Statistical Shape Modelling of Tendinopathic Achilles Tendons: Insights into Shape Variations

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Summary

The Achilles tendon (AT) plays a crucial role in movement, but its shape may influence mechanical behavior and injury susceptibility. While previous studies and simulations suggest that tendon morphology affects stress distribution, in vivo investigations remain limited. This study employed statistical shape modeling (SSM) to analyze shape variations in 33 tendinopathic ATs reconstructed from 3D ultrasound imaging. Principal component analysis (PCA) revealed that the first three components accounted for 81.88% of the total variation, primarily capturing differences in width, length, thickness, and cross-sectional shape. Additional variations included curvature, swelling, rotation, and insertional widening. These findings may support the notion that tendinopathy alters tendon morphology, which may have implications for mechanical function and clinical assessment.

Introduction

The Achilles tendon (AT) is a key structure in human movement, yet its shape and morphology remain understudied compared to its mechanical properties. Recent simulation studies suggest that tendon shape influences stress distribution and mechanical efficiency [1]. Additionally, tendinopathy has been shown to alter AT morphology, particularly through increased thickness and reduced intra-tendinous sliding [2**]**. However, the extent of these structural adaptations and their impact on tendon mechanics require further investigation. Identifying how shape variations contribute to tendon pathology may improve our understanding of its functional consequences. This study applies statistical shape modeling (SSM) to investigate shape differences in tendinopathic ATs, offering new insights into tendon morphology.

Methods

This study analysed 33 midportion tendinopathic Achilles tendon meshes reconstructed from 3D freehand ultrasound data in the ALTER study at KU Leuven [1].

The reconstructed 3D meshes underwent mirroring (if needed), smoothing, and remeshing to improve shape accuracy while preserving geometric integrity. Error assessments ensured remeshing accuracy, and the meshes were reoriented and standardized for comparability before statistical shape modelling. Procrustes analysis was conducted to normalize tendon lengths while preserving shape characteristics though, length variations were not entirely removed. SSM was applied following an established framework [3]. PCA was performed to extract modes of shape variation.

Results and Discussion

From 33 tendinopathic AT meshes, PCA identified PC1 (57.16%) as the dominant mode of variation, associated with width and length differences. PC2 (18.71%) captured tendon thickness, while PC3 (6.01%) reflected cross-sectional shape variations (Figure 1). PC4 (3.04%) represented proximal curvature, and PC5 (2.70%) indicated localized swelling. Lesser components included rotational differences (PC6, 1.68%), distal curvature changes (PC7, 1.53%), and insertional widening (PC8, 1.31%). The shape variations align with individual differences in length, width, cross-sectional area, and thickness seen in healthy populations [4].

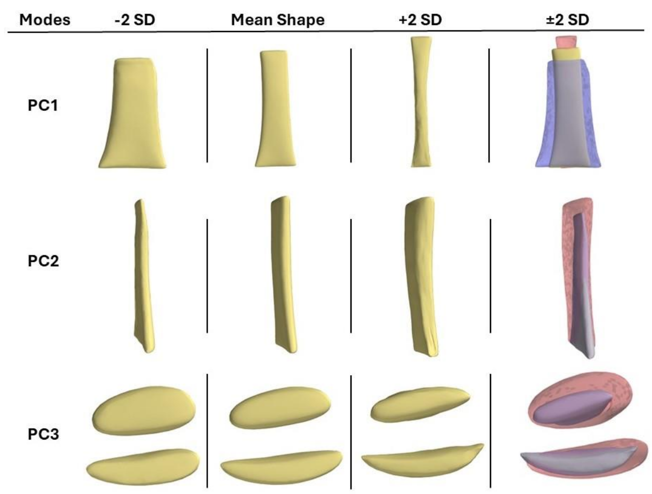

Figure 1: Shape variations in tendinopathic ATs with ±2 SD showing extremes relative to the mean. In PC3, the upper and lower images represent proximal and distal tendon views, respectively.

Conclusions

This study provides new insights into the shape variations of tendinopathic ATs, highlighting differences in width, thickness, and cross-sectional geometry, along with smaller region-specific variations. Utilizing SSM, these findings provide a foundation for our future research to compare shape variations with healthy tendons and to explore how these morphological differences influence tendon stress-strain characteristics, function, and the progression of tendinopathy.

References

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