

# Quantifying Mechanical and Morphological Properties of Plantar Foot Soft Tissues: A Systematic Review of Measurement Techniques and their Clinimetric Properties

Alessandro Vicentini<sup>1,2</sup>, Marieke A. Mens<sup>3</sup>, Arjan Malekzadeh<sup>4</sup>, Jaap J. van Netten<sup>1,2</sup>, Mario Maas<sup>5</sup>, Sicco A. Bus<sup>1,2</sup>

<sup>1</sup> Amsterdam UMC, University of Amsterdam, Department of Rehabilitation Medicine, Meibergdreef 9, Amsterdam.

<sup>2</sup> Amsterdam Movement Sciences, Rehabilitation and Development, Amsterdam, The Netherlands.

<sup>3</sup> Department of Radiology and Nuclear Medicine, Haaglanden Medisch Centrum, Lijnbaan 32, The Hague.

<sup>4</sup> Amsterdam UMC location University of Amsterdam, Medical Library, Meibergdreef 9, Amsterdam, The Netherlands.

<sup>5</sup> Department of Radiology and Nuclear Medicine, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands.

## Summary

Diabetes-related foot ulcers pose a significant risk for morbidity and amputation. The mechanical and morphological properties of plantar soft tissues likely influence ulceration, but it is unclear which techniques have the best clinimetric attributes to quantify them. Therefore, we systematically reviewed the reliability, validity, and repeatability of existing techniques. Following PRISMA guidelines, we searched MEDLINE, EMBASE, and Web of Science for studies assessing tissue mechanical and/or morphological properties in adults. Out of 127 studies assessing plantar soft tissues properties, 36 investigated the clinimetric properties of the measurement techniques (ten techniques for mechanical and six for morphological properties). Limited clinimetric assessments complicates inter-study comparisons. The clinimetric properties of Ultrasound (US), Shear Wave Elastography (SWE) were comprehensively investigated, with US and SWE demonstrating high reliability, but also limitations related to operator dependency. Further research should identify more valid and reproducible techniques for plantar soft tissue evaluation.

## Introduction

Diabetes-related foot ulcers pose a significant risk for morbidity and amputation. The mechanical (stiffness, elasticity) and morphological (thickness) properties of the plantar soft tissues play a role in distributing mechanical stresses and ulcer development. Nevertheless, it remains unknown which measurement technique has the best clinimetric attributes to quantify these properties. This systematic review aims to investigate the existing measurement techniques and determine which demonstrate the best clinimetric attributes (reliability, validity, and repeatability) to assess the mechanical and morphological properties of plantar foot soft tissues.

## Methods

Following PRISMA guidelines, we systematically searched MEDLINE, EMBASE, and Web of Science for studies assessing plantar soft tissues properties in adults. We included studies investigating clinimetric properties and used published cut-off data to interpret reliability, validity, and repeatability assessments. Methodological quality was evaluated using the COSMIN Risk of Bias tool.

## Results and Discussion

Out of 3,857 screened studies, 127 evaluated the plantar soft tissues mechanical and/or morphological properties, of which 36 investigated the clinimetric properties of measurement techniques. Ten techniques evaluated mechanical properties, while six techniques assessed morphological properties. Reliability (27/36) and repeatability (23/36) were frequently reported, while validity was assessed in only four studies. The most reported methodological limitations across the studies were the inconsistent statistical approaches and poor blinding, affecting overall quality. Ultrasound (US) and Shear Wave Elastography (SWE) had both reliability and validity investigated. US demonstrated excellent intra-rater (ICC = 0.75–0.99) and inter-rater (ICC = 0.70–0.93) reliability, with moderate-to-strong validity ( $r = 0.5–1.0$ ) compared to Magnetic Resonance Imaging (MRI) and radiography. SWE exhibited excellent intra-rater reliability (ICC > 0.90) and strong validity ( $R^2 = 0.91$ ) but showed systematic measurement bias. For both US and SWE, inter-rater reliability could be influenced by operator-dependent factors such as transducer pressure and positioning, coupling gel application, and operator experience. Furthermore, limited sound wave penetration reduces spatial resolution, making deep tissue visualization challenging. Magnetic Resonance Elastography (MRE) showed promise to address these limitations and assess tissue viscoelasticity. Nevertheless, MRE's reliability and validity remain unexplored and its application on the foot requires further validation.

## Conclusions

The limited assessment of clinimetric properties complicates inter-study and inter-technique comparisons of measurement techniques to quantify plantar soft tissue morphological and mechanical properties. US and SWE emerged as reliable and valid techniques, but showed limitations related to operator dependency. More research into clinimetric properties is needed, with MRE being a promising technique that requires further validation to determine its reliability, validity, and repeatability for quantifying plantar soft tissue properties.

## Acknowledgments

This research received funding the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie Doctoral Network grant agreement No 101073533.