Patient-specific optimization of insole material properties: A pilot study

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ABSTRACT

Diabetes mellitus (type 2) is the most frequent cause of non-traumatic lower-limb amputations. It is indicated that footwear significantly affects the course of the diabetic foot syndrome. This usually works by using an orthotic insole designed to distribute pressure evenly over the plantar surface. As it stands, the prescription of diabetic footwear is intuitive in nature and is mainly provided through subjective measurements [1]. In this context the present study aims at developing a computational tool to facilitate the patient-specific, evidence-based choice of insole material for people with diabetes.

For this purpose a novel in-vivo measurement based procedure was designed for insole material optimization. During the first step of this procedure the morphology and the macroscopic mechanical behaviour of the plantar soft tissues is analysed using a specialized device for ultrasound indentation[2]. This device combines ultrasound and dynamometry to measure the tissue's force/deformation curve. The indentation tests are simulated using a 2D finite element (FE) model (Fig.1b). The foot is considered to consist of rigid bone and a bulk soft tissue. The geometry of this tissue is reconstructed from the ultrasound images (Fig.1a) and its mechanical behaviour is defined using the Ogden hyperelastic model. The material coefficients are inverse engineered using the data from in-vivo tests to create a model that imitates the plantar tissue's macroscopic response to loading. This model is finally used to simulate the contact between foot and insole and to calculate their contact pressure (Fig.1c). The mechanical behaviour of the insole is defined using the Ogden HyperFoam material model. An optimization algorithm is employed to calculate the material coefficients that minimize the plantar pressure.

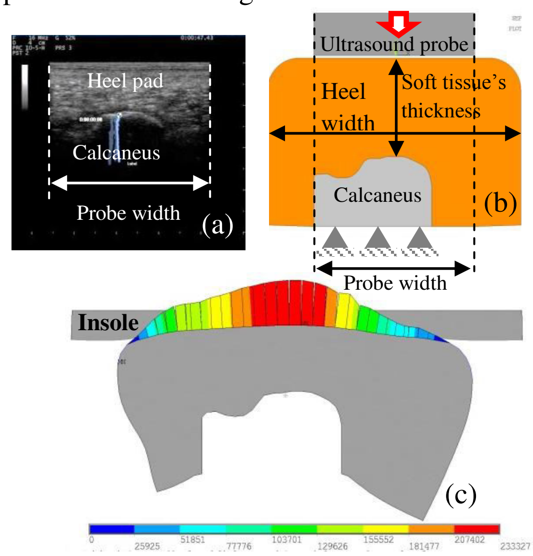

Figure: An Ultrasound indentation image (a) and the geometry of the FE models simulating the in-vivo tests (b) and the contact pressure (Pa) between heel and insole (c).

As a first step this procedure was employed to analyse the mechanical behaviour of the heel pad of a single subject and to find the optimum material properties for insoles that have different thicknesses. The results showed that the optimum insole material can reduce plantar pressure up to 21% compared to a rigid insole. Moreover the values of the optimum material coefficients are strongly influenced by the insole's thickness indicating that a combination of different insole thickness and material properties could be more effective in minimising plantar pressure.

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References

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