PLANTAR PRESSURE REDUCTION BY FOOTWEAR: A FINITE ELEMENT MODEL

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Therapeutic footwear is routinely prescribed to provide plantar pressure relief at highly loaded areas underneath the feet of people with diabetes (Foto and Birke, 1998). A number of researchers have investigated the effect of flat and total contact orthoses and their thickness on plantar pressure re-distribution using two or three dimensional finite element (FE) models (Lemmon *et al.*, 1997; Chen *et al.,* 2003). These analyses have been performed at only one instant during the support phase of walking. Peak pressures are likely to occur at different stages of gait depending on the anatomical location of interest (e.g. hallux vs. metatarsal heads).

The objectives of this study were i) to simulate plantar pressure under the first ray for the entire duration of the late support phase and ii) to investigate the influence of five different insole materials on plantar pressure redistribution under the areas that have a high risk of ulcer formation in the setting of diabetic peripheral neuropathy (first metatarsal head and hallux). A FE model of the foot and the insole was chosen as a tool to simulate these conditions.

METHODS

A FE model of the first ray of the right foot of a male subject (95 kg, 1.88 m) with a flat insole was developed (Figure 1). The details of the model have been explained elsewhere (Budhabhatti *et al.*, 2004). Bone orientation and the loads applied to the model were calculated by an optimization procedure that

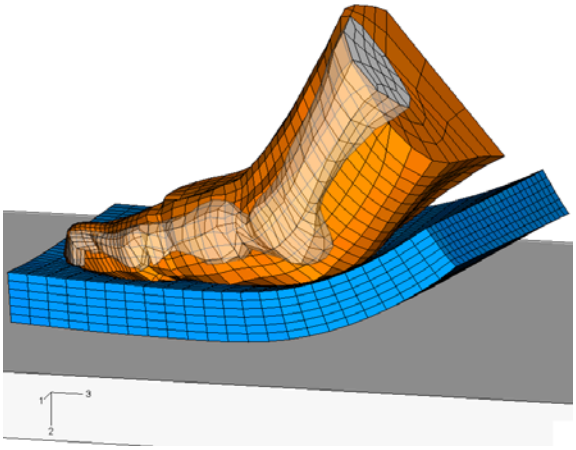

Figure 1: FE model of foot & insole during push-off.

minimized the difference in barefoot pressures predicted by the model and measured experimentally at the initiation of late stance (Erdemir *et al.,* 2004). The model was first configured and loaded to simulate the initiation of late stance. To model the push-off phase, the forces applied to the base of the metatarsal head and the metatarsophalangeal joint moment were incrementally decreased to zero. Simultaneously, the first metatarsal was subjected to an incremental rotation in its orientation with respect to the ground up to 45 degrees (Fauth, 2002). Five different footwear materials (Firm and Medium Plastazote, Puff, Puff-lite, and Poron) were simulated. Material thickness was set at 15 mm and material properties were obtained from data fits to compression tests (Figure 2). Hyperform material properties were used in the model (ABAQUS Theory Manual) and frictional contacts between the foot and

insole and the insole and ground plane were modeled.

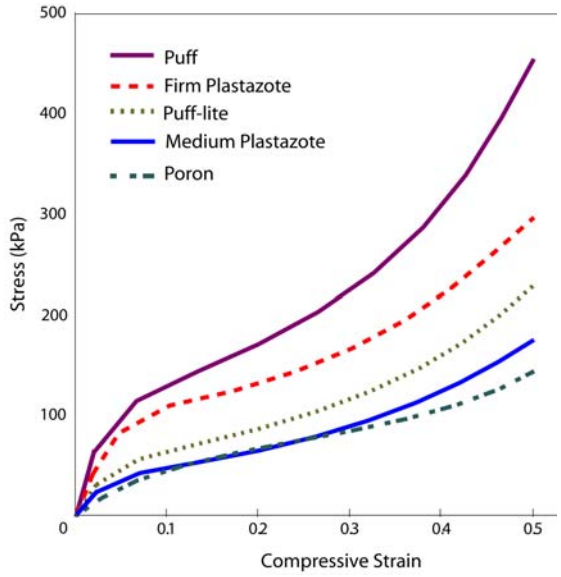

Figure 2: Stress-strain behavior of insole materials.

RESULTS AND DISCUSSION

The peak plantar pressures for the barefoot condition (experimental and model) along with five footwear materials are shown in Figure 3. Barefoot model predictions of peak hallux and metatarsal head pressures were in good agreement with experimental measurements. The simulation protocol was capable of identifying both peak metatarsal head and hallux pressures that occurred at different instants of push-off. The time of occurrence of peak hallux pressures (approximately 55% of push-off phase) was later than peak metatarsal loading (approximately 15% of push-off phase), an observation made possible by simulation of the entire late-support phase.

All materials resulted in a reduction of peak pressures compared to the barefoot walking simulation underneath the regions of interest (Figure 3). Poron resulted in a 70% decrease in hallux pressures and 50% reduction in metatarsal head peak pressure. Puff reduced pressures by 12% and 22% although it is rarely used in a single layered insole.

The methodology presented here can be used to predict plantar pressure relief under various conditions. This study can also be extended to test therapeutic footwear interventions that combine different insole materials and geometries and to the study of subject-specific models.

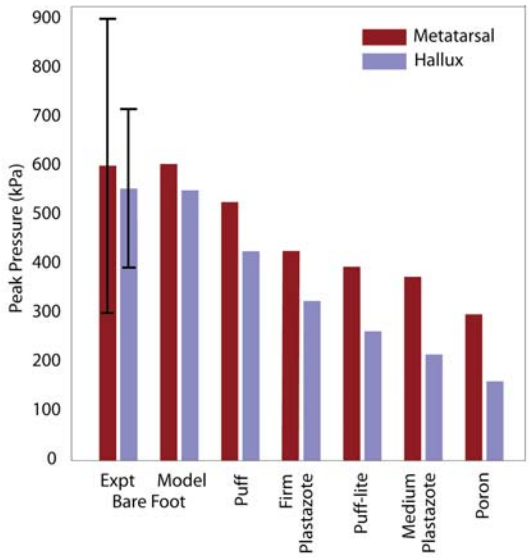

Figure 3: Peak plantar pressures for different footwear materials. Mean ± SD of five barefoot walking trials of the subject from whom model geometry was obtained is also shown (Expt).

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