The relationship between foot torsional stiffness and multi-segmental foot kinetics during running

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Summary

Foot torsional stiffness (FTS) influences foot kinetics, a contributing factor to running-related injuries, during gait. However, it is unclear how FTS affects multi-segmental foot kinetics during running. Midfoot passive resistance torque and forefoot frontal plane motion were measured in fourteen females to calculate FTS. Participants ran barefoot with rearfoot strike at 3.3 m/s ± 10% along a 10 m runway. We examined the relationship between FTS and foot kinetics, including peak moments, peak power (positive and negative), and work (positive and negative) at ankle and midfoot. FTS was significantly correlated with peak moment ($\rho = -0.56$, $p = 0.04$), peak positive power ($\rho = 0.54$, $p = 0.05$), and positive work at midfoot ($\rho = 0.74$, $p < 0.01$) but showed no correlation with ankle kinetics. These results suggest that the influence of FTS on foot kinetics differs according to functional phases and/or levels of exercise intensity.

Introduction

The foot has two abilities to absorb and generate force in bipedal locomotion. Passive mechanical properties affect foot function, and FTS is one index that reflects such properties. Previous studies on gait reported that FTS affects foot kinetics in relation to the history of running-related injuries [1]. However, the influence of FTS on foot kinetics during running is uncertain. The purpose of the present study was to investigate the relationship between FTS and multi-segmental foot kinetics during running.

Methods

Fourteen female runners with rearfoot strike participated in this study. Midfoot passive resistance torque and forefoot angle relative to rearfoot were measured simultaneously from maximum forefoot eversion to inversion (Figure 1). We calculated the slope of the regression line in the range from 10° eversion to 10° inversion of forefoot and determined its value, normalized by each participant's body weight, as the FTS [2]. Participants were attached to reflective markers and plantar pressure sensor and asked to run at 3.3 m/s ± 10% on a 10-m runway. We synchronously collected plantar pressure, ground reaction force, and kinematics including shank, rear-, and forefoot during the running task. Ankle and midfoot moments were calculated from distal to proximal using the Newton-Euler equation. Joint power was calculated as the scalar product of the joint moment and angular velocity. Joint work was calculated as the time integration of the joint power. The kinetic parameters examined at ankle and midfoot were peak moment, peak power (positive and negative), and work (positive and negative) in the sagittal plane. The relationships between FTS and foot kinetics were explored using Spearman's rank correlation coefficients ($\alpha = 0.05$).

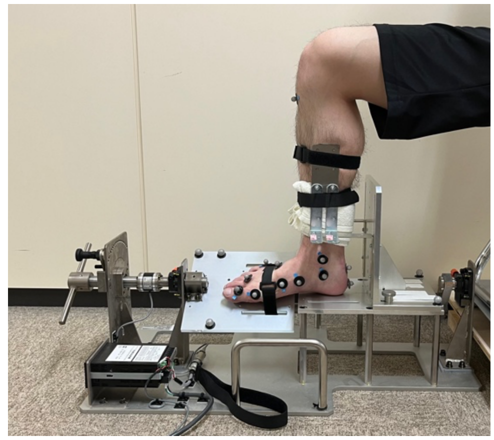

Figure 1: Measurement of midfoot passive resistance torque and foot kinematics.

Results and Discussion

FTS was significantly correlated with peak moment ($\rho = -0.56$, $p = 0.04$), peak positive power ($\rho = 0.54$, $p = 0.05$), and positive work at midfoot ($\rho = 0.74$, $p < 0.01$). High FTS was associated with large moment, positive power, and positive work at midfoot. The medial longitudinal arch elevates during the propulsive phase, allowing the foot to generate force efficiently. Considering that arch elevation leads to forward displacement of the center of pressure, the results of the present study could be explained by an increase of the moment arm in high torsional stiffness foot. On the other hand, FTS was not significantly correlated with ankle kinetics. FTS is calculated as the stiffness of forefoot relative to rearfoot and reflects the passive mechanical properties of the soft tissues across midfoot. The effect of FTS may be weak in early stance, where the load is primarily applied to rearfoot, and in mid-to-late stance, where the contribution of the extrinsic foot muscles is large.

Conclusions

FTS affected foot kinetics during the propulsive phase of running as well as during gait, although the significant correlation was only observed at midfoot. These results suggest that the influence of FTS on foot kinetics differs according to functional phases and/or levels of exercise intensity.

References

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