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Abstract Summary :

Using a Finite Element Model to Investigate Second Metatarsal Stress During Running

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Summary

Second metatarsal (2MT) stress fracture is a common and burdensome injury amongst runners, however understanding of the risk factors leading to injury is limited. Finite Element (FE) modelling represents a viable biorealistic alternative to invasive studies and simple beam theory models. This study shows the design and validation of a simple subject-specific FE model of the 2MT incorporating geometrically accurate soft tissue and loading. Results show a good comparison with both recent models and bone staple strain gauge data.

Introduction

Stress fractures of the 2MT are a common and burdensome injury amongst runners [1-3]. However current understanding of the factors that may predispose an athlete to this injury is limited. Simple geometric models of the 2MT loading during running have been used in the past [1] as a viable alternative to invasive direct measurement, but these require many assumptions regarding geometry. In contrast the FE method has been used more recently to investigate stress distributions in the metatarsals during running [4], however, biorealistic models often have prohibitively long development, construction and run times when investigating groups of participants [5] and many simplifications are needed to produce a model that can investigate groups of participants in a realistic timeframe. Therefore the purpose of this study was to develop and validate a FE model that allows estimation of the stresses acting on the 2MT during the ground contact phase of one running step. The model incorporates subject-specific geometry and soft tissue effects, whilst minimising the complexity and therefore computing cost. This model will be used to compare stresses in the second metatarsal during running with different habitual foot strike modalities.

Methods

Data were collected from eighteen (10 female) participants (age 24 ± 7.8 years; mass 64.8 ± 11.2 kg; height 1.68 ± 0.09 m). 2MT bone geometry was determined using MR images. Unilateral, synchronous kinetic (1000 Hz) and kinematic (200 Hz) data were collected during barefoot running at 3.6 ms^{-1} with a habitual foot strike (10 rearfoot, 8 non-rearfoot strikers).

Geometrically accurate 2MT and encapsulating soft tissue geometry were recreated from MR images, separating cortical and trabecular tissues. Kinematic and kinetic data were used to determine loads under the foot at discrete points during stance. The boundaries between tissue types were modelled as a fixed encapsulation, and the interface between the foot and the ground was modelled using contact elements with a coefficient of friction equal to 0.6 [5]. A FE simulation was used to determine deformation of the tissues and corresponding stress patterns and magnitudes under the application of load.

Results and Discussion

Initial results from one participant show a maximum stress on the dorsal surface of the 2MT of 35.04 MPa (Figure 1) equivalent to 2061 με, which compares well with both existing recent models showing median strain of 1937 με during overground running in minimalist shoes [4] and bone staple strain gauge data showing 1891 με during barefoot treadmill jogging [3]. It is expected that non-rearfoot strikers will display greater peak stress during running than rearfoot strikers.

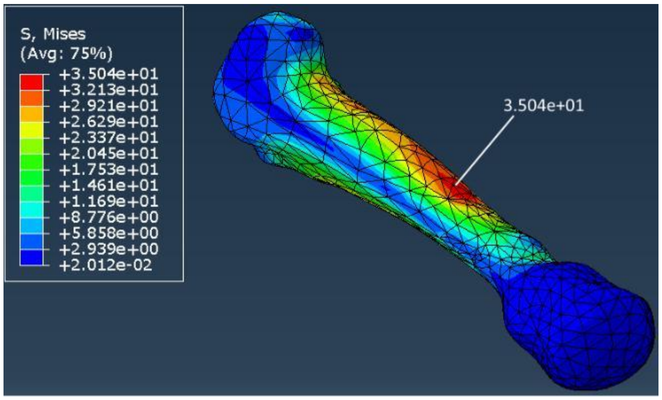

Figure 1: stress distribution (MPa) on the second metatarsal at midstance showing maximum stress location on the dorsal surface.

Conclusions

A FE model of the 2MT and surrounding soft tissues has been developed and initial results show a good match to previous models and bone strain gauge experiments in vivo. This model represents a powerful tool to answer questions such as "How does foot strike modality affect the stresses in the second metatarsal during running?"

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