Age-related differences in foot structure and mobility

N. Marcial[1,2], U. Kuruganti[2] and V. Chester[2]

[1] University of New Brunswick/ Mechanical Engineering, Fredericton, Canada
[2]Andrew and Marjorie McCain Human Performance Laboratory/ University of New Brunswick, Fredericton, Canada

Abstract— **Previous research has suggested that changes in foot anthropometrics occur with age, however, further research is warranted. The use of portable technology, such as of three-dimensional (3D) body scanners, to collect foot anthropometrics facilitates the exploration of potential differences between and within individuals. Therefore, the purpose of this study was to examine age-related differences in foot anthropometrics using a 3D foot scanner. Sixteen young (8 males, 8 females, mean age 23.6±3.7 years) and sixteen older (8 males, 8 females, mean age 71.6±5.9 years) adults without foot deformities or lower-extremity injuries were recruited. Eight anthropometric measures of each foot were obtained during weight bearing (WB) and non-weight bearing (NWB) conditions using a portable, white light, 3D scanner (TechMed 3D Inc., QC). Measures included dorsal arch height (DAH), foot length (FL), truncated foot length (TFL), forefoot width (FFW), midfoot width (MFW), rearfoot width (RFW), arch height ratio (AHR) and foot mobility magnitude (FMM). Significant differences in foot measures between age groups were analyzed using an independent samples t-test. A secondary comparison between age groups was also evaluated using an analysis of covariance (ANCOVA) with TFL as a covariate. The older group had greater arch height ratio (AHR) during weight bearing (WB) and non-weight bearing (NWB), as well as greater dorsal arch height (DAH) in the NWB condition, suggesting that the older group had a higher arch. Further, the older group had significantly greater rearfoot width (RFW) during WB than the younger group, indicating a greater splay of the metatarsus in the older group. After controlling for the TFL, the older group also showed a greater DAH in the NWB condition. In addition, the forefoot width (FFW), RFW and midfoot width (MFW) in the NWB condition were also significantly greater for the older adults. Furthermore, for the WB condition, the older group had significantly greater DAH and RFW. Additionally, the older group showed less mobility of the foot. Preliminary results based on the sample size of the study provide evidence of anthropometric foot variations between younger and older adults. Examining differences in foot structure and mobility between younger and older adults is fundamental for comprehending foot mechanics and function during movements, such as gait.**

Keywords— **Foot structure, foot mobility, foot anthropometrics, 3D body scanner.**

I. Introduction

Previous research has identified age-related changes in foot structure and mobility. Changes in foot structure with age include lowering of the transverse arch [1, 2], increased soft tissue stiffness [3], toe deformities, as well as flatter, longer, and wider feet than younger adults [2,4]. Age-related changes in foot function include decreased proprioception [5], and decreased muscle strength, such as ankle and toe plantarflexor weakness [2,6,7]. Toe plantarflexor weakness affects the grasping function of the toes in older adults when executing weight-bearing activities, resulting in impaired balance and functional ability [3]. Age-related changes in foot mobility include decreased range of motion (ROM) of the ankle and 1st metatarsophalangeal (MTP1) joints [2,6,7,8,9], a decreased subtalar joint inversion-eversion ROM, a more pronated posture of the foot as well as a more pronated position with reduced joint mobility and less efficient propulsion when walking [3]. Due to the important role played by the foot in adapting to uneven terrain, a reduced ROM in the joints of the foot and ankle is strongly associated with impaired balance and functional ability in older people [10,11]. Such age-related changes may lead to alterations in foot mechanics during movement and could impact an individual's quality of life.

Various methods have been used to measure foot structure and mobility, including clinical assessments, radiographs, and magnetic resonance imaging. Limitations of these methods include subjectivity [12], cost, limited access, and radiation exposure. Previous research has shown that three-dimensional (3D) scanners are very accurate and provide higher inter- and intra-rater reliability [13,14] compared to manual measurements. This portable technology addresses most of the limitations mentioned above and provide researchers and clinicians with reliable and accurate subject-specific images and anthropometric measures. In addition, data collection is relatively rapid and safe for both paediatric and adult populations. Therefore, the aim of the study was to determine age-related differences in foot structure and mobility using a 3D foot scanner. To our knowledge, no previous studies have compared the foot structure and mobility between older and younger adults using a 3D body scanner. The study of these differences will allow a better understanding of how clinical changes in foot structure and mobility may impact movement in older populations.

II. Materials and methods

A. Participants

Thirty-two healthy adults (n = 32) participated in the study. Sixteen young participants (8 male, 8 female, mean age 23.62 ± 3.73 years, mean weight 69.1 ± 16.4 kg, mean height 1.71 ± 0.12 m) and sixteen older participants (8 male, 8 female, mean age 71.64 ± 5.94 years, mean weight 82.9 ± 13.0 kg, mean height 1.71 ± 0.12 m) with no known musculoskeletal conditions or lower-extremity injuries were recruited. The study was approved by the University Research Ethics Board (REB ##2014-049). Informed consent was obtained from all participants. The study was conducted according to the Declaration of Helsinki.

B. Instrumentation

A white-light 3D body segment scanner (TechMed 3D Inc., Quebec City, QC), which captures 13 frames per second was used to collect eight foot measurements (Table 1). Also, a high contrast material fabric (white and black) was used as a backdrop (Fig. 1) and placed over the floor to mask the floor or any other unwanted surface (i.e. to ensure a clear image of the foot was collected when the participants were in a particular stance/sitting position). Moreover, six adhesive reflective markers that are registered by the scanner were placed on six different anatomical landmarks of each participant's foot. These markers have a circular reflective surface that is 6 mm in diameter, and a black border that is 2 mm wide. In addition, MSoft (MSoft 3.0, TechMed 3D Inc., Quebec City, QC), which is a data acquisition and processing tool, was used to render the 3D image of the scanned foot. Height and weight of participants were measured using a weight scale and stadiometer.

C. Procedure

All data were collected in the Andrew and Marjorie McCain Human Performance Laboratory at the University of New Brunswick. Measurements of the foot were obtained using the Techmed 3D scanner (Fig. 1). Prior to scanning the foot, each participant was asked to stand with their feet shoulder-width apart in order to place the reflective scanner markers on the foot (Fig. 2). The scanner markers were placed on the first and fifth metatarsophalangeal joints, the medial and lateral aspect of the midfoot, and the medial and lateral aspect of the heel.

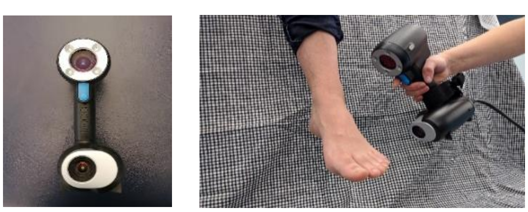

Fig. 1 Handheld portable scanner and high contrast material background.

Table 1 Foot measurement definitions.

Foot measurement	Definition
Forefoot width (FFW)	Width between the most medial portion of the 1st metatarsophalangeal joint and the most lateral portion of the 5th metatarsophalangeal joint [13].
Midfoot width (MFW)	The width perpendicular to 50% of the foot length on both the medial and lateral sides of the foot [15].
Rearfoot width (RFW)	Width at 16% of the foot length on both the medial and lateral sides of the foot [13].
Foot length (FL)	Distance from the pternion to the tip of the longest toe [15].
Truncated foot length (TFL)	Distance between the pternion of the heel to the joint line of the 1st metatarsophalangeal joint [16].
Dorsal Arch Height (DAH)	Distance between the supporting surface and the highest point of the instep taken at 50% foot length [17]. Also known as instep height.
Arch height ratio (AHR)	Calculated as a ratio of DAH during weight bearing to the participant's TFL [17].
Foot mobility magnitude (FMM)	A composite measure of ΔDAH and ΔMFW and is calculated by taking the square root of the sum of both variables after each has been squared [18].

The two markers for the metatarsophalangeal joints were identified through palpation, the two midfoot markers were placed according to 50% of foot length, and the two heel markers were placed according to 16% of foot length, both measured by a custom 3D printed device (Fig. 3). After the reflective scanner markers were placed, participants were asked to complete two scans: 1) weightbearing (WB) and 2) non-weightbearing (NWB). The WB scans were performed first. For the WB scans, the participants stood with their feet shoulder-width apart and their weight distributed evenly across both feet. For the NWB scans, participants were asked to sit at the end of a table with both legs hanging in a perpendicular position from the knee to the ankle, perpendicular to the thigh and the floor with their hands at their sides [18,19,20]. Once the position was reached for WB and NWB conditions, the scans of both feet were captured for a total of 4 scans (2 scans x 2 feet). Following the procedure, the scanner markers were removed.

D. Data Analysis

Three-dimensional marker coordinates from the reflective scanner markers were used to measure FFW, MFW and RFW. The rest of the measurements previously mentioned were automatically measured by the 3D scanner. Post-processing of the 3D scans was completed using the MSoft software. The scanning process displayed a rendered 3D mesh of the foot. First, the accepted 3D scan was aligned so the software could compute accurate 3D foot measurements. Once aligned, the unnecessary parts of the mesh were removed.

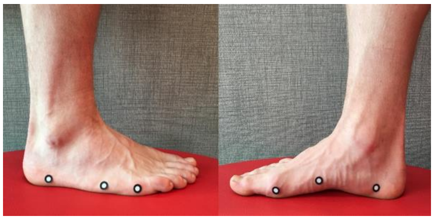

Fig. 2 Lateral and medial view of the foot with the markers.

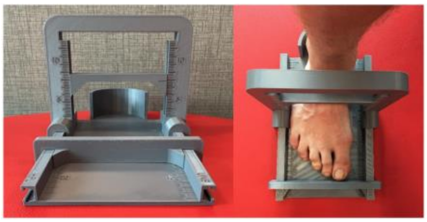

Fig. 3 Custom 3D printed device.

The software generated a final rendering of the mesh and outputted a 3D image in SDL format. Afterwards, the "point-to-point distance" function created a 3D vector of the shortest distance between scanned reflective markers to extract the forefoot, midfoot and rearfoot marker. After post-processing was completed, the foot measurements were exported for statistical analysis. Significant differences ($p<0.05$) in foot measures between age groups were analyzed using an independent samples t-test. To address reduced foot length, that may result as a function of toe deformities, a secondary test between age groups was completed using an analysis of covariance (ANCOVA) with TFL as a covariate. All statistical analyses were completed using R Studio (RStudio 2018, RStudio, Inc., USA).

III. Results

Significant differences in the majority of foot measurements were found between age groups. For the weight bearing (WB) condition, the older group had a dorsal arch height (DAH) and rearfoot width (RFW) greater than the younger group. These results suggest that the older group had a higher arch and a greater splay of the calcaneus. After controlling for the truncated foot length (TFL), the older group also showed a significantly greater DAH and RFW. For the non-weight bearing (NWB) condition, the older group had a greater arch height ratio (AHR) and greater DAH than the younger group. After controlling for the TFL, the older group also showed a greater DAH in the NWB condition. In addition, the forefoot width (FFW), RFW and midfoot width (MFW) in the NWB condition were also significantly greater for the older adults (Table 2). Although there were no significant differences between groups for the foot mobility magnitude (FMM), the older group demonstrated less mobility of the foot.

Table 2 Independent sample t-test and ANCOVA results.

Foot measurement	Condition	Younger (N=16) Mean ± SD	Older (N=16) Mean ± SD	t-test P value	ANCOVA P value
DAH (cm)	WB	6.6 ± 0.69	6.85 ± 0.54	0.10	<.001
FL (cm)	WB	25.70 ± 2	25.88 ± 1.39	0.67	-
TFL (cm)	WB	19.07 ± 1.54	18.73 ± 1.11	0.31	-
FFW (cm)	WB	9.43 ± 0.94	9.42 ± 0.62	0.96	0.25
RFW (cm)	WB	6.24 ± 0.6	6.65 ± 0.64	0.01	<.001
MFW (cm)	WB	8.64 ± 0.95	8.64 ± 0.55	0.99	0.22
AHR	WB	0.34 ± 0.02	0.36 ± 0.02	<0.01	-
DAH (cm)	NWB	7.22 ± 0.61	7.5 ± 0.49	<0.05	<.001
FL (cm)	NWB	24.57 ± 2.06	24.55 ± 1.47	0.97	-
TFL (cm)	NWB	18.24 ± 1.63	17.74 ± 1.19	0.16	-
FFW (cm)	NWB	8.38 ± 0.90	8.53 ± 0.52	0.43	<.01
RFW (cm)	NWB	5.95 ± 0.53	6.42 ± 0.59	<0.01	<.001
MFW (cm)	NWB	7.95 ± 0.81	8.05 ± 0.42	0.53	<.01
AHR	NWB	0.39 ± 0.02	0.42 ± 0.02	<0.001	-
FMM	-	0.95 ± 0.25	0.91 ± 0.23	0.52	-

IV. Discussion

This study aimed to examine the differences in foot structure and mobility between younger and older adults. The results suggest age-related differences in foot structure and mobility, particularly in the arch height and rearfoot width.

When the foot is loaded by the body weight, the foot structure experiences deformations such as widening between the first and fifth metatarsal. In this study, the older group showed a significantly wider RFW, in both the WB and NWB condition. The MFW and FFW were also significantly wider for the older group in the NWB condition. These findings are supported by previous research [2,4]. While previous studies have reported that older adults have longer feet [2,4], our analysis showed no significant differences in FL between age groups.

The older group exhibited a significantly higher arch in both the WB and NWB condition, as indicated by AHR. Previous research has shown varied results regarding the arch height in older adults. A few studies [2,4] have reported that the elderly (+65 years old) tend to have flatter feet. However, one study [19] found that older adults (65- 70 years old) had a greater foot arch height. These three studies used different techniques and instruments to measure the arch height (manual measurements and plantar pressure mats) and therefore, the comparison of data is challenging.

The AHR is calculated as a ratio of DAH during weight bearing to the participant's TFL and has been reported to have high within- and between-rater reliability [16].

Nonetheless, inconsistencies in the literature, such as different definitions for TFL as well as the percentage of weight bearing used to obtain the DAH, make comparisons of the results between studies difficult. Further, the older group showed a lower FMM, suggesting less mobility of the foot for the older adults. It has been previously reported low-arched feet are usually more mobile, and high-arched feet tend to be stiffer [20]. Similarly, our findings showed a higher arch height and less mobile foot (i.e. stiffer feet) for the older group. Moreover, Arnold et al. [21] has reported reduced mobility of the older foot during dynamic movement. This reduction in foot mobility may be reflected in a balance impairment in the older adults [10]. Also, Cornwall and McPoil [22] found that participants with greater foot mobility as measured by the FMM, had greater MFW compared to participants with less foot mobility. However, in our study there were no significant differences for the MFW between younger and older adults in the WB condition. The opposite was found in the present study for the NWB condition, where the younger group had greater foot mobility but showed a significantly reduced MFW when compared to the older group. As only a few studies have examined age-related differences in foot structure and mobility using objective methods (e.g. pressure mats and radiographs), and no other studies have used a 3D body scanner, arch height data is inconsistent across studies. The arch structure has an important role when evaluating the foot function in the clinical setting, as it is often used to classify the posture of the foot.

Limitations of the current study include small sample size, possible marker placement error and uneven weight distribution. While participants were asked to stand with their feet shoulder-width apart and their weight distributed evenly across both feet, it is possible that participants did not distribute their weight evenly on their feet when standing, explaining the increased AHR and RFW for the WB condition. However, this would not explain the significantly increased AHR and RFW during the NWB condition in the older group. Therefore, future recommendations include increasing sample size and relating age-related differences in foot structure and mobility to dynamic movement.

V. Conclusion

This is the first study to use a 3D body scanner to examine age-related differences in foot structure and mobility. The preliminary results of this work suggest age-related differences in foot structure and mobility. Further research is warranted to examine the impact of these changes on foot/ankle mechanics and function. This knowledge may be useful for understanding typical and atypical motions in older individuals.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Author: Nayeli Marcial
Institute: University of New Brunswick
Street: 15 Peter Kelly Dr.
Country: Canada
Email: nayeli.marcial@unb.ca