Dynamic foot function during running: implications for bone stress injury

Julia Nicolescu[1], Olivia Vogel[1], Andrew R. Wilzman[1], Irene S. Davis[2], Adam S. Tenforde[3], Karen L. Troy[1]
[1]Worcester Polytechnic Institute, Worcester, MA, [2]University of South Florida, Tampa, FL, [3]Harvard Medical School, Cambridge, MA
Jnicolescu@wpi.edu

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INTRODUCTION: The metatarsals are a common site of bone stress injury (BSI) in military professionals and running athletes, representing as much as 38% of these injuries (Rizzone et al., 2017). A recent prospective study identified biomechanical risk factors for second and third metatarsal BSI in military professionals (Dixon et al., 2019). They found that those with BSI had significantly lower static arch height index (AHI) and greater foot abduction during running compared to non-injured controls (Dixon et al., 2019). Varus forefoot has also been implicated as a risk factor because it is associated with greater midfoot pronation or arch flattening, which can increase bending moments in the second metatarsal (Buchanan & Davis, 2005). Anatomic differences are not modifiable. However, landing biomechanics and the resulting dynamic foot behavior can be altered through a combination of footwear and activation of intrinsic and extrinsic muscles supporting the arch of the foot. For example, arch height index, a measure of arch collapse during static weight bearing, can be modified through active contraction within the feet. These factors may also affect foot power generation and performance during running. Here, we examined associations between static arch height index, dynamic arch height index, foot strength, Chopart and Lisfranc joint power and work in the sagittal plane during barefoot running. We hypothesized that static AHI would be positively associated with foot strength, leading to more positive work at the relevant joints during the stance phase of running.

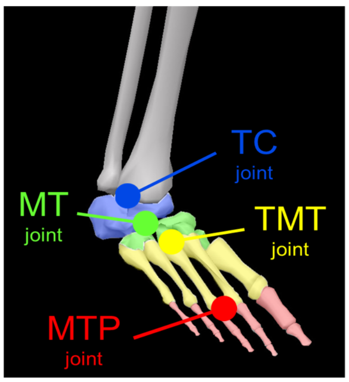

Figure 1. Multisegmented foot model consisting of rearfoot, midfoot, forefoot, and phalanges implemented for kinetic and kinematic calculations. The midtarsal joint (MT) and tarsometatarsal joint (TMT) are analyzed in this study.

METHODS: Foot measurements and biomechanics were acquired on 20 volunteers (age: 21.9 ± 1.3, height: 1.7 ± 0.1 m mass: 62.1 ±7.3 kg, 10 male/10 female) who regularly ran in shoes at least 24 km/week. Each volunteer provided written informed consent to participate in this institutionally approved study. Arch height index was calculated in weightbearing as the ratio of the dorsum height at 50% total foot length, and the truncated foot length (Williams & McClay, 2000). Based on previous criteria, foot structure was classified as planus, rectus, or cavus (Hillstrom et al., 2013). We also calculated dynamic AHI during stance phase at the instant of footstrike and at its minimum value. Dynamic arch deflection was calculated as the change between the AHI at contact and the minimum AHI during stance. Foot doming, greater toe pull, and lesser toes pull strength were measured with a custom foot dynamometer, according to previously described methods (Ridge et al., 2017). Biomechanics data were collected during barefoot fast jogging at a self-selected speed. Sixty-five markers (16 on each foot) were placed on the lower extremity. Data were collected with a 10-camera motion capture system (Vicon Vantage, Vicon Motion Systems) operating at 100 Hz and 2 force platforms (AMTI Optima, AMTI) operating at 1000 Hz. Data were processed in Visual3D (C-motion, company info) to define a 5 segment (4 joint) lower leg and foot biomechanical model (Figure 1). We quantified the positive and negative work done by each joint during the stance phase. To test our hypotheses, we computed Pearson correlations between static arch height, dynamic arch height at footstrike, dynamic arch deflection, foot strength, and work at the MT (Chopart) and TMT (Lisfranc) joints. Because our sample was underpowered to detect many of the relationships of interest, we considered correlation coefficients ≥0.5 to be of potential importance.

RESULTS: Complete data were available on 9 participants. Static AHI, doming strength, and greater toe strength were not related to any of the work measures at the MT and TMT joints. Dynamic arch deflection was negatively correlated with static AHI (r=-0.582) and total negative work in the ankle/foot (r=-0.759, indicating more negative work with greater arch deflection). Lesser toes pull strength was associated with an increase in TMT joint positive work (r=0.748) and an accompanying decrease in MT joint positive work (r=-0.51), resulting in an increase in percent positive work contribution coming from the TMT joint (r=0.78) Lesser toes pull strength was also negatively associated with AHI at footstrike (r=-0.50) (Figure 2).

DISCUSSION: Our hypothesis that greater static AHI would be associated with increased foot strength was supported, specifically with lesser toes pull. The relationship between dynamic arch deflection and static AHI supports previous work indicating AHI as an important metric. However, static AHI did not show an association with any of the foot strength and performance metrics. Individuals with stronger toe flexors appear to stiffen their foot before footstrike and may alter their footstrike pattern in the process (e.g. from rear to forefoot). In doing so, a larger portion of the work/power of the ankle and foot complex occurs at the TMT joint. Our data support the notion that people with flatter arches have weaker feet that deflect more during running, resulting in more negative work. It also suggests that strengthening intrinsic foot muscles, especially toe pull, could represent an intervention target to reduce dynamic arch deflection. This, in turn, may reduce risk of metatarsal BSI through mechanisms of reduced bending moments. Further research is necessary to determine if arch deflection patterns differ in individuals with metatarsal BSI. It is also unclear how the arch behaves during shod running, which is more typical for these participants.

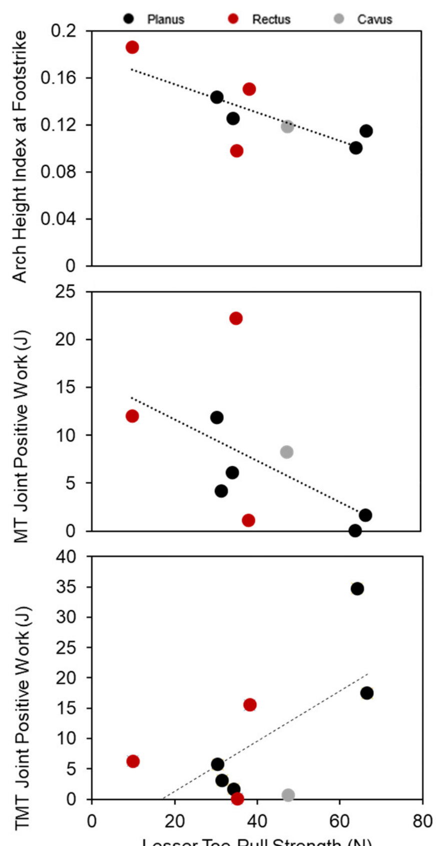

Figure 2. AHI at footstrike, MT joint positive work, and TMT joint positive work as a function of lesser toes pulling strength. Data is grouped by static AHI.

SIGNIFICANCE/CLINICAL RELEVANCE: This work is significant because it adds to our understanding of foot dynamic arch behavior during running. In particular, it suggests that people with strong toe flexors are more effective at reducing arch deflection during the stance phase while running barefoot. The manner in which this affects metatarsal loading and injury risk is not yet known. However, our research suggests that within a healthy population, lesser toes pull strength may be a more useful measure of foot function than static arch heigh index and could represent a target for intervention.

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