TISSUE INTERNAL STRAINS COMPUTED BY A FINITE ELEMENT MODEL OF THE HUMAN HEEL AND MEASURED FROM MR IMAGES

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Introduction

Pressure ulcers are a severe disease mostly prevalent in patients that are bedridden or on wheelchair bound. These wounds can start developing in the deep layers of the skin of specific parts of the body, mostly on heels or sacrum, making them hard to detect in their early stages. It is recognized that prevention could be possible with the implementation of patient-specific Finite Element (FE) models to calculate dangerous levels of strains in the deep tissues that could trigger a pressure ulcer [1]. Validation of such FE models is a complex task. The current implemented techniques are limited as they consider only external displacements and pressures, or cadaveric samples [2]. In this work, we propose an *in vivo* technique for evaluating the simulations provided by an FE model of the human heel. This solution is based on the 3D non-rigid registration between two Magnetic Resonance (MR) images (one with heel at rest and the other one after applying a surface load below the heel) that is used to estimate tissue *in vivo* internal strains.

Methods

A Magnetic Resonance-compatible device has been designed to apply external loads on the heel while acquiring 3D MR images [3] (Figure 1). Using non-rigid registration techniques, the deformation field between the undeformed and deformed configuration is computed. From the obtained deformation map the Green-Lagrange strain filed is subsequently calculated. On the other hand, the segmentation from the unloaded MR image allowed to generate an ANSYS FE model of the heel. The MR load experiment was then simulated to compare the shear strain results between the FE method and the image registration (Figure 2).

Results

The MR-compatible device permitted to obtain good quality images allowing for a reliable image registration. The strain distribution, calculated respectively with 3D image registration and FE, resemble the expected results showing the highest strains around the bony prominence of the calcaneus (Figure 2).

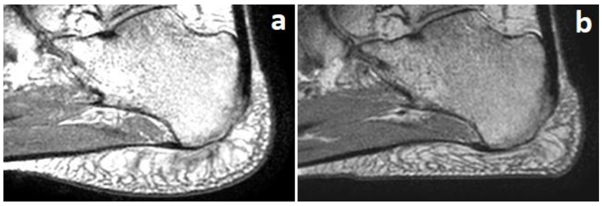

Figure 1: (a) MR image of the heel at rest. (b) MR image of the loaded heel.

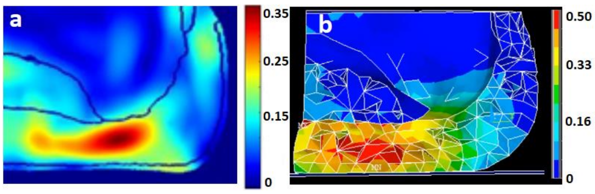

Figure 2: Comparison of tissue shear strains. (a) Green Lagrange strains map estimated from the displacement field computed in the image registration [2]. *(b) Hencky shear strains computed by ANSYS.*

Discussion

The implemented technique adds a useful tool for better understanding the propagation of strains in heel deep tissues that could generate pressure ulcers. Strain estimations through 3D image registration offers a promising technique for evaluating FE models for biomechanical applications. Further investigation is required towards identifying optimal material parameters to be implemented in the FE model. This would allow to find a stronger match in terms of magnitude and location of computed strains with both techniques.

References

[1] K. K. Ceelen, A. Stekelenburg, S. Loerakker, G.J. Strijkers, D.L. Bader, K. Nicolay, F.P.T.Baaijens & C.W.J. Oomens (2008). Compression-induced damage and internal tissue strains are related, *J. Biomech*., vol. 41, no. 16, pp. 3399–3404.

[2] B. E. Keenan, S. L. Evans, and C. W. J. Oomens, "A review of foot finite element modelling for pressure ulcer prevention in bedrest: Current perspectives and future recommendations," *J. Tissue Viability*, Jun. 2021, doi: 10.1016/J.JTV.2021.06.004.

[3] A. Trebbi, A. Perrier, M. Bailet, and Y. Payan, "MR-compatible loading device for assessment of heel pad internal tissue displacements under shearing load.," *Med. Eng. Phys.*, vol. 98, pp. 125–132, Dec. 2021, doi: 10.1016/J.MEDENGPHY.2021.11.006.

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