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Development of a finite element model for the heterogeneous structure of the calcaneal fat pad to study its loading distribution. Insights for stress-related injuries

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Introduction: The calcaneal heel pad is a heterogeneous structure composed by fat clusters separated by an elastic fibrous-septa. Fat clusters are composed by fully grown adipocytes that bounded together form fat cambers arranged in a honeycomb structure[1]. The fibrous-septa is crucial to maintain the structural integrity and separate the fat clusters. The role of the heel pad is fundamental in the absorption of impact forces during ambulation. Its complex structure is used to distribute the mechanical loads in such a way that the single fat cells can sustain the pressure without permanent damage. A good understanding on the mechanical properties and the loading distribution of the calcaneal fat pad could give insight in stress-related injuries as diabetic ulceration and plantar fasciitis[2].

Methods: The objective of the present study is to develop a three-dimensional subject-specific heel pad Finite Element(FE) model that considers the honeycomb structure composed by fat clusters and fibrous-septa and their biomechanical properties. In order to gain insight on the stress propagation inside the fat pad structure an MRI-compatible device was built in order to apply displacements on the human heel sole and measure the corresponding force. The device is capable of applying compression and shear forces independently to analyze the mechanical response for both types of loads. MRI data were acquired in five different scenarios, including a rest position and two loading configurations for the compression and shear respectively(Figure1). The MRI data were then processed in order to generate a FE model of the heel and estimate the soft tissue elasticity parameters by comparison with the different loading situations(Figure2).

Results: The heel tissues showed a hyperelastic material behaviour. Under compression and shear loading the calcaneal pad initially has low stiffness, subsequently, increasing the load, the fibrous-septa and the fat clusters come under tension and compression respectively, limiting the deformation.

Conclusions: The numerical model developed in this study can be used to define a protocol to establish a set of parameters to describe patient specific material properties of the calcaneal fat pad. This will allow to analyse with multiscale models the amount of load distributed to the single fat cells which is not possible with experimental tests. Finally, this would lead to an optimization in the design of orthotics and shoes to avoid dangerous strains that could generate pressure injuries.

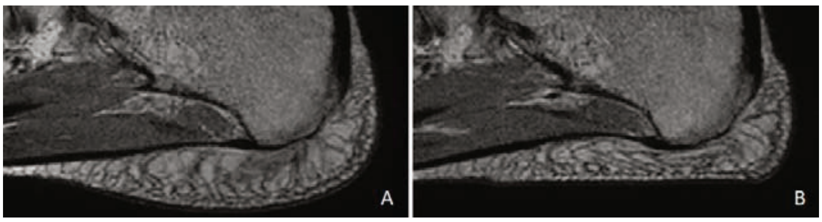

Figure1. The deformation of the internal soft tissues of the calcaneal pad, a comparison between(A) relaxed and(B) vertically loaded configuration.

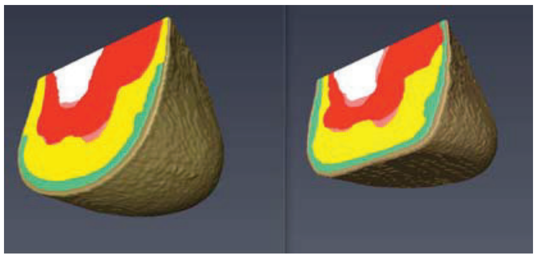

Figure2. Comparison between the segmented surfaces of the heel in relaxed and vertically loaded configuration.

References

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