Plantar tissue compressive and shear material properties change during gait activity and rest periods

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Summary

This study investigates plantar tissue material properties (PTMP) using a novel device integrating ultrasound imaging, load cells, and an accelerometer to dynamically measure both the compressive and shear stiffness of plantar tissue in a healthy participant. Pilot data gives new insights that both compressive and shear stiffnesses in plantar tissue change during gait and after rest periods which may contribute to biomechanical functional advantages or precede tissue damage. Future work is needed to investigate more participants from clinical demographics.

Introduction

Plantar tissue mechanical properties (PTMP) are critical for foot health, enabling efficient load transfer during gait and supporting an active lifestyle [1]. PTMP changes, due to aging or diabetes, increase stiffness, leading to foot deformities and diabetic foot ulcers, which impair mobility [2]. While plantar tissue experiences both normal and shear stress, most research focuses on normal stress, neglecting the role of shear stress in tissue performance [3]. Existing methods primarily measure compressive properties under controlled conditions. This study aimed to develop a device and measure PTMP in a healthy participant during gait and rest periods.

Methods

A novel device was developed to measure PTMP, specifically both compressive and shear stiffness (Figure 1).

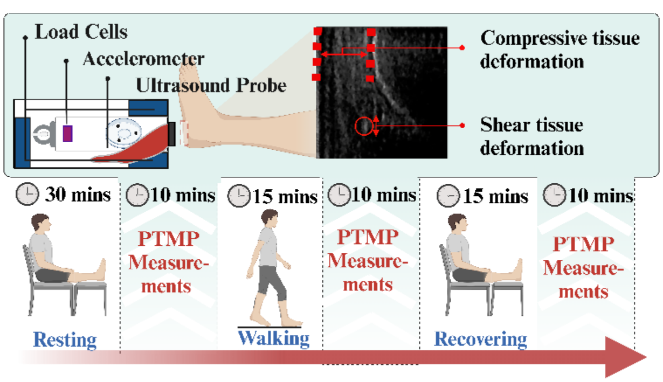

Figure 1: Ultrasound measurement device used to collect plantar tissue material properties during resting and walking.

This device integrates real time tissue deformation imaging through ultrasound (L15 6L25N, ClarUs EXT-1M, TELEMED, Lithuania), force measurement through load cells (LCEB-10, Omega Engineering, UK), and loading rate through an accelerometer (MMA8451, ADAFRUIT INDUSTRIES, USA). The device was validated using a silicone phantom (Ecoflex™ 00-10), compared against a test machine (Instron 3344L3927) using dynamic loading at 1Hz. The device produced a measurement accuracy of 96% and 97% for compression and shear measurements respectively. Measurements of PTMP and temperature were taken from a healthy participant after resting, walking and a recovery period (figure 1).

Results and Discussion

Walking increased both compressive and shear plantar tissue stiffness by 52% and 133% respectively (Figure 2).

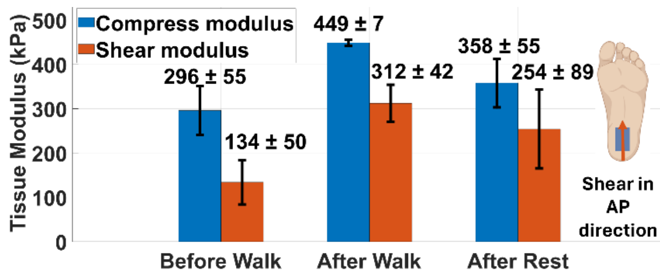

Figure 2: Heel Pad Compression and Shear Modulus Measured Before and After Walking and After a Recovery Period

After rest, both stiffness measures decreased by approximately 20% but remained above baseline. Foot temperature remained stable across all tests (23.2±0.5°C), indicating that the observed changes were biomechanical rather than temperature-related. The increase in stiffness during activity supports efficient load transfer and energy dissipation, while incomplete recovery suggests potential tissue strain or fatigue. The greater increase in shear stiffness highlights its critical role in plantar biomechanics, warranting further research in diverse populations, including diabetic and aging individuals.

Conclusions

This study introduces a novel device to measure compressive and shear stiffness dynamically *in vivo* in human plantar tissue. Findings show stiffness changes during gait and rest, offering insights into biomechanical adaptations. Future work should conduct testing in larger and diverse clinical populations to assess implications for tissue health and injury.

References

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