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Original Article

Altered stiffness of microchamber and macrochamber layers in the aged heel pad: Shear wave ultrasound elastography evaluation

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KEYWORDS
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Abstract *Background/Purpose:* To compare shear modulus of heel pad microchamber and macrochamber layers between young and elderly people using shear wave ultrasound elastography (SWUE), with the intent to clarify age-related changes.
Methods: This single-center prospective cross-sectional study was conducted between March, 2014 and March, 2016. Shear modulus of entire heel pad (G_{entire}), macrochamber layer (G_{mac}), and microchamber layer (G_{mic}) were measured with SWUE.
Results: Elderly participants (15 men, 15 women; age = 66.9 ± 6.2 years) had significantly higher G_{mic} (103.8 ± 20.7 vs. 60.1 ± 9.8 kPa; $p < 0.001$) and G_{entire} (39.4 ± 10.5 vs. 34.1 ± 5.4 kPa; $p = 0.005$), but a significantly lower G_{mac} (21.7 ± 7.5 vs. 27.9 ± 4.9 kPa; $p < 0.001$) compared with those of young participants (15 men, 15 women; age = 26.4 ± 2.9 years). Positive correlations were observed between age and G_{mic} ($r = 0.79$, $p < 0.001$) and between age and G_{entire} ($r = 0.28$, $p = 0.03$), and negative correlation between age and G_{mac} ($r = -0.46$, $p = 0.001$).
Conclusion: SWUE revealed that the heel pad macrochamber layer was slightly softer but the microchamber layer was exaggeratedly stiffer, making the entire heel pad stiffer in the elderly

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group than in the younger group, implying age-related compensation in heel pad layers to retain foot function.

Introduction

The heel pad, located beneath the calcaneus bone, is a specialized tissue that plays an important role in maintaining foot health by providing shock absorption and supporting load-carrying during standing and locomotion.[1–3] The function of the heel pad is determined by its specialized architecture and mechanical properties.[4,5] With aging, the mechanical properties of the heel pad may decline, leading to a higher prevalence of foot problems in older populations.[6,7]

Several studies have investigated age-related changes in the mechanical properties of the heel pad; despite the use of a variety of tools, the authors drew a consistent conclusion that the heel pads of elderly people were stiffer than those of young people.[6–9] However, these studies evaluated the heel pad as a single, homogeneous component. Notably, the heel pad is actually inhomogeneous and can be divided anatomically into two layers, a superficial thinner, stiffer microchamber layer and a deep thicker, softer macrochamber layer.[10–12] It remains unclear whether the increased heel pad stiffness in elderly people is attributable to stiffening in the microchamber layer, macrochamber layer, or both.

Shear wave ultrasound elastography (SWUE), which allows a noninvasive and quantitative evaluation of soft tissue elasticity,[13] has been applied to evaluations of elasticity in living soft tissues, including tendons, muscles, and ligaments.[14–16] As regions of interest (ROI) can be located at different depths, SWUE allows individual evaluations of the elasticities of different heel pad layers. A higher shear wave velocity within the ROI indicates a stiffer tissue. Accordingly, the primary aim of this study was to determine and compare the elasticities of the microchamber and macrochamber heel pad layers between young and elderly people using SWUE. The hypothesis was that both the microchamber and macrochamber layers, and thus the entire heel pad, would be stiffer in the elderly group.

Materials and methods

Participants

This prospective cross-sectional study was approved during the planning stage by the institutional review board, and each study participant provided informed consent before evaluation. The study was performed between March 25, 2014 and March 22, 2016.

The young group comprised 30 healthy participants [15 men, 15 women; mean age = 26.4 ± 2.9 years; mean body mass index (BMI) = 22.6 ± 4.8 kg/m^2]. The elderly group also comprised 30 healthy participants (15 men, 15 women; age = 66.9 ± 6.2 years; BMI = 23.6 ± 3.0 kg/m^2). All participants were recruited in a medical center using convenience sampling. No participant was an elite athlete or employed at a job requiring standing for >8 h per day. The exclusion criteria were heel pain within the previous 1 year, diabetes mellitus, any history of rheumatologic diseases, and foot trauma and/or surgery.

Shear wave ultrasound elastography system

Heel pad thickness and elasticity were measured using an Aixplorer® ultrasound system (SuperSonic Imagine, Aix-en-Provence, France) equipped with a linear array transducer (SuperLinear SL15-4 with a frequency of 4–15 MHz and frame rate of 20,000 frames/s). The preset probe setting was used as the general mode, and the SWE Opt. Setting was used as the penetration mode while in the SWUE mode, because the elastogram of the deeper portion in the macrochamber layer could not be clearly shown in the standard and resolution modes. Defaults were used for all other settings. While in the SWUE mode, the system produced a color elasticity map superimposed on a corresponding B-mode image. The color elasticity map represented soft tissue elasticities ranging from stiff to soft, indicated by red and blue, respectively. For the quantitative analysis, the maximum, minimum, standard deviation, and mean shear modulus were determined in kPa units by the software built in the system. The shape of the ROI could not be modified because it was a commercialized system. The mean shear modulus was used for statistical analysis.

Measurement of heel pad thickness and shear modulus

Each participant reclined in a prone position on the treatment table with their feet suspended off the end of the table and relaxed during the evaluation. The plantar heel skin was cleansed with alcohol to improve ultrasound penetration. To position the ultrasound transducer, a line marker was drawn on the plantar heel skin along the direction connecting the second toe and the middle tip of the heel. A generous amount of gel was applied to the transducer surface, which was then placed perpendicularly on the plantar heel skin along the line marker. By keeping a sufficient amount of gel between the skin and transducer, the transducer preload could be kept within 0.6 N (measured by a force sensor), thus minimizing elasticity variation. Once the calcaneal tuberosity and microchamber and macrochamber layers of the heel pad were clearly identifiable in the B-mode image,