Introduction
The diabetic foot is one of the most serious complications of diabetes mellitus and it can lead to foot ulceration and amputations. Finite element (FE) analysis allows characterising and quantifying the loads developed in the different anatomical structures and how these affect foot tissue in dynamic conditions [Cavanagh PR, 2008]. In this study two experimentally kinematics-kinetics based FE models of the hindfoot of a healthy and a diabetic neuropathic subjects were developed in order to define more efficient subject specific computational model of the hindfoot that accounts for in-vivo kinematics, kinetics and plantar pressure data together with foot magnetic resonance images (MRI) data.

Methods
Experimental procedure
The biomechanical analysis of the foot was carried out as in [Sawacha Z, 2012; Sawacha Z, 2009] on 10 healthy ((HS), age 58.7±10 years, BMI 24.5±2.6 kg/m²) and 10 diabetic neuropathic subjects ((DNS), age 63.2±6.4 years, BMI 24.3±2.9 kg/m²). 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. For each patient’s foot the hindfoot, midfoot, forefoot and tibia subsegments 3-dimensional (3D) kinematics, kinetics (ground reaction forces) and plantar pressure were estimated.

FE models
The MRI of the foot of both a HS and a DNS were acquired, and 2D subject specific FE models were created: a healthy FE model (HFE) and a neuropathic one (NFE). MRI were then segmented with Simpleware ScanIP-ScanFE (v.5.0) in order to get a slice of the hindfoot passing through the line of the malleoli. The slice was imported into ABAQUS (Simulia,v.6.12) and meshed with quadrilateral elements according to the literature [Goske S, 2006]. An horizontal rectangular element was drawn in ABAQUS under the heel slice to simulate the ground support. Six different loading conditions were applied to each model considering different phases of the stance phase of gait. FE simulations were run with the kinematics and kinetics data of the HS as input to HFE and of the DNS to NFE. Validity of the models was assessed through the comparison between the experimental peak plantar pressures and the simulated one (pressure values are shown in Fig.1). Root Mean Square Error in percentage of the experimental peak value (RMSE%) was evaluated with this purpose.

Results
Results showed that if the specific force of the hindfoot was used as load in the simulations, there was a better agreement between the experimental and the simulated data then when the whole force acting on the foot was used (mean RMSE% changed from 13% to 25%). In particular best results have been achieved with the HFE model loaded with the HS data of the same subject used to generate the geometry and by applying the specific hindfoot force. In this case the model underestimated the contact pressure distribution of 4.2% and the peak of 1.1%. Meanwhile when applying the whole force it overestimated the pressure distribution of 14.7% and the peak of 48.23.

Discussion
The FE models developed herein allowed reaching good agreement between simulated and experimental data when accounting for subject specificity in each input variable.

References