The Ankle's Roll in Landing: Distal-to-Proximal Insights for ACL Injury Prevention

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Summary

Non-contact anterior cruciate ligament (ACL) injuries frequently occur during the early stage of landing, where joint forces exceed the ligament's capacity. This study examined how ankle mechanics influence the knee within the first 40ms of landing, analysing data from 42 participants using mixed-effects models. Initial contact (IC) dorsiflexion positively correlated with IC knee flexion angles and increased vertical ground reaction forces (vGRF) but reduced flexion angular displacement. Negative plantarflexion impulse (nPFI) decreased peak knee extension moment (pExM) while increasing vGRF. Eversion displacement (EvD) positively influenced negative adduction impulse (nAddI), and dorsiflexion power smoothness (DPS) emerged as critical for modulating pExM. These findings underscore the importance of ankle mechanics in reducing knee loading during the early stage of landing, supporting a distal-to-proximal approach in ACL injury prevention.

Introduction

ACL injuries commonly occur during rapid deceleration tasks, with structural failure likely occurring between 30-40ms following contact [1, 2]. While knee-based factors like IC extension and abduction angles are associated with injury risk, the interplay between early ankle and knee mechanics remains unclear. The plantarflexors, particularly the soleus, play a pivotal role by absorbing energy and reducing ACL strain [3-5]. Unlike hamstrings, which cross the knee and require a degree of knee flexion to protect the ACL, the soleus acts independently of knee position, making it critical during low knee flexion angles typical of many injury scenarios [1]. This study examined ankle measures and their influence on knee biomechanics during the early landing phase, addressing gaps in distal-to-proximal control strategies for ACL injury prevention.

Methods

Forty-two participants (21 males, 21 females) performed three horizontal single-leg hops over 40% stature followed by immediate vertical countermovement jumps in a lab environment. Reflective markers tracked kinematics at 250 Hz, with vGRF sampled at 1000 Hz. IC angles, joint displacements, peak moments, as well as negative angular impulse and Weighted Smoothness Indices (WSI) of joint powers were calculated. Mixed-effects linear models examined ankle predictors' influence on knee outcomes, prioritising participant-specific variability through conditional R^2, including 'sex' as a fixed effect.

Results and Discussion

Significant ankle predictors were identified and compiled to formulate accurate knee prediction models (Figure 1). IC knee flexion positively associated with IC DF ($\beta = 0.84$, $p < 0.001$) and negatively with foot strike angle ($\beta = -0.99$, $p < 0.001$). nPFI reduced pExM ($\beta = -5415.15$, $p < 0.001$) and increased vGRF ($\beta = 33585.87$, $p = 0.005$). EvD positively associated with nAddI ($\beta = 0.0002$, $p = 0.003$). Additionally, DPS demonstrated a negative association with pExM ($\beta = -0.006$, $p < 0.001$) and positive association with abduction smoothness ($\beta = 0.758$, $p < 0.001$). These findings highlight the critical role of foot position, nPFI, and DFPs in modulating vGRF and knee loading in early landing.

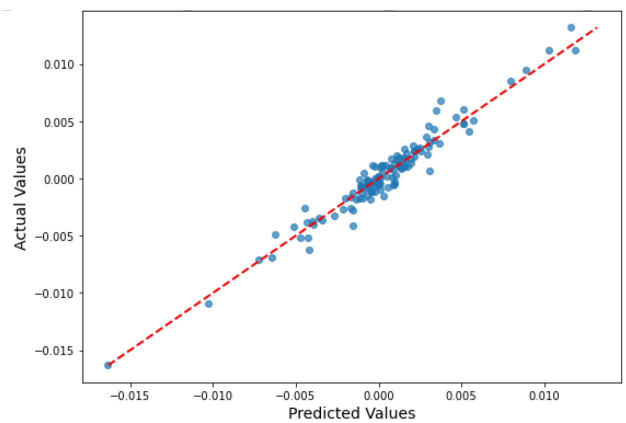

Figure 1: Negative adduction impulse Predicted vs Actual. Sig. predictors: eversion displacement ($p = 0.003$), peak eversion moment ($p = 0.008$), negative plantarflexion impulse ($p = 0.000$), negative inversion impulse ($p = 0.000$), Group variation ($p = 0.003$)

Conclusions

This study highlights the critical role of ankle mechanics in shaping knee biomechanics during early landing. Findings underscore the protective influence of the ankle's IC position, negative plantarflexion impulse, and DPS on knee joint loading, supporting the integration of distal-to-proximal control strategies in ACL injury prevention programs.

References

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