Reducing flight time during running decreases tibial-fibular strains: a finite element analysis

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Summary

The efficacy of grounded running to reduce tibial/fibular strains was investigated using motion analysis and participant-specific finite element analysis. Grounded running reduced peak tibial/fibular strains by 17% and strained volume (i.e., volume of bone experiencing strain >3000 με) by 48%. Thus, grounded running may represent a promising gait modification strategy to reduce bone strains, particularly for slower runners and individuals recovering from injury.

Introduction

Grounded running (i.e., running with reduced flight phase) has been associated with decreases in both external (e.g., ground reaction forces) and internal forces (e.g., muscular forces) [1, 2]. While these findings suggest grounded running may represent an effective gait modification strategy for those recovering from bone injuries; the effect of grounded running on bone strains remains unexplored. Thus, our purpose was to quantify changes in tibial/fibular strains between a preferred and grounded running technique.

Methods

Nine physically active participants ran on an instrumented treadmill (Bertec Corps., Columbus, OH) using preferred and grounded running techniques for 5 minutes each at 2.2 m/s. Grounded running was characterized by a reduced flight phase. Three-dimensional ground reaction forces and running kinematics were recorded at 2.5 minutes for 30 seconds. A computed tomography (CT) scan of each participants' left leg was segmented to create a finite element (FE) model of the tibia-fibula complex. The FE model, solved in Abaqus (version 2021, Dassault System, RI, USA) [3], included physiologically realistic boundary conditions that were previously validated against tibial bone pin studies [4]. To further validate FE outputs, a virtual strain gauge was placed between the midshaft and 2 cm distal on the medial tibial surface [5], mimicking strain gauge placement in Burr et al. [6]. Strains at the virtual strain gauge site were compared to experimental studies, and peak strain (i.e., 90th percentile pressure-modified von Mises strain) and strained volume (i.e., bone volume experiencing strains >3000 με) across the entire model were calculated as primary outcomes.

Results and Discussion

Peak strains at the virtual strain gauge site were comparable to experimental studies. During overground jogging at 2.8 m/s, Burr et al.[4] reported maximum principal strains of 625 ± 15 με, minimum principal strains of -879 ± 73 με, and maximum shear strains of 1444 ± 141 με (mean ± standard deviation). In the preferred condition of our study, the model predicted maximum principal strains of 853 ± 313 με, minimum principal strains of -955 ± -454 με, and maximum shear strains on 1809 ± 522 με. Importantly, grounded running significantly reduced peak strains and strained volume compared to preferred running. Peak strains decreased from 4193 ± 737 με in preferred running to 3498 ± 738 με in grounded running ($p = 0.002$). Strained volume was reduced from 9680 ± 3159 mm³ in preferred running to 6305 ± 2905 mm³ in grounded running ($p = 0.007$). Using an inverse-power-law relationship between peak strain and cycles to failure, the observed 17% reduction in peak strain would correspond to a 256% increase in fatigue life.

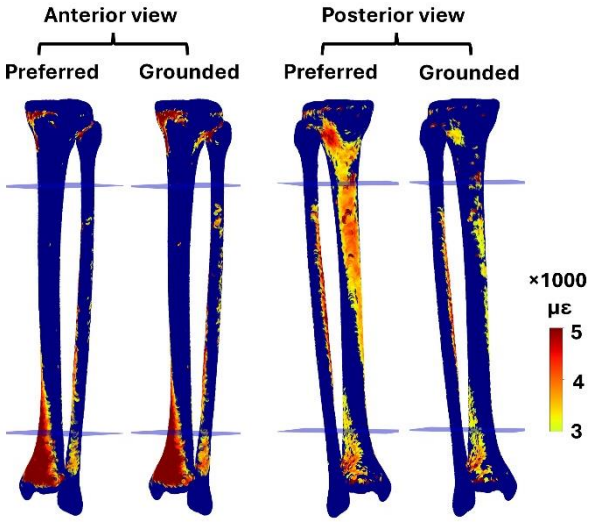

Figure 1: Anterior and posterior views of the tibia-fibula complex. Elements experiencing strains >3000 με are visualized with a jet color scale in this heat map. Only the elements between the two horizontal planes were considered in calculating the primary outcomes.

Conclusions

Grounded running significantly reduced tibial/fibular strains, suggesting its potential as an effective gait modification strategy, particularly for slower runners and those recovering from stress fractures and other bone related injuries.

Acknowledgments

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References

[1] Bonnaerens et al., (2019). *Med Sci Sport Exer*, **51**: 708-15
[2] Bonnaerens et al., (2012). *Med Sci Sport Exer*, **54**: 1842-49.
[3] Khassetarash et al., (2023). *J Biomech Eng*., **145**: 041007
[4] Yang et al., (2014), *PLOS ONE*, **9**: e94525
[5] Baggaley et al., (2024), *J Exp Biol*, 227, 246770
[6] Burr et al., (1996), *Bone*, **18**: 405-410