A DIABETIC FOOT MULTISCALE MODEL FOR PLANTAR ULCER PREVENTION

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Introduction

The diabetic foot is one of the major complication of diabetes mellitus that can lead to callosity and ulcers formation [Cavanagh P, 2008]. Finite element (FE) analysis allows to characterise and quantify the loads developed in the different anatomical structures and to understand how these affect foot tissue in dynamic conditions [Goske S, 2006]. The aim of this work is to create a patient specific multiscale 3-dimensional (3D) FE model of a diabetic neuropathic subject (NS) foot. This multiscale model includes a biomechanical foot model (BFM) together with a biological-tissue model (BTM).

Methods

Experimental procedure

The biomechanical analysis of the foot was carried out as in [Sawacha Z, 2012] on one NS (age, 72 years, BMI, 25.1 kg/m^2). The experimental setup included a 6 cameras stereophotogrammetric system (60-120 Hz BTS S.r.l, Padova), 2 force plates (FP4060-10, Bertec Corporation, USA), 2 plantar pressure systems (Imagortesi, Piacenza). The signals coming from all systems were synchronized [Sawacha Z, 2012]. The patient's hindfoot, midfoot, forefoot and tibia subsegments 3D kinematics and kinetics was estimated. The protocol was approved by the local ethic committee.

FE models

The MRI of the foot of a NS was acquired with 1.5T devices (Philips Achieva and Siemens Avanto, Spacing between slides: 0.6-0.7mm, Slice thickness: 1.2-1.5mm). MRI images were then segmented with Simpleware ScanIP-ScanFE (v.5.0). ABAQUS (Simulia, v.6.12) was used either to generate the mesh and/or to run FE simulation. BFM was meshed with quadrilateral elements. The FE simulation procedure depicted in Fig. 1 was performed in order to define the BFM. Four different loading conditions were applied to the BTM considering different phases of the stance phase of gait. FE simulations were run with the kinematics and kinetics data of the NS as input. In BTM, a novel mathematical approach based on the Thermodynamically Constrained Averaging Theory is applied to define diabetic ulcer initiation [Sciumè G, 2012]. The BTM consists of two phases: one solid for the tissue cells and their extracellular matrix, and one fluid (the interstitial fluid). The solid phase may become necrotic depending on the stress level and on the nutrients availability.

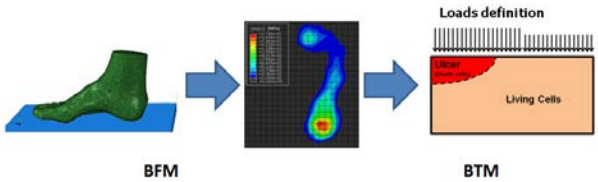

Figure1: BFM to BTM workflows.

Validity of the model was assessed through the comparison between the experimental peak plantar pressures and the simulated one.

Results

Results showed that when applying the foot subsegments ground reaction vertical component as input together with the subject specific kinematics there was a better agreement between the experimental and the simulated data than when applying the whole foot ground reaction vector. In correspondence of the bone structure, peak of stress were present at the metatarsal and talus bones.

Discussion

The model developed herein can help in predicting ulcer formation and evolution on the foot of diabetic subjects.

References

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