Reliability of Shore Hardness as a Surrogate for Heel Pad Stiffness: A Correlative Study Using Ultrasound Imaging

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Summary

The reliability of Shore hardness (SH) as a surrogate for in-vivo heel pad biomechanics is unclear. SH was measured in 74 Indian participants using a Shore durometer, and heel pad ultrasound imaging was employed to assess tissue compressibility under two loading conditions. Correlation analysis revealed weak to moderate correlation between SH and relative tissue compression in the skin layer at full body weight but no significant correlations for deeper layers.

Introduction

Shore hardness (SH) is widely used as an accessible and non-invasive measure of plantar tissue stiffness; however, its reliability in assessing the soft-tissue biomechanics of the superficial and deeper subcutaneous layers remain unclear.

In simulation, SH indicated bulk-tissue deformability despite its sensitivity to skin thickness (subcutaneous tissue stiffness) and not exhibiting a one-to-one relative change with skin and subcutaneous tissue stiffnesses [1]. An empirical study found SH to correlate with shear wave elastography at specific plantar foot regions but not others [2].

Methods

SH is evaluated as a surrogate for in-vivo heel pad stiffness by correlating SH values (measured under no load) with ultrasound-derived relative layer compression under half and full body weight in a population (N=74) of participants in Bangalore, India. SH was measured on the right heel pad using an AD-100 Shore durometer. The durometer was manually pressed against the heel pad until its indenter was level with its base.

Heel pad morphology (skin, microchamber, and macrochamber layers) was imaged using the portable L15 HD3 ultrasound scanner from Clarius Mobile Health Corp., under three conditions: (1) a manually operated near-zero load image for clarity, and (2-3) two tele-operated images with the participant standing on a metallic frame embedding the ultrasound scanner under their right heel at half and full body weight (BW). Layer-wise thicknesses were annotated in Kinovea 0.9.5, and relative compression (in %), or Elasticity Index (EI), were referenced to the thickness at near-zero load.

Results and Discussion

Table 1 presents Pearson's correlation coefficients (and p-values) between SH and EI for different tissue layer combinations: (1) skin only, (2) skin and microchamber combined, and (3) all three layers combined. The findings indicate a weak to moderate negative correlation between SH and EI in the skin layer (i.e. stiffer heals exhibit lesser relative skin compression), which is statistically significant at full body weight ($r = -0.2299$, $p = 0.0488$) but not at half body weight ($r = -0.1645$, $p = 0.1449$). This suggests that SH may partially capture the stiffness of the superficial skin layer under higher loading conditions. However, the absence of significant correlations for deeper tissue layers indicates that SH does not adequately reflect the mechanical properties of the entire heel pad structure. Figure 1 presents a scatter plot of the participants' EI for the skin layer against their corresponding SH measurements.

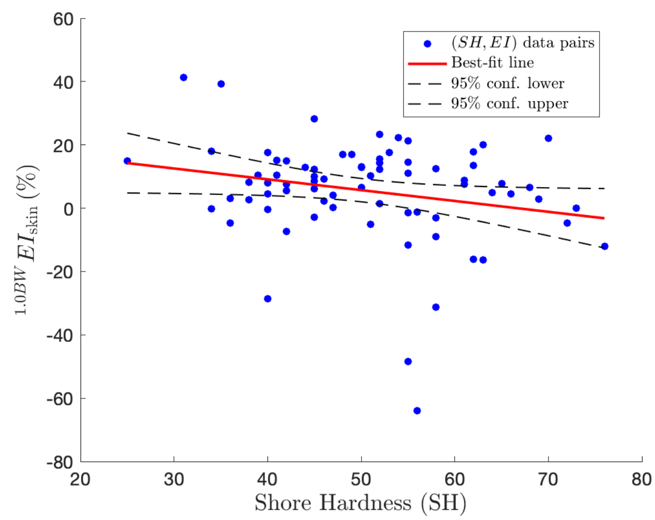

Figure 1: Linear regression analysis of elasticity index (EI) for the skin layer against Shore hardness (SH) measurements.

Table 1: Pearson's correlation (with p-value) between heel Shore hardness (SH) and the elasticity index (EI) of different tissue layers for a population (N=74) of barefoot and shod Indian participants. (* indicates compromised data normality assumption)

	$^{0.5BW}EI_{skin}$	$^{0.5BW}EI_{skin+micro}$	$^{0.5BW}EI_{skin+micro+macro}$	$^{1.0BW}EI_{skin}$	$^{1.0BW}EI_{skin+micro}$	$^{1.0BW}EI_{skin+micro+macro}$
SH	-0.1645 (0.1449)*	0.0060 (0.9575)	0.0244 (0.8296)	-0.2299 (0.0488)	0.0965 (0.4132)	0.0667 (0.5722)

Conclusions

SH provides a limited but significant indication of skin layer stiffness under full body weight but does not reliably capture deeper tissue properties.

References

[1] Panagiotis EC et al. (2022). *Med. Eng. Phys.*, **105**: 1-7.
[2] Panagiotis EC et al. (2024). *Sensors*, **24**: 1-11.