Stance (1.5m/s)	3
Figure 4.7	Avg peak eversion moment vs. AHI	5
Figure 4.8	Avg peak inversion moment vs. AHI	5
Figure 4.9	Inclination and deviation angles vs. AHI	5
Figure 4.10) Normalized peak eversion moment vs. deviation angle	5
Figure 4.11	Normalized peak eversion moment vs. inclination angle	7
Figure 4.12	2 Norrnalized peak inversion moment vs. inclination angle	7

Figure 4.13	3 Norrnalized peak eversion moment vs. deviation angle	
C		
Figure 5.1	STJ moments vs. stance: Scott & Winter and this study	

LIST OF TABLES

Table 4.1 Comparison of inclination and deviation angles from various studies	30
Table 5.1 Comparison of inclination and deviation angles from various studies.	39

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CHAPTER ONE

INTRODUCTION

1.1 Statement of the Problem

Adult acquired flatfoot deformity (AAFD) has become the pathology with the second most dramatic increase in prevalence in the field of podiatry within the past twenty years (Richie 2004). Also known as posterior tibial tendon dysfunction (PTTD), this condition occurs when the longitudinal arch of the foot collapses at a point after which the skeleton has fully matured. This deformity can cause a large amount of pain and may require physical therapy or more invasive surgical techniques as forms of treatment.

There are several different causes of AAFD, including nerve, ligament and tendon damage that can lead to subtalar joint subluxation. The subtalar joint is one of two joints in the ankle and is responsible for moving the foot inwards and outwards. Some of the crucial anatomic roles of the subtalar joint include helping establish a smooth gait, walking on uneven surfaces, absorbing forces during heel strike, and extending the extremes of ankle motion (Sangeorzan). The joint rotates the foot on the calcaneus and the navicular bone about the talus (DiLeo 2006). The subtalar axis is on average located 23° medial to the midline of the foot in the transverse plane, but studies by Inman indicate a rather large spread in this location ranging from 4° to 47°. Additionally, the axis is projected upward from the horizontal in the saggital plane on average 41°, but again Inman's studies indicate variability from 20° to 68°.



Figure 1.1 Anatomy of the ankle joint (Wheaton Franciscan Healthcare: http://www.eorthopod.com)



Figure 1.2 Location of subtalar joint axis in relation to the transverse plane (*top*) and the midline of the foot (*bottom*). (*From* Morris JM. Biomechanics of the foot and ankle. Clin Orthop 1977;14)

This high degree of intersubject variation in conjunction with the talus' external inaccessibility means that little is known about the mechanics of the subtalar joint. Sangeorzan states: "Understanding a joint requires that we understand what motion it undergoes, how it distributes weight, and what role it plays in the musculoskeletal system." One way we can better understand the motion of the subtalar joint is to model it. The subtalar joint is well-modeled as a mitered hinge (Inman 1969). The angle and position of that hinge is what varies from individual to individual. Another way of learning more about the subtalar joint is by using a motion analysis system with force plates to collect data on the motion and the ground-force reactions associated with the joint. This information provides key insight into the physiological events occurring inside the joint, specifically the moments created by the ligaments and muscles in the ankle. Knowing more about subtalar joint mechanics could certainly provide information crucial to the treatment of AAFD and other gait disorders.

As mentioned previously, locating the subtalar joint and axis is a difficult task because the talus cannot be identified externally. In the past, there have been several different methods of locating this axis, most being quite invasive and time-consuming. Close and colleagues (1967) sought to track subtalar joint motion during walking by surgically implanting pins into the calcaneus and the talus of subjects of varying arch types. After the procedure, the subjects were monitored during walking with a motion picture camera. The data gathered was then used to find the motion during the stance phase of walking, the total range of voluntary motion, and the medial deviation of the axis. It is interesting to note that differences were seen among arch types, but the invasiveness of this method increased the length of the study dramatically and at least one subject expressed discomfort due to the pin implants.

Subtalar axis moments were analyzed in the Scott and Winter (1991) study. A motion analysis system was used with markers placed on the calcaneus and the lower leg. The actual location of the subtalar joint was determined by manually manipulating the joint on each subject. The joint was rotated at the neutral position and the point with the least amount of motion on each side of the foot was marked. Also, the mathematical model used in this study assumed that the joint could be modeled as a simple hinge. Joint rotations and moments were the main focus of this study, and the joint kinetics and kinematics were only analyzed during stance as opposed to the entire gait cycle. In addition, anatomical differences between subjects, such as arch type, were not noted in this study.

Klein and colleagues (1996) carried out a study that involved the analysis of the moment arm length of different muscles in the lower leg during subtalar joint movement in cadavers. No correlation between moment arm length of the leg muscles and arch height was found. However, it is also important to note that moment arm length is not the only factor that nefound eds to be considered when looking at the moment; the force that the muscle exerts must also be taken into account. In addition, the mechanics of the subtalar joint *in vitro* may be different than those *in vivo*.

Elvira and colleagues (2008) examined the *in vivo* subtalar joint kinematics in race walkers of different arch types. Footprint arch indexing was used to classify each subject based on arch height. Each subject was videotaped with two gen-locked digital video cameras during maximum speed, and this data was then used to calculate the

different angles that describe movement of the ankle joint. Significant differences were found among arch heights, with higher arches being indicative of greater calcaneal angles and more negative tibial angles. However, only video footage of the subjects was taken and no ground reaction force measurements were made. Thus, moments about the subtalar axis could not be calculated.

A new development in this field, the Subtalar Axis Locator (SAL), allows for an accurate, non-invasive, and quick method of finding the subtalar axis. This device functions by causing the foot to move into dorsiflexion, thus immobilizing the talocrural joint so that the subtalar joint can be isolated and identified through the use of markers and the motion analysis system. Then, the located subtalar joint can be observed during walking with the motion analysis system and force plates. The device could accurately locate the subtalar joint within a reasonable error as compared to the method of location by use of MRI. However, when put into practice, SAL demonstrated several problems that made the device unfit for clinical use. It was bulky, had many distinct components and moving parts, and most importantly, it required the reposition of the tracking cameras. Thus, a second iteration of the device was created and addressed those three major design issues.

1.2 Objectives of the Project

The purpose of this study was two-fold. First, the second iteration of the Subtalar Axis Locator (SAL) had to be validated for repeatability. It had already been successfully tested for accuracy in subtalar joint location, but further testing needed to be done to show that the device would repeatedly locate an individual's subtalar joint in the same spot each time. This was done by using an eight-camera motion analysis system with ground force plates in conjunction with post-processing using OpenSim biomechanical modeling software.

The second main objective was to use SAL and the motion analysis system to find the muscular subtalar joint moments in people of varying arch types. Arch type was determined by measuring the distance between the floor and the navicular bone during standing, and data collection on the subtalar joint moments was collected during the process of walking.

Specific Aims of the Project:

- Make modifications to an existing method for locating the STJ axis (SAL device) from measured foot motions, and test its repeatability.
- 2. Use STJ axes measured using SAL to determine internal (muscular) STJ moments during walking in young, healthy subjects.
- Determine if arch height correlates with peak internal STJ moments during walking.

1.3 Hypothesis

Subjects with flat feet will have more medially deviated STJ axes and experience ground reaction forces in early stance that attempt to force the foot into pronation, thus requiring a larger muscular supination moment.

<u>Rationale</u>: Many patients with AAFD have a pathology related to the posterior tibial tendon, the tendon that runs from the back of the leg, underneath the medial mallelous of the tibia and then inserts onto the second, third and fourth metatarsals. Damage to this tendon leads to flattening of the medial longitudinal arch of the foot, and the patient tends to walk on the inner border of their foot, or rather tends to pronate more than usual

(Hockenbury 2009). This lends itself to the conclusion that the lower the arch, the greater the muscular supination moments about the subtalar joint. In addition, Kirby (1987) also hypothesized that those with low arches experience ground reaction forces in early stance that attempt to force the foot into pronation, thus requiring a larger muscular supination moment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background on Subtalar Joint

The ankle joint can be divided into two main joints: the talocrural joint- which is responsible for ankle flexion and extension- and the subtalar joint- which is responsible for inversion and eversion of the foot. The subtalar joint rotates the foot on the calcaneus and the navicular bone about the talus and is typically located at about 23 degrees medial to the midline of the foot in the transverse plane and 41 degrees upward from the horizontal in the saggital plane.



Figure 2.1 Location of subtalar joint axis in relation to the transverse plane (*top*) and the midline of the foot (*bottom*). (*From* Morris JM. Biomechanics of the foot and ankle. Clin Orthop 1977;14)

However, these locations are extremely variable among individuals. In fact,

studies by Inman indicate variation in the transverse plane from 4 degrees to 47 degrees

and variation in the saggital plane from 20 degrees to 68 degrees. In addition to this variation, the subtalar joint lacks of external bony landmarks, presenting problems for locating the axis through motion analysis software. Many joints such as the knee joint or elbow joint can be easily modeled and located by using motion analysis software and markers located on a distinct position above the joint and one below the joint. This modeling process is not possible for the subtalar joint because these set landmarks cannot be located externally; thus, the subtalar joint axis is extremely difficult to locate. Without knowing the location of this axis, it is difficult to fully understand its role in the musculoskeletal system. As of yet, we do know that the subtalar joint is crucial in helping establish a smooth gait, walking on uneven surfaces, absorbing forces during heel strike, and extending the extremes of ankle motion (Sangeorzan 1991). However, as mentioned before, the location of the subtalar joint axis is extremely variable among individuals, leading to the conclusion that the specific role that it plays and the moments about the axis involved during walking are just as variable in each individual.

2.2 Methods for Locating Subtalar Joint Axis

2.2.1 Cadaver studies

There have been several studies dedicated to subtalar joint axis location. The early studies looked at cadavers. Manter (1941) used glass plates with arches to locate the subtalar joint axis in cadavers with respect to the calcaneus. He found the average joint axis inclination in the saggital plane to be 42 degrees and the average deviation to be 16 degrees medial to the midline of the foot.

Isman and Inman (1969) also worked with cadavers, locating the subtalar joint axis by manually moving the talus into pronation and supination while keeping the calcaneus static. Their studies resulted in rather consistent intraspecimen axis orientation while demonstrating significant variation in interspecimen axis orientation. This study demonstrated that the amount of variability among individuals is so great that axis location should be done on a person-to-person basis.

Similarly, Lewis (2007) established the validity of using dorsiflexion and motion analysis to locate the subtalar joint axis. This study immobilized the talocrural joint in cadaver specimen and specifically monitored just the motion of the tibia in relation to the calcaneus, thus approximating the location and orientation of the of the subtalar joint axis. This technique was validated by comparing the axis to that computed from calcaneus-talus bone motions. These results demonstrated little motion at the talocrural joint and reliable estimates of the subtalar joint axis.

2.2.2 In vivo studies

The next leap in these studies was to locate the subtalar joint axis *in vivo*. The study by Arndt (2004) took an invasive approach in which intracortical pins were inserted under local anesthesia in the tibia, talus and calcaneus with external marker clusters. Then, these markers were traced by a video motion analysis system as kinematic data was collected during walking trials on a flat surface. The locations of the subtalar joint axis determined in this way were very similar to the locations found in cadaver specimen by Manter (1941) and Isman and Inman (1969).

Kirby (1987) showed similar location results in his non-invasive *in vivo* approach that used range of motion methods and palpation to axis location. In this study, the foot was dorsiflexed, putting tension on the Achilles tendon and locking the talus into place in such a way as to not cause the foot to pronate or supinate. Then, the projection of the subtalar joint axis was identified and located.

The next step in locating the axis came in the form of a system that incorporated data from a 3-segment 2 hinge model system with data from marker motion analysis (van den Bogert 1994). This study suggested that the subtalar joint axis could be located by monitoring the motion of the foot in relation to the shank. Using these measured motions in conjunction with the 2 hinge model system motions, the location of the subtalar joint axis determined in 14 participants. The average axis oreientations determined in this study were similar to those found in the cadaver studies.

Lewis et al (2009) further validated the method from Lewis et al (2007) that determines the subtalar joint axis through the process of immobilizing the talocrural joint and monitoring motion of the tibia with respect to the calcaneus. In this study, the same method was used but validation was carried out by magnetic resonance imaging. These results indicated motion in primarily the subtalar joint, thus forming the basis for the development of the Subtalar Axis Locator.

2.3 Subtalar Joint Moments during Gait

It is not simply enough to know the location of the subtalar joint axis; the moments about this joint during gait are also quite important. Close et al (1967) tracked subtalar joint motion during walking by surgically implanting pins into the calcaneus and the talus of subjects of varying arch types, and then monitoring the motion during walking with a motion picture camera. This data was then used to find the motion during the stance phase of walking, the total range of voluntary motion, and the medial deviation of the axis. The results of this study showed differences among arch types, but the invasiveness of this method increased the length of the study dramatically.

Proctor and Paul (1982) worked to determine forces that occur in the subtalar joint during gait. They carried out a three-dimensional analysis of the human ankle joint *in vivo* in which the ankle was treated as two joints, the talocrural and the talocalcaneonavicular- or subtalar- joint. Anatomical dimensions from cadaveric anthropometric data were used in this study as well. A system of three cine cameras and force plates was used to acquire data during the stance phase of normal locomotion. Results indicate that peak forces on the posterior facet of the talocalcaneal articulation were 2.4 times body weight and peak forces on the anterior facet were 2.8 times body weight.

Scott and Winter (1991) also used a motion analysis system to monitor the subtalar joint axis through markers placed on the calcaneus and the lower leg. The actual location of the subtalar joint was determined by manually manipulating the joint on each subject as the joint was rotated at the neutral position. The point with the least amount of motion on each side of the foot was marked. After gait analysis and an inverse dynamic analysis, internal moments from muscles and other soft tissues acting about the subtalar joint axis were determined. Ultimately, it was found that in early stance, a slight supination moment is seen, followed by a pronation moment that peaks at approximately 0.5 Nm/kg at 80% of stance.

The *in vivo* study by Elvira (2008) not only looked at the subtalar joint kinematics during gait but also compared these results in terms of arch height. Arch height was determined through footprint arch indexing and each subject was videotaped during

maximum race walking speed. Significant differences were found among arch heights, with higher arches being indicative of greater calcaneal angles and more negative tibial angles. In addition, those with higher arches exhibited more pronounced, longer support on the lateral side of the foot while those with lower arches supported with the medial side.

2.4 Subtalar Joint Function and Foot Type

Thus, we see the interrelation of arch type and subtalar joint function. Arrangio (2004) used data from a cadaveric specimen to create a biomechanical model that demonstrated that a flattened foot increases the load on the head of the first metatarsal from 10% to 24% of the body weight. A flattened foot also increases the moment about the subtalar joint from 3.4 to 11.9 Nm. Another study by Arrangio in 2007 continued to focus on the biomechanical model for analysis, but more data was collected on flat, normal, and high arches based on cadaveric specimen. Similar subtalar joint kinematics data were found. Load on the first metatarsal increases to 37% body weight in the flat foot compared to 12% for the normal foot. In addition, the moment about the subtalar joint increases from 5.6 N m to 21.6 Nm. Through a process called lateral column lengthening, a bone graft into the heel bone allows the surgeon to create an arch. This process of creating an arch decreased the load on the first metatarsal to 10% and decreased the moment about the subtalar joint to 8.1 Nm.

2.5 Methods of Assessing Arch Height

Elvira (2008) used footprint arch indexing to assess arch height, finding this method to be a good predictor as to whether the subject will exhibited more support with the medial or the lateral side of the foot. However, this is not the only method that exists. Franettovich et al (2007) demonstrated the high reliability of the Arch Height Index- the ratio of the Arch Height to Truncated Foot Length- as both static and dynamic measures. Using video of the medial aspect of the foot during standing, walking and jogging, arch height and arch height ration measurements were obtained. It was found that the measurements of arch height and arch height ratio taken statically are good ways in which to classify the foot in a clinical setting. These methods also show potential in estimating foot posture during dynamic activity in those with lower-limb injuries.

Latey et al (2010) found near-perfect intra-rater reliability for Arch Height for both passive (0.97 to 0.99) and elevation tasks (0.96 to 0.98) across stances. However, a statistically-significant difference in Arch Height was found in seated versus either standing or knee bend. To calculate the Arch Height Index, Richards et al (2006) used the Arch Height Index Measurement System (AHIMS), which demonstrated high reliability for both inter- and intra-rater measurements. This device measures arch height by a horizontal bar in the frontal plane that is lowered to rest on the dorsum of the foot at a point half the total foot length from the heel. Feet are then classified by the Arch Height Index.

Butler et al (2008) also established the inter- and intra-rater reliability of the AHIMS. They found that this device greatly simplifies the measurement procedure for recording the Arch Height Index, thus allowing for ease of identifying potential structural factors that predispose individuals to lower-extremity injuries.



Figure 2.2 Arch Height Index Measurement System

CHAPTER THREE

METHODS

3.1 Changes to SAL II

There have been a series of changes made to the SAL device. The first iteration of SAL was made of plastic because it was made for use in an MR imaging facility (see Figure 3.1). However, this device had several different moving parts and was rather bulky. In addition, it was difficult to see the markers so the tracking cameras needed to be repositioned.



Figure 3.1 The first iteration of the SAL device. Note the collection of complicated moving parts (Lewis 2009)

SAL II addressed these issues with SAL I by making the device more compact with fewer moving parts (see Figure 3.2). The marker clusters were also redesigned and placed in ways that they could be more easily seen by the tracking cameras. However, there were still several changes to the SAL II device that were needed to be made. This device is meant to be used long-term in the professional setting of the biomechanics testing lab, and thus the appearance of the device had to reflect that setting. Participants will feel more comfortable using an unknown device if it looks like a professional device. In addition, subject comfort and movement of the tibia needed to be addressed.



Figure 3.2 SAL II device before changes were made

During the pilot-testing procedures, it was noted that the participant's leg often sunk too far into the pad. This sinking caused the leg to move during testing and also produced an unsightly bulging of the padding. It was determined that a firmer pad was needed in order to minimize the movement of the leg. By applying forces that move the tibia, not as much STJ motion will be seen. The new pad had to provide firm support of the participant's leg while also providing comfort as well. Once the new, firmer pad was found, it was completely covered with the same vinyl material that had been used on the previous pad. The difference made here was that the old pad was only covered by the vinyl on three sides. Padding could be seen from the two other open sides. This was not aesthetically-pleasing. In addition, the parts of the foam pad open to the elements could not be sanitized effectively between uses. By totally covering the pad in the vinyl material, the entire pad could be sanitized. The pad also had a more professional appearance as no parts of the padding could be seen bulging from the sides. The next step to improving SAL II aesthetics was to make all of the device parts a uniform color. It was decided that black should be the color of choice. The mount holding the padding was black and the vinyl covering the padding was black. The stool itself was then painted black with spray paint. These changes all served to make SAL II a device that was more appropriate for use in the professional setting of the biomechanics lab (see Figure 3.3).



Figure 3.3 SAL II once changes were made

3.2 Design Changes to Marker Clusters

3.2.1 Tibial Cluster

The next problems that needed to be addressed related to the marker clusters affixed to the skin over the tibia and calcaneus. The tibial cluster had problems with the markers falling off the molded plastic base because the markers were simply attached with double-sided tape. This was a serious problem because changes to the placement of the markers during the SAL trials would change the calculated orientation of the subtalar joint axis. The location of the subtalar joint axis is determined during the SAL trials in the beginning of the testing. This location is based on how the calcaneus cluster moves in relation to the tibia cluster during the foot wagging. If the markers or marker clusters move during the time the axis is being located, these markers are no longer identifying the correct placement of the subtalar joint axis. Thus, this renders any subtalar joint moment calculations useless. The layer of padding on the tibial cluster was removed and four holes were drilled into a hard plastic called Aquaplast (WFR/Aquaplast Corp.; Avondale, PA) in the places where the markers had been taped to the cluster. When heated, Aquaplast becomes flexible and can be molded to better fit the tibia and the calcaneus. Once the Aquaplast cools, it hardens and keeps its shape. Then, four new markers with internal threading were then fixed to the Aquaplast with four plastic screws. The padding layer was reattached with double-sided tape. This method effectively ensured that the markers on the tibial cluster would remain rigidly fixed to the molded plastic plate throughout the entire testing procedure. (See Figure 3.4)



Figure 3.4 Tibial marker cluster after changes were made

3.2.2 Calcaneus Cluster I

More complex problems affected the calcaneus marker clusters. Two iterations of the calcaneus cluster were made during this process. The first issue addressed when creating the first of these calcaneus clusters was that one of the medial markers on the right calcaneus often hit the left foot during walking. This caused the participant to walk either with a wider stance or to simply hit the marker and change the position of the cluster on the calcaneus. A wider stance would mean that the participant would not be walking normally and thus the data collected about moments about the subtalar joint would not accurately reflect the moments that typically occur. In addition, hitting the marker with the opposite foot and causing cluster shifting means that the location of the clusters now indicate the axis is. This leads to inaccurate calculations of moments about the subtalar joint axis.

Therefore, the four stalks were removed from the cluster, and new placement of the markers was analyzed. It was determined that there was not enough space on the Aquaplast cluster to place all four stalks in such a way as to not interfere with the opposite foot. Thus, a new way of placing the stalks had to be devised. This led to the idea of having several plastic offshoots machined. These knobs each had two threaded holes that would fit the marker stalks, with each hole set at a 30° offset on either side of the middle of the knob. The knobs had a threaded hole on the bottom as well so that it could be fixed to the cluster with a screw. This two-holed design of these knobs allowed for two marker stalks to come from the same area, thus allowing all four marker stalks to fit appropriately on the cluster without interfering with the other foot. All four marker

stalkers were attached to the cluster and participants were able to walk without either hitting the markers or walking with a wider stance.

The next issue addressed was whether the placement of the calcaneus cluster was altered during walking by the fatty tissue located under the heel. There was a concern that during walking, the fatty tissue would compress, causing the skin around the calcaneus to bulge, and the marker cluster to move relative the the calcaneus. As mentioned previously, cluster movement creates problems when trying to calculate subtalar joint moments accurately. In order to see if this fatty tissue was causing any problems, the cluster was pilot tested. The marker cluster was attached to two different pilot subjects and video footage of the cluster as the foot hit the ground was taken. No substantial sudden movement of the cluster was seen around the time of heel strike. In addition, motion analysis data (calcaneus cluster marker locations) were collected during walking. Again, no cluster movements consistent with fat pad bulging were seen, thus reducing concern regarding the potential problem of the fatty heel tissue.

Thus, with this new calcaneus cluster, all identified problems with the original cluster were addressed and official pilot data collection began. However, during this testing several new problems with the first cluster became apparent, leading to the second iteration of the calcaneus cluster.

3.2.3 Calcaneus Cluster II

The first issue at hand was that the data for one of the pilot subjects had to be thrown out due to migration of the calcaneus cluster during the walking trials. It had been thought that a self-adhering taping product called Coban (3M Corp.; St. Paul, MN) was enough to attach the cluster to the foot but this turned out not to be the case during pilot testing, when migration of the calcaneus cluster was observed. Therefore, to address this problem, double-sided tape was added to the part of the padding on the cluster that came in contact with the calcaneus. This would keep the cluster flush against the skin. In addition, Coban was then used to secure the cluster to the foot (see Figure 3.5).



Figure 3.5 Wrapping of Coban around ankle to secure calcaneus cluster to foot

Some of the migration was also thought to result from the inertia of the cluster. The 0.125 in diameter steel threaded rod stalks added extra weight to part of the cluster; a cluster whose weight was more evenly distributed would cause less cluster movement and also be less likely to interfere with the participant's natural gait. The metal stalks were replaced with lightweight plastic stalks of the same length. The plastic knobs were replaced with lighter plastic knobs as well. Each knob had two holes drilled at locations that would lead to the marker stalks having the least amount of interference with the opposite foot while maintaining the greatest amount of clearance from the floor and the foot and leg.

An all-purpose glue (Gorilla Glue Co.; Cincinnati, OH) was used to attach the stalks to the Aquaplast and the markers to the stalks. This permanent attachment of the stalks to the Aquaplast also targeted another problem seen during the pilot testing. The metal stalks had been difficult to secure to the Aquaplast and thus could easily move. This movement of the markers could lead to the problems mentioned previously. In addition, it was noted that the padding along the inside of the cluster was pulling away, no longer being flush against the Aquaplast. If the padding is not flush against the cluster, then the calcaneus is not flush against the cluster, and incorrect movements of the calcaneus may be recorded. Therefore, Gorilla Glue was also used to fix the padding flush against the Aquaplast.

It was hoped that with these changes that the second iteration of the calcaneus cluster (see Figure 3.6) would be better able to accurately reflect the movement of the calcaneus.



Figure 3.6 Calcaneus marker cluster II

3.3 Creation of the Arch Height Measurement System

The purpose of this research is to see how arch height affects the mechanics of the subtalar joint. By carrying out an extensive literature review of different ways to classify and measure arch height, it was determined that the most common way is to use the Arch Height Measurement System (AHMS) to find the Arch Height Index (see Figure 3.7). The Arch Height Index is the ratio of the arch height at one-half the total foot length to the truncated foot length. This method has demonstrated high inter-rater and intra-rater reliability. Thus, Dr. Jinsup Song from Temple University was contacted for the specific design of the AHMS and the device was machined at Noll Laboratory by Denny Ripka. The AHMS was made to measure the Arch Height Index for right feet. However, the device can be taken apart and put together to measure left feet as well.



Figure 3.7 Top view of Arch Height Measurement System

3.4 Establishment of the Protocol

A detailed, established protocol is not only necessary so that the same process is carried out for every subject in the study, but so that other researchers can repeat the same protocol without deviating from the original study. The process of establishing a protocol was a lengthy process of trial and error in which several different problems were encountered and addressed.

3.4.1 Tipping of the SAL Base

The first of these problems was that the SAL base would tip during foot wagging. This meant that force of the polyurethane cord was not just causing the right amount of dorsiflexion of the foot. Without the correct amount of dorsiflexion, the talocrural joint may not be immobilized and so subtalar joint motion and talocrural joint motion could be seen. In addition, the tipping of the SAL base could mean that the force of wagging the foot was not simply causing subtalar joint motion either. This could also potentially mean that subtalar joint and talocrural joint motion were seen.

In order to fix the problem of the SAL base tipping, the base was fixed to a 2'x4'x1" piece of plywood with Gorilla Glue. The researcher would stand on the plywood platform while wagging the foot, further preventing the base from tipping.

3.4.2 Common Speed across Subjects

Another problem with the original protocol was that no controlled-speed was chosen for the subjects; trials were only taken at the subjects' comfortable speed. This prevents any comparison of subtalar joint moments at a specific speed across subjects. The controlled-speed was set to 1.5 m/s and an existing timing system that uses optical sensors, reflectors and a digital timer was used. The optical sensors were the located on the ceiling and the reflectors were located on the floor along the walkway. There were two pairs of reflectors that were 5m apart along the walkway. The two reflectors in each pair were located 2m apart across from each other. Thus, this system was used to ensure that each subject walked at 1.5 m/s +/- 10%. This meant that each subject walked at his comfortable speed for five good trials and at 1.5m/s +/-10% for five good trials. In practice, about ten trials at each speed were required to obtain five good trials.

3.4.3 Appropriate Foot Placement on Force Plates

During the original protocol, the researcher made sure that the right foot- which was the foot with the markers- hit squarely on the force plate. However, nearly all of these trials also included the left foot hitting the force plate in some way as well. This created problems because more than one foot hitting the force plate leads to inaccurate readings of ground reaction forces since force plates cannot isolate forces from each foot. Just one total reading of all the forces exerted everywhere on the force plate is outputted. Thus, the protocol was edited to indicate that only the right foot can touch the force plate during data collection (see Appendix A for protocol).

3.5 Post-Processing

In order to turn the motion analysis and force plate raw data into useful data such as subtalar joint axis location and subtalar joint moments, we had to use carry out postprocessing with Matlab code. First, the locations of the marker clusters were found in the global reference plane. Then, an anatomical coordinate system was created by looking at one frame of the Landmark Anatomical Markers trial and identifying the location of the head of the second metatarsal (T), lateral malleolus (LM), medial mallelous (MM), the lateral femoral epicondyle (LFE), and the medial femoral epicondyle (MFE). Then the inter-malleolar midpoint (IM) was calculated as the midpoint between the LM and MM and the inter-condyler midpoint (IC) was calculated as the midpoint between the LFE and MFE (see Figure 3.1).



Figure 3.8 Location of anatomical landmark markers

The next step is to establish the tibial coordinate system. The origin of the tibial coordinate system were located at IM, the z unit vector was in the direction of the line segment from LM to MM, the x unit vector was in the direction of the cross product of the line from IC to MM and the z vector, and the y unit vector was in the direction of the cross product of the z unit vector and the x unit vector. The tibial cluster markers were then identified in the tibia anatomical frame.

The calcaneus coordinate system was then established. The origin was located at IM, the y unit vector was in the direction of the global y, the z unit vector was in the

direction of the cross product of line from T to IM and the y vector, and the x unit vector was in the direction of the cross product of the y vector and the z vector. At this point the calcaneus cluster markers were identified in the calcaneus anatomical frame.

Helical axes representing subtalar joint rotation were computed from the relative motion of the tibia and calcaneus in the following manner. Homogeneous 4x4 transformation matrices describing the motions of the tibia and calcaneus with respect to the ground were found from the tibia and calcaneus cluster markers using a least squares technique (Challis 1995) and from those transformations, tibia to calcaneus transformations were computed. Displacement matrices describing changes between tibia-to-calcaneus transformation that occurred between frames were computed for all possible pairs of frames. Helical axes were computed from these displacement matrices (Spoor & Veldpaus 1980). The resulting collection of helical axes was then used to find a single average axis using the confluence axode techniques described by Lewis et al. (2006).

This subtalar joint axis found in using the above procedure from SAL trial data was defined by the point P on the axis and the unit vector **u** along the axis, both expressed relative to the calcaneus frame. Moments of the ground reaction force about the subtalar joint axis during walking were computed according to:

$$\mathbf{M}_{\mathrm{STJ}} = \mathbf{u} \cdot (\mathbf{r} \ge \mathbf{F})$$

where M_{STJ} is the moment about the subtalar joint, **r** is the distance from P to the center of pressure (COP) and **F** is the ground reaction force vector originating from the COP (see Figure 3.9)



Figure 3.9 The necessary values to calculate the moments about the subtalar joint axis

CHAPTER FOUR

RESULTS

The Arch Height Measurement System was tested 16 different times with 8 subjects aged 21-22 (2 males, 6 females). During these 16 trials, the average arch height index was 0.380+/-0.03 (range 0.330-0.427). In addition, the average intersubject standard deviation was 0.014.

The average inclination angle for all three subjects was 12.8 +/- 10.7 while the average deviation angle was 10 +/- 5.0 (see Table 4.1). For all three subjects, there is an inversion force exerted by the muscles on the foot while the ground reaction forces are exerting an eversion force during the first 20% of stance (see Figures 4.1-4.6). Then, the muscles exert an eversion force for nearly the rest of stance. In Subjects 2 and 3, however, there was a clear eversion moment at the end of stance. In general, among each subject, each trial resulted in very similar STJ moments. There was one trial during the comfortable speed with Subject 3 that was thrown out because the right foot did not completely touch the force plate. The general shape of the curve of STJ moments throughout stance are very similar between the comfortable speed and 1.5 m/s.

	Inclination Angle (deg.)	Deviation Angle (deg.)
Present study (n=3)	12.8 +/- 10.7 (1-22)	10 +/- 5.0 (5-15)
Inman (1976) (n=46)	42 +/- 9 (21-69)	20 +/- 11 (1-44)
van Langelaan (1983) (n=10)	41 +/-9 (28-55)	26 +/- 8 (7-35)
Leardini et al. (2001) (n=6)	53 +/- 6 (44-61)	38 +/- (33-47)
Lewis et al.(2009) (n=25)	33.4 +/- 10.7 (12-63)	18.0 +/- 10.4 (3-37)

Table 4.1 Comparison of inclination and deviation angles from various studies



Figure 4.1 Subtalar joint moments normalized by body weight plotted versus percent stance for Subject 1 walking at a self-selected comfortable speed. Three trials are shown. Positive values indicate an internal inversion moment, with the ground reaction force everting about the subtalar joint. In each trial a small internal inversion moment in early stance was followed by a larger internal eversion moment in late stance.



Figure 4.2 Subtalar joint moments normalized by body weight plotted versus percent stance for Subject 2 walking at a self-selected comfortable speed. Three trials are shown. Positive values indicate an internal inversion moment, with the ground reaction force everting about the subtalar joint. In each trial a small internal inversion moment in early stance was followed by a larger internal eversion moment in late stance.



Figure 4.3 Subtalar joint moments normalized by body weight plotted versus percent stance for Subject 3 walking at a self-selected comfortable speed. Three trials are shown. Positive values indicate an internal inversion moment, with the ground reaction force everting about the subtalar joint. In each trial a small internal inversion moment in early stance was followed by a larger internal eversion moment in late stance.



Figure 4.4 Subtalar joint moments normalized by body weight plotted versus percent stance for Subject 1 walking at 1.5 m/s. Three trials are shown. Positive values indicate an internal inversion moment, with the ground reaction force everting about the subtalar joint. In each trial a small internal inversion moment in early stance was followed by a larger internal eversion moment in late stance.



Figure 4.5 Subtalar joint moments normalized by body weight plotted versus percent stance for Subject 2 walking at 1.5 m/s. Three trials are shown. Positive values indicate an internal inversion moment, with the ground reaction force everting about the subtalar joint. In each trial a small internal inversion moment in early stance was followed by a larger internal eversion moment in late stance.



Figure 4.6 Subtalar joint moments normalized by body weight plotted versus percent stance for Subject 3 walking at 1.5 m/s. Three trials are shown. Positive values indicate an internal inversion moment, with the ground reaction force everting about the subtalar joint. In each trial a small internal inversion moment in early stance was followed by a larger internal eversion moment in late stance.

The normalized magnitude of the average peak eversion moment for each subject during walking trials at 1.5 m/s were greater than those at the comfortable speed (see Figure 4.7). Peak eversion moment also increased with increasing arch height (see Figure 4.7). The normalized peak inversion moment was greater during the comfortable speed with two of the subjects, but there seemed to be no potential correlation between arch height and peak inversion moment (see Figure 4.8). As arch height increased, there was also an increase in deviation angle, but there seemed to be no trend between arch height and inclination angle (see Figure 4.9). In addition, the peak eversion moment increases with increasing deviation angle for both speeds (see Figure 4.10). It is unlikely that there is a correlation between peak eversion moments and inclination angles at either speed (see Figure 4.11), but there does seem to be the potential for a positive relationship between peak inversion moment and inclination angle at the comfortable speed (see Figure 4.12). No potential correlation is seen between peak inversion moments and deviation angle at either speed (see Figure 4.13).



Figure 4.7 Magnitude of the average peak internal eversion moments normalized by body weight plotted versus arch height index. Three subjects each represented by a different arch height index are shown. Moments are the average of five trials.



Figure 4.8 Magnitude of the average peak internal inversion moments normalized by body weight plotted versus arch height index. Three subjects each represented by a different arch height index are shown. Moments are the average of five trials.



Figure 4.9 Average inclination and deviation angles plotted versus arch height index. Three subjects each represented by a different arch height index are shown. Angles are the average of three SAL trials.



Figure 4.10 Magnitude of the average peak internal eversion moments normalized by body weight plotted versus deviation angle. Three subjects each represented by a different deviation angle are shown. Moments are the average of five trials. Deviation angles are the average of three SAL trials.



Figure 4.11 Magnitude of the average peak internal eversion moments normalized by body weight plotted versus inclination angle. Three subjects each represented by a different inclination angle are shown. Inclination angles are the average of three SAL trials. Moments are the average of five trials.



Figure 4.12 Magnitude of the average peak internal inversion moments normalized by body weight plotted versus inclination angle. Three subjects each represented by a different inclination angle are shown. Inclination angles are the average of three SAL trials. Moments are the average of five trials.



Figure 4.13 Magnitude of the average peak internal inversion moments normalized by body weight plotted versus deviation angle. Three subjects each represented by a different deviation angle are shown. Deviation angles are the average of three SAL trials. Moments are the average of five trials.

CHAPTER FIVE

DISCUSSION

5.1 Results Summary

The purpose of this study was to determine whether subtalar joint (STJ) mechanics during gait depend upon- arch height. The inclination and deviation angles of the subtalar joint axis were measured using a motion-based technique in which a specialized loading apparatus was used to apply subtalar joint motion. Peak inversion and eversion moments exerted by muscles about the STJ axis were computed from motion analysis and force plate data. Arch height indices were measured using a caliper specially designed for this purpose.

The average inclination angle for all three subjects was 12.8 +/- 10.7 degrees while the average deviation angle was 10 +/- 5.0 degrees. The average inclination angle was much less than the previous studies by Inman (1976), van Langelaan (1983), Leardini et al. (2001), and Lewis et al. (2009) (see Table 5.1). The average deviation angle was similar to that of the study by Lewis et al. (2009) but there were differences when compared to other similar studies.

	Inclination Angle (deg.)	Deviation Angle (deg.)
Present study (n=3)	12.8 +/- 10.7 (1-22)	10 +/- 5.0 (5-15)
Inman (1976) (n=46)	42 +/- 9 (21-69)	20 +/- 11 (1-44)
van Langelaan (1983) (n=10)	41 +/-9 (28-55)	26 +/- 8 (7-35)
Leardini et al. (2001) (n=6)	53 +/- 6 (44-61)	38 +/- (33-47)
Lewis et al.(2009) (n=25)	33.4 +/- 10.7 (12-63)	18.0 +/- 10.4 (3-37)

Table 5.1 Comparison of inclination and deviation angles from various studies

All three subjects exhibited STJ moment patterns during gait that were consistent with those previously measured by Scott and Winter (1991) (see Figure 5.1) in which each subject demonstrated a slight internal inversion moment that gave way to a larger internal eversion moment. These peak eversion moments averaged about 0.5 Nm/kg in the Scott and Winter (1991) study as opposed 0.19 Nm/kg in this study.



Figure 5.1 The unnormalized STJ moments found during stance in the study by Scott and Winter (1991) (above) were similar to the average normalized STJ moment across all three subjects in comfortable walking during early stance in this study (below).

The arch height indices obtained by the AHMS in this study were rather comparable to those measured by the AHMS at Temple University and the University of Delaware by Richards et al. (2005). The average AHI for this study was 0.391 while that of Temple University in the was 0.351 and that of the University of Delaware was 0.353. This comparable data indicates that the Penn State AHMS will be a reliable device for AHI measurement in future studies.

5.2 Possible Implications

The results from this study have several different implications. This study helped establish the repeatability of the AHMS that was developed in the Penn State Biomechanics Laboratory. This provides the Penn State Biomechanics Laboratory group with a reliable and previously-published classification of arch height that is used by biomechanists at Temple University and the University of Delaware. The AHMS can therefore be used with confidence in other studies related to arch height.

In addition, the results from the three SAL trials for each subject produced repeatable STJ axis locations. This confidence in the ability of SAL II to repeatedly output the same STJ axis location means that a faster, more efficient, and non-invasive method of STJ axis location. By improving the ease with which the axis can be located, further testing and studies of STJ mechanics can be carried out and more knowledge of subtalar joint mechanics in normal and pathological populations can be gained.

This study represents a preliminary attempt to understand how differences in subtalar joint mechanics may depend upon arch height. By using the finalized protocol along with the AHMS and the SAL II device, more knowledge can be gained on how arch height affects the mechanics of the foot and ankle in those with AAFD and other gait disorders.

5.3 Limitations

Limitations to this study include those related to the subject population, the data processing, and the assumptions related to the SAL device and markers. Because data were collected from only three subjects, no meaningful correlations or statistical tests could be made. The study was also limited in that the subjects were all healthy students between the ages of 21 and 22 years and of normal body weight. Studying older subjects or obese subjects might have yielded greater variation in arch height as arch height is known to decrease over time and with increased body weight. The subtalar joint axes computed from the SAL data in this preliminary study did not correspond well to axes measured in other studies, some of which employed techniques similar to those used here. Specifically, the STJ axes found here were less inclined with respect to the calcaneus X-Y (quasi-transverse) plane, and this calls into question the validity of the STJ moments measured during gait. These differences in axis orientation may be attributed to problems with implementation of the SAL method (such as problems with marker tracking during SAL trials), or to differences in how the calcaneus coordinate system was established. Another potential source of error comes from the assumption that there is little to no talocrural movement during the SAL trials. This assumption was validated for STJ axis location performed with SAL I using MRI by Lewis et al. (2009), but SAL II STJ axis location has not verified by MRI in this study, and it is possible that the loading of the foot has been altered by modifications to the device.

Similarly, the study assumes that the skin-mounted markers accurately track motion of the calcaneus and the tibia in both SAL trials and gait trials. This assumption is also supported by the work of Lewis et al. (2009). but has not been validated by tracking bone motions using imaging or other means.

5.4 Conclusion

This establishment of protocol and preliminary testing provides the basis for future studies of the relationship between arch height and subtalar joint mechanics. The SAL II device and this protocol could be used across a large population to see if there is a correlation between arch height index and STJ moments and/or STJ axis locations. This population would involve a range of ages and arch height indices. The population could then be divided into the categories of low AHI, medium AHI, and high AHI and then correlations to deviation angle, peak eversion moment, etc. could be made. During this study, the SAL trials could also be moved on top of a platform (approximately 3' in height) in the gait lab in order to improve the cameras' viewing capabilities of the calcaneus markers.

It may also be interesting to study subtalar joint moments of healthy subjects during stair-climbing and running, as this would provide great insight into the forces that occur in the ankle during more strenuous activities. Another possible future study would compare healthy subjects to those with acquired adult flatfoot deformity, pediatric flatfoot in cerebral palsy, or other gait disorders with substantial STJ involvement. Notable observations would include differences in STJ axis location and in STJ moments, leading to further understanding of the internal ankle mechanics of those with these disorders. This further understanding of subtalar joint axis location and moments could eventually lead to potential treatment options for those with these disorders.

There is a limited amount of information currently known about subtalar joint mechanics. Gait disorders affect these mechanics, but in ways not fully understood. By using the SAL II device, the Arch Height Measurement System, and the included established protocol there are a variety of different studies that can be pursued to better our knowledge of subtalar joint mechanics. With this knowledge will come the ability to understand various gait disorders like AAFD and thus leading to improved treatment options for those with these disorders.

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APPENDIX A

Final Protocol

Preliminary Steps

Before the subject arrives, calibrate the 6 camera motion analysis system with force plates. Make sure the correct marker set with the 14 markers is loaded. Once the participant arrives, obtain informed consent. If not already done, have the subject change into shorts and remove his shoes and socks. Record the subject's weight to the nearest quarter of a pound, and height to the nearest tenth of a centimeter.

Arch Height Measurement System

Then place the Arch Height Measurement System on a platform at the top of a transient staircase. The subject sits on a chair and places the right foot in the AHMS device, being sure the heel is pressed against the back curved surface. Then, adjust the truncated foot length locator to the location of the head of the first metatarsal. Make sure the foot and truncated foot length locator are touching. Now adjust the total foot length locator so that it is touching the most distal part of the foot. Record truncated foot length and total foot length to the nearest millimeter. Place the arch height locator at the location that is 2 cm greater than half the total foot length. Record the arch height to the nearest millimeter. Remove the subject's foot from the AHMS and repeat AHMS steps two more times. Have the subject stand and repeat.

Subtalar Axis Locator Set-up and Trials

The subject sits down in a chair next to the device and the right leg is placed on the SAL device, with the foot hanging off the end as much as possible. The foot is then strapped into the base with the Velcro strap, being sure that the closest end of the device is 14 cm from the bottom of the heel. The Velcro strap minimizes tibia motion during foot wagging so that more motion of the subtalar joint can be seen. Attach calcaneus cluster with double-sided tape. Then take 4" Coban and starting at the superior portion of the foot, wrap counterclockwise around the heel and the medial portion of the cluster. Then come up along the lateral side of the cluster, back around the medial portion and then up between the two sets of marker stalks. Cut the Coban and press it to itself. Be sure it is tight enough to ensure the cluster is held to the skin but not too tight as to restrict ankle motion or cause pain.

Next, the foot plate is strapped on and a length of polyurethane cord is attached to the turnbuckle based on the subject's shank length. Once the elastic cord is hooked onto the rear eye bolts of the base plate, the turnbuckle can be fine-tuned to ensure that tension is exactly 5 lbs by making sure the distance between the marks is 4 inches. It is important that 5 lb of force are exerted because this is the amount of force needed to minimize talocrural joint motion as established in the MRI studies by Lewis et al (2009). Next, the heights of the front eye bolts are adjusted while the wagging cords are taut so that the cords are aligned with the malleoli. By having the cords placed in this specific location, one ensures that all the moments applied to the foot pass as close to the talocrural joint axis as possible, thus immobilizing this joint. Attach tibial cluster with double-sided tape, being sure it does not interfere with the polyurethane cord. To establish a baseline marker pattern for the software, a static test must first be taken. Be sure all of the markers can be seen. Once completed, the full SAL testing can begin.

The computer should be set to run a 10 second trial while the operator gently and alternately pulls the handles until stiff resistance from the subject's ankle is felt. This

should be done to a metronome set at 60 BPM. Each trial should begin with the subject's foot in eversion. Then, at the first beat, the foot is moved to inversion, then eversion, inversion, etc. with each movement occurring at a beat. Repeat two more times and check the recordings to be sure that all 8 markers can be seen. Undo the straps and unclip the polyurethane cord. Carefully remove the subject's leg from the device, taking great care as to not hit or shift either marker cluster. If this does occur, the SAL trials must be redone.

Landmark Anatomical Markers

Place a marker at each location: head of the second metatarsal (T), lateral malleolus (LM), medial mallelous (MM), a location on the floor directly behind the center of the heel (H), the lateral femoral epicondyle (LFE), and the medial femoral epicondyle (MFE). Have the subject stand with tibia vertical and knees locked. Collect one 3-second trial. Remove the markers from the anatomical landmarks, leaving the tibia and calcaneal clusters in place.

Walking Trials

Before walking trials begin, zero the force plates. Have the subject start at the red line at the far end of the gait lab and have them begin walking when recording begins. They should look straight ahead and walk at their preferred comfortable speed. This is considered a good trial if the right foot hits the force plate completely. If the right foot only partially hits the force plate or if the left foot hits the force plate in any way, this is not a good trial. Record 5 good walking trials at this speed. Now, record 5 more good walking trials at 1.5 m/s, as determined by the electric eyes. Remove marker clusters.

APPENDIX B

Testing Data Sheet

Subject Name:		Subject #:	
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Birthdate: ____/___/____

Gender: $\square M$ $\square F$

- □ Calibration
- □ Informed consent
- □ Change clothes- shorts, no socks
- □ Height: _____ Weight: _____
- □ AHMS in chair on stairs

	Trial 1	Trial 2	Trial 3
Total Foot Length			
(cm)			
0.5 Total Foot			
Length (cm)			
Truncated Foot			
Length (cm):			
Arch Height taken			
at 0.5 Tot FL + 2			
cm (cm)			

□ SAL

- Put on calcaneus and tibia markers
- Static trial 0
- o 3 10s trials to metronome 60 bpm (start at eversion, inversion, etc.)
- □ Landmark Anatomical Markers
 - o 6 Locations: T, LM, MM, H, LFE, MFE
 - o Stand with tibia vertical and knees locked
 - Take 3 sec static trial
 - Remove markers
- □ Take 5 good walking trials at each speed
 - o comfortable
 - o 1.5 m/s

VITA

Katherine K. O'Kelly

EDUCATION

B.S. Bioengineering, B.S. International Studies

The Schreyer Honors College at The Pennsylvania State University University Park, PA Study Abroad, Alicante, Spain, Spring 2009

Avondale, PA

Elkton, MD

WORK EXPERIENCE

Electronic Products Quality Engineering Intern

W.L. Gore & Associates

- Benchmarked electrical and mechanical performance of microwave cable assemblies and created a . sampling plan to monitor future products
- Analyzed electrical and mechanical capabilities of connector redesign while examining and determining specific failure modes

Medical Products Engineering Research and Development Intern

W.L. Gore & Associates

- Characterized mechanical performance of new hernia patch product designs
- Researched market performance of competitive medical products as part of a hernia patch benchmarking project

RESEARCH EXPERIENCE

Biomechanics Research Laboratory Assistant

The Pennsylvania State University

- Kinesiology Department 2010 - 2011 Validated repeatability of a device for non-invasive ankle joint location and made necessary mechanical alterations to the design
- Analyzed ankle joint moments through the collection of ground reaction forces and joint motion data during walking

Mechanical Engineering Research Laboratory Assistant

The Pennsylvania State University Mechanical Engineering Department Sept. 2008 - Jan. 2009

- Redesigned suturing instrument used for minimally-invasive endoscopic surgery
- Created and developed a surgical instrument training device for testing prototype performance

LEADERSHIP/ACTIVITIES

Physicians for Human Rights

President, 2010-2011

- Coordinated seminars with professionals in the field of international healthcare to promote campus-wide awareness of global health inequities
- Vice President and Fundraising Chair, 2009-2010
- Organized a service trip to Tanzania to assist with patient treatment
- Led fundraising campaigns to finance the organization's service trip

Mashavu Medical Device Design Group

- Designed and constructed a low-cost thermometer to promote affordable healthcare in Kenya
- Built circuitry of the device to allow for direct connection to a computer so that the patient's health information could be quickly and accurately uploaded to an online database

Summer 2010

Summer 2009