Effects of Minimalist Footwear and Stride Length Reduction on the Probability of Metatarsal Stress Fracture: A Weibull Analysis with Bone Repair

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Introduction

Physical activity such as distance running exposes bones of the lower extremity to lengthy bouts of repetitive loading, which causes mechanical fatigue characterized by the manifestation of tissue microdamage. If the rate of microdamage accumulation is greater than the rate of bone repair, tissue quality may be diminished resulting in an increased risk of stress fracture. The metatarsal bones are highly susceptible to this injury, encompassing 10% of all stress fractures in active populations (Iwamoto et al., 2003). Microdamage formation in bone is a strong function of strain magnitude; therefore, mechanisms that reduce bone strain may also reduce stress fracture risk.

Purpose of the study

The purpose of this research was to determine the effect of minimalist footwear and stride length reduction on the probability of metatarsal bone stress fracture in running.

Methods

Fourteen male recreational runners (age: 26.2 ± 4.2 y; height: 178.4 ± 5.4 cm; mass: 75.6 ± 5.6 kg) participated in this study. Subjects ran more than 10 km/week, had no lower limb injuries within 3 months prior to testing, were rearfoot strikers, and had no prior experience running in minimalist footwear.

Computed tomography (CT) scans were obtained for each subject's right foot in both a traditional (cushioned) and minimalist (uncushioned) shoe. Subjects subsequently ran overground at their preferred speed for a 5-km run (±5%) in four conditions (Table 1) while motion capture and plantar pressure data were collected.

Table 1. Description of running conditions.

Condition	Shoe Type	Stride Length
1	Traditional	PSL
2	Traditional	90% PSL
3	Minimalist	PSL
4	Minimalist	90% PSL

PSL = preferred stride length

Seven retro-reflective markers were adhered to each shoe to create a rearfoot and a forefoot segment. The sagittal angle of the rearfoot segment was added to the neutral metatarsal angles from the CT scans to obtain sagittal-plane metatarsal angles throughout ground contact. These metatarsal angles were then combined with plantar pressure data to calculate forces acting on the metatarsal head using a musculoskeletal (MSK) model of the metatarsophalangeal joint (Stokes et al., 1979). Metatarsal bones were segmented from CT scans to create subject-specific finite element (FE) models. Elements were assigned isotropic, linear-elastic material properties as a function of bone apparent density (Rho et al., 1995). The proximal end of the FE models were

constrained and forces from the MSK model were applied distally at the metatarsal heads. Von Mises equivalent strains were computed from the FE model to obtain a single scalar representation of strain magnitude for each element. A Weibull analysis that incorporated the effects of strain magnitude and stressed volume on damage accumulation as well as damage repair by basic multicellular units was used to calculate a subject-specific probability of failure (P_{fr}) for a running volume of 20 km/week over 100 days (Edwards et al., 2009).

Repeated measures ANOVAs were used to test for differences in P_{fr} between conditions for each metatarsal ($p \leq 0.05$). A Bonferroni post-hoc correction was used to account for experimentwise error.

Results

No significant interactions were observed between shoe type and stride length. The P_{fr} was significantly greater in the minimalist shoe for metatarsals 1, 2, and 4 (Table 2), however no significant differences in P_{fr} were observed between stride length conditions.

Discussion and Conclusion

The minimalist shoe was associated with a higher risk of P_{fr}, or stress fracture when compared to running in a traditional shoe. A post hoc examination revealed smaller metatarsal angles at the timepoint of peak plantar force in the minimalist shoe, causing a greater applied bending moment to the bone and a larger strain. While small reductions in strain were observed at 90% PSL, these were not large enough to overcome the additional damage that occurred from an increased number of loading cycles for the 20 km/week distance.

These results suggest that running in minimalist shoes significantly increases one's risk of developing a metatarsal stress fracture, while running at a reduced stride length is not an effective technique to mitigate metatarsal stress fracture risk. Further research is required to determine if the increased bending moment observed in minimalist shoe conditions was a function of cushioning, heel-to-toe drop, or some combination of the two.

Table 2. Estimated marginal means for peak P_{fr} (%) as a function of shoe type and stride length (SD).

Met	**1**	**2**	**3**	**4**	**5**
TS	0.004 (0.007)	0.56 (0.26)	0.22 (0.70)	0.02 (0.02)	0.004 (0.007)
MS	0.050 (0.080)	6.53 (2.53)	0.86 (1.94)	0.15 (0.18)	0.037 (0.080)
p	**0.036**	**0.024**	0.081	**0.008**	0.115
PSL	0.027 (0.054)	4.01 (6.47)	0.49 (1.10)	0.09 (0.11)	0.018 (0.030)
90% PSL	0.026 (0.037)	3.08 (3.86)	0.59 (1.55)	0.08 (0.09)	0.022 (0.060)
p	0.908	0.262	0.480	0.558	0.672

TS = traditional shoe, MS = minimalist shoe, met = metatarsal

References

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