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Commentary

Commentary on “Speed and surface steepness affect internal tibial loading during running”

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It is a pleasure to write a commentary on the work of Dr. Hannah Rice and colleagues,[1] who have advanced our understanding of how the mechanical loading environment of the tibia changes as a function of running grade and speed. It is important that we understand how the tibia is loaded during conditions that an individual is likely to encounter when running as it is these internal loads which we believe are responsible for the development of bone-stress injuries.[2] A comprehensive understanding of tibial loading during running on graded terrain will aid in the development of exercise programs that minimize bone-stress injury risk.

Bone-stress injuries are thought to occur due to mechanical fatigue of bone, where repetitive loading and cumulative bouts of activity result in the accumulation of microdamage within bony tissue.[3] Microdamage accumulation weakens the bony tissue, and if sufficient time is not provided for repair and adaptation, a bone-stress injury will occur. In this framework, it is the peak loads that largely dictate the rate of tissue degradation from cyclic damage, and this has been well quantified in *ex vivo* mechanical testing of bone.[4−6]

The work of Rice et al.[1] fits nicely within the fatigue−failure framework as the authors quantified the bending moments and stress experienced by the tibia during uphill, downhill, and level running, with a focus on peak magnitudes. Previous work has examined internal tibial loading across grades of running at a constant speed;[7] however, this does not reflect how individuals traverse graded terrain in a natural environment.[8,9] Instead, individuals tend to speed up when they run downhill and slow down when they run uphill, relative to their level running speed.[8,9] With this in mind, Rice et al.[1] quantified the internal loading of the tibia while individuals ran at 2.5 m/s, 3.0 m/s, and 3.5 m/s at each of 6 grade conditions (0%, ±5%, ±10%, and ±15%). The authors quantified bending moments about the medial−lateral axis and bone stress on the anterior and posterior peripheries of the tibia at the distal one-third of the tibia, a common location of bone-stress injury.

The authors observed that steep downhill running (−10% and −15%) reduced bending moments and the peak anterior and posterior stress while steep uphill running (10% and 15%) increased bending moments and the peak anterior and posterior stress, compared to level ground running. The results of Rice et al.[1] may be counterintuitive to individuals who perceive downhill running to be more deleterious to bone due to the high impact magnitudes experienced during downhill running.[10,11] However, this is unlikely given that the fatigue life of bone is governed by strain magnitude,[4,12] and bone strain peaks at mid-stance.[13] Furthermore, no difference in fatigue life (indicative of rate of damage accumulation) has been observed in bone loaded at high and low strain rates.[5,6] Vertical loading rate is likely a poor surrogate measure of tissue-level loading; a hypothesis supported by recent prospective injury studies that observed no relationship between the vertical ground reaction force loading rate and running-injury incidence.[14−17] Instead, biomechanical variables which seek to act as surrogate measures of *in vivo* tissue-level (bone) loading should match the stress-strain response of the respective tissue (bone) during running.

This represents the utility of the work by Rice et al.[1] by using an approach which estimates tibia stress resulting from the applied loads. This is in contrast to studies which have used the axial ankle joint contact force as a metric of bone load.[18,19] The axial force contributes only a small amount to the normal stress magnitude (<30%)[7,20] and it can lead to erroneous conclusions about relative risk of injury. For instance, uphill running is associated with reduced axial force[1,7] resulting from a change in the orientation of the ankle joint contact force where it is oriented more posteriorly compared to level and downhill running.[1,7] Examining just the axial force would suggest that uphill running

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is associated with reduced tibial loading but this is unlikely to be the case as demonstrated by the findings of Rice et al.[1] Instead, by incorporating the internal tibial bending moments, which contribute >70 % to the normal stress,[7,20] we are able to derive tibial loading metrics which may more closely reflect the *in vivo* loading environment of the tibia. Much work is needed to validate estimates of internal tibial loading; however, the results of Rice et al.[1] demonstrate the utility of incorporating more complex models of bone loading into relative risk assessments of running activities.

Collectively, the results of Rice et al.[1] advance our understanding of tibial loading during running, suggesting that steep downhill running may reduce the damage potential to the tibia while steep uphill running may increase the damage potential. More work is needed to understand how factors such as hill length, graded running experience, and fatigue influence the individual response to graded running. However, this is an important step towards developing exercise programs that can maximize the health benefits and minimize the injury risk of running.

Authors' contributions

MB drafted the initial and final versions of this commentary; AK edited the commentary and provided key insights. Both authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

Both authors declare that they have no competing interests.

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