A combined musculoskeletal model to investigate the relationships between ACL injury risk factors and ligament loading

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Summary

This study aims to develop a comprehensive musculoskeletal model that includes the internal soft tissue structures of the knee joint, specifically the anterior cruciate ligament (ACL), along with trunk and lower extremity muscles. By accurately predicting ACL ligament loading, the model will address gaps in understanding injury mechanisms. The research will involve validating the model through forward dynamics, comparing geometries of ligaments and muscles with existing models, and examining relationships between conventional ACL injury risk factors and ligament loading during common motion tests. This approach seeks to enhance injury prevention strategies and improve outcomes for individuals at risk of ACL injuries.

Introduction

ACL injuries, affecting millions globally, often occur noncontact during activities like jumping and rapid stops[1], compromising knee stability. They can lead to severe complications and economic burdens[2]. Identifying risk factors and understanding biomechanical loading are crucial for developing effective prevention and treatment strategies, enhancing quality of life[3]. Personalized musculoskeletal models offer biomechanical insights into joints, ligaments, and muscles during dynamic movements. They help identify potential ACL injury risk factors, crucial for creating effective prevention strategies.

Methods

This study introduces a groundbreaking computational musculoskeletal model that integrates an existing discrete element knee model, complete with knee ligaments, into a full-body framework that includes all significant lower limb and trunk muscles (**Figure 1**). The knee ligaments' mechanical properties underwent thorough validation via forward dynamics testing. 15 healthy participants engaged in various single-leg support activities while motion capture, ground reaction, and EMG data were gathered concurrently (**Figure 2**). The model was personalized using an EMG-driven approach to estimate lower-extremity muscle forces, with synergy extrapolation predicting unmeasured deep muscle excitations. Linear regression analysis was applied to quantitatively explore the connections between potential risk factors, such as knee kinematics and muscle forces, and ligament loading.

Results and Discussion

The developed model showed adequate joint stability and preserved accurate ligament and muscle geometries relative to existing models. A notable positive correlation emerged between the peak knee abduction angle or anterior tibial translation and the peak ACL strain during the landing phase. The quadriceps were found to reduce ACL load, while the hamstrings increased it.

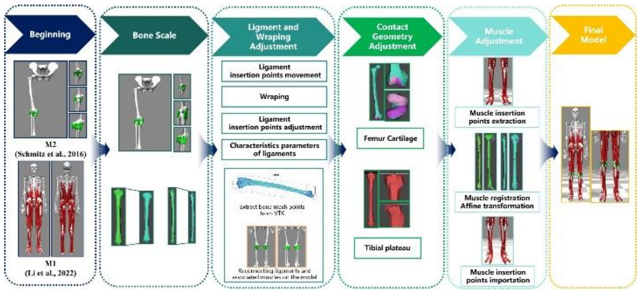

Figure 1: Model creation.

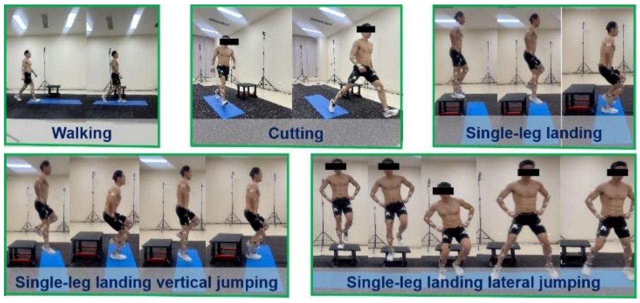

Figure 2: Paradigms.

Conclusions

The musculoskeletal model can be an essential tool for exploring ACL injury mechanisms, offering profound insights into the risk factors linked to ACL injuries.

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References

[1] Boden et al. (2000). *Orthopedics*, **23**: 573-578.
[2] Wiggins et al. (2016). *Am J Sports Med*, **44**: 1861-1876.
[3] Hootman, J. M. et al. (2012). *J Athl Train*, **47**: 589-590.