Participant-Specific Tibial Stress Estimation during Running with Different Foot Strike Patterns

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Summary

This study examined the influence of footstrike manipulation on tibial stresses in 18 recreational runners. Participant-specific 3D tibial models were used to quantify tibial stresses, whereby a simplified hollow elliptical cross-section was obtained from a tibia model generated using statistical shape modeling. An imposed forefoot strike pattern resulted in the highest tibial stress magnitudes at the distal 1/3 of tibia, driven by elevated muscular contributions, potentially increasing the risk of tibial stress injuries.

Introduction

Tibial stress injuries at the distal 1/3 of the tibia are a problematic injury among runners. Footstrike pattern alterations may induce kinematic and kinetic changes that contribute to these injuries. Quantifying tibial stress typically requires invasive methods or computational approaches using medical imaging to obtain participant-specific tibial geometry. Advances in statistical shape modeling (SSM) and an open-source tibia model [1] allow for the estimation of 3D tibial geometry without imaging techniques. Non-invasive methods combining musculoskeletal modeling and beam theory [2] have been used to estimate tibial stresses, employing simplified geometries such as a hollow ellipse [3], that are not scaled to the participant. This study aims to evaluate the influence of footstrike manipulation on tibial stress using participant-specific geometry from SSM and a simplified tibial modeling approach.

Methods

Eighteen recreational runners (9 females, 9 males; 34.2 ± 2 yrs; 167.2 ± 5.9 cm; 62.1 ± 6.5 kg) completed overground running trials at 4.0 m/s (±5%) using a habitual rearfoot strike (hRFS). They then performed imposed rearfoot (iRFS) and forefoot (iFFS) strikes in random order. Kinematic (120 Hz) and kinetic (1200 Hz) data were collected using 3D motion cameras and force plates.

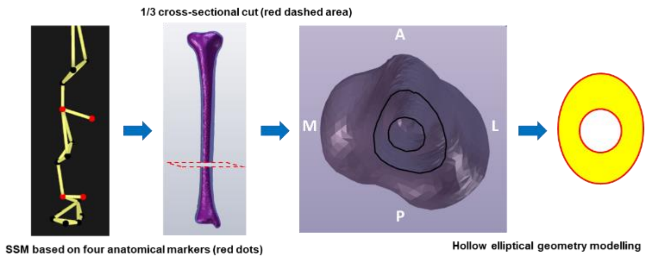

Figure 1: Workflow for simplified participant-specific tibia modeling using a statistical shape model (SSM).

A participant-specific 3D tibia model was generated using SSM with four anatomical markers, modifying the previous approach that used nine markers [1] (Figure 1). A hollow elliptical model [3] of the distal 1/3 cross-sectional area (CSA) was scaled using predicted cortical and trabecular dimensions (antero-posterior and medio-lateral lengths) from the SSM. Tibial stresses at the anterior and posterior peripheries were quantified via musculoskeletal modeling and beam theory using a customized MATLAB script [2]. Statistical analysis included one-way ANOVA ($p < 0.05$) and Bonferroni-corrected post-hoc tests.

Results and Discussion

The average participant-specific hollow elliptical CSA was 311.5 ± 85.6 mm². Tibial stress at the anterior periphery during iFFS was 42.5% greater than iRFS ($p < 0.001$) and 17.2% greater than hRFS ($p = 0.013$), while hRFS exhibited 21.4% higher stress than iRFS ($p = 0.002$) (Figure 2). Similarly, tibial stress at the posterior periphery during iFFS was 38.6% greater than iRFS ($p < 0.001$) and 15.9% greater than hRFS ($p = 0.010$), while hRFS showed 19.6% greater stress than iRFS ($p = 0.002$) (Figure 2). The greater muscular contribution to bending moments observed in iFFS, which was 30.8% greater than iRFS and 12.7% greater than hRFS, likely explains the increased tibial stresses at the anterior periphery under tension and the posterior periphery under compression.

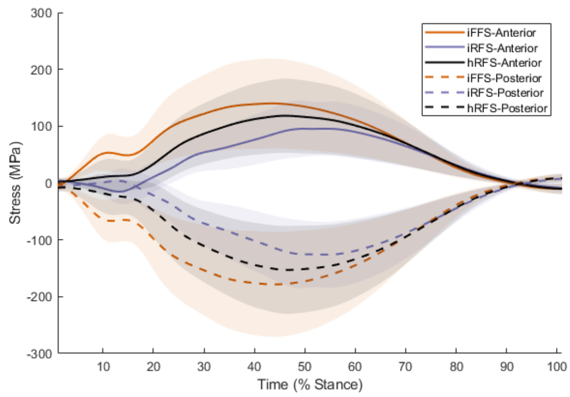

Figure 2: Tibial stresses at the anterior and posterior peripheries (iFFS: imposed forefoot strike; iRFS: imposed rearfoot strike; hRFS: habitual rearfoot strike).

Conclusions

Footstrike manipulation significantly influenced tibial stresses, with an imposed forefoot strike producing the highest magnitudes at the distal third of the tibia due to elevated muscular contributions to bending. These findings highlight the potential risk of tibial stress injuries with forefoot striking and the importance of considering footstrike patterns in injury prevention strategies.

References

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