GAIT ANALYSIS DRIVEN 3D FINITE ELEMENT MODEL OF THE DIABETIC NEUROPATHIC FOOT

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Introduction

Diabetic foot is an invalidating complication of diabetes that can lead to foot ulcers. Three-dimensional (3D) finite element (FE) analysis allows characterizing the loads developed in the different anatomical structures of the foot in dynamic conditions [Chen WM, 2010]. The aim of this study was to develop a subject specific 3D FE model of both a neuropathic and a healthy subject's foot whose subject specificity can be found in term of foot geometry (obtained from MRI), in-vivo kinematics and kinetics measured data.

Methods

Experimental procedure

The biomechanical analysis of the foot was carried out as in [Sawacha Z, 2012] on 10 healthy (HS - age 58.7±10 years, BMI 24.5±2.6 kg/m^2) and 10 diabetic neuropathic subjects (DNS - age 63.2±6.4 years, BMI 24.3±2.9 kg/m^2). A 6 cameras motion capture system (60-120 Hz, BTS S.r.l, Padova), 2 force plates (FP4060-10, Bertec, USA), 2 plantar pressure (PP) systems (Imagortesi, Piacenza). The signals coming from all systems were synchronized. For each patient the hindfoot, midfoot, forefoot subsegments and tibia 3D kinematics, kinetics (ground reaction forces) and PP were calculated.

FE models

The MRI of the foot of both a HS (HS1) and a DNS (DNS1) were acquired, and 3D subject specific FE models were created: a healthy FE model (HFE) and a neuropathic one (DNFE, Figure 1). MRI were then segmented with Simpleware ScanIP-ScanFE (v.5.0) into 30 bones (grouped into hindfoot, midfoot, forefoot), cartilage (in the space between the bones) and the foot skin in order to get a 3D representation of the whole foot and ankle. The model was meshed in Simpleware-scanFE with tetrahedral elements according to the literature [Young PG, 2008] and imported into ABAQUS (Simulia,v.6.12). An horizontal rectangular element was drawn in ABAQUS under the foot to simulate the ground support. Materials properties were adopted from previous literature [Chen WM, 2010; Cheung JT, 2005]. Four different loading conditions were applied considering different phases of the stance phase of gait (heel strike, loading response, midstance and push off). FE simulations were run with the kinematics and kinetics data of the HS as input to HFE and of the DNS to DNFE. Validity of the models was assessed through the comparison between the experimental PP and the simulated ones (peak and mean values in the 3 foot subareas and in the whole foot).

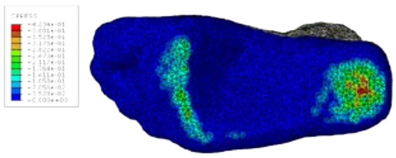

Figure 1:Simulated PP in DNFE during midstance.

Results

Results showed that there was a good agreement in the overall pattern between predicted and measured PP distribution when the kinematic-kinetic data of HS1 and DNS1 were used. However, when the gait data of the subjects in the two groups were adopted for the simulations, the HFE underestimated the PP in each foot subarea, while the NFE resulted in mean errors between experimental and simulated data below the 20% in the peak pressure values.

Discussion

Reliable PP and internal stresses during gait were obtained by means of a neuropathic subject's 3D FE model. This knowledge is crucial in understanding the aetiology of diabetic foot.

References

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