THE EFFECT OF MIDSOLE PLUGS INSERTED INTO THERAPEUTIC FOOTWEAR FOR LOCALIZED PLANTAR PRESSURE RELIEF

Jeffrey J. Saucerman, Brian W. Loppnow, David R. Lemmon, John R. Smoluk and Peter R. Cavanagh

The Center for Locomotion Studies and the Departments of Engineering Science and Mechanics; Kinesiology; Biobehavioral Health, Medicine, Orthopaedics and Rehabilitation; Bioengineering Program

The Pennsylvania State University, University Park and Hershey, PA
Email: celos@psu.edu Web: www.celos.psu.edu

INTRODUCTION

Midsole plugs have been used in diabetic footwear to relieve focal areas of pressure under the foot (Brill et al., 1994). However, no current study in the literature has investigated the effects of midsole plugs to determine how well a plug may relieve plantar pressure. Additionally, there has been some debate on whether or not a plug intended for local pressure relief will redistribute stress by creating unwanted stress concentrations elsewhere. Through the use of both experimental methods and finite element (FE) models, the current research analyzes the effects of cylindrical midsole plugs made from soft foam. The FE model is then used to examine possible design modifications to plugs.

METHODS

Ten experimental conditions were examined in a single subject with elevated plantar pressure under the second metatarsal head (MTH). The experimental footwear consisted of an open sandal with a cloud crepe outsole, a cork midsole and an open-cell foam insole. Soft foam plugs of varied sizes were inserted into each midsole. Plug diameters of 19.0 and 25.4 mm were used, with plug depths of 3.2 and 9.6 mm. A high resolution Pliance pressure mat (Novel USA, Minneapolis MN) with 256 sensors in a 4 x 4 cm area was used to record plantar pressures from the subject during treadmill walking at a constant speed of 3.37 km/hr.

The subject’s anatomical geometry was obtained from a sagittal plane ultrasound image, and a simplified two-dimensional plane strain FE model was created (see Figure 1). The model represents a second metatarsal embedded in homogeneous soft tissue. Footwear was added to the mesh using I-DEAS software (Structural Dynamics Research Corporation, Milford OH) to complete the model of the MTH2.

Using material properties from the literature, soft tissue was characterized to be hyperelastic, while footwear materials utilized a hyperfoam model available in ABAQUS (Lemmon et al., 1997). Boundary conditions included a proximal restraint together with vertical and shear loading on the proximal end of the metatarsal. Footwear was constrained both vertically and horizontally.
To validate the FE model, custom code was used to convert a three-dimensional pressure distribution into a representative sagittal two-dimensional pressure distribution. Each experimental trial was compared to a matching FE model, and the difference in peak pressure was computed. A variation of the cylindrical midsole plug was prototyped using the FE model. By altering the material properties of elements in the midsole, a taper was introduced into the top of the plug. It was hypothesized that a taper may alleviate stress concentrations created by the plug.

RESULTS AND DISCUSSION

The FE model yielded results similar to the experimental pressure measurement. Model plantar pressure distributions were compared to experimental data, and peak pressures were generally found to be within 10% of experimental values. Both model and experiment demonstrated maximal pressure relief with a 6.4 mm insole, 25.4 mm plug diameter, and a plug depth of 9.6 mm. This combination allowed a pressure reduction at the control peak pressure site of 18.3% in experiments and 14.1% in the model compared to a 6.4 mm insole alone.

Analysis of the plantar pressure distributions from conditions with a plug showed that stress concentrations did appear during the propulsion phase of gait (see Figure 2). Although plantar pressure was relieved under the second metatarsal head, it was redistributed to the proximal edge of the midsole plug. These edge effects were sometimes even greater than the peak pressure seen in shoes with no plugs.

The prototype design of a tapered plug demonstrated the ease with which new designs may be tested in an FE model. The tapered plug caused a 20%, or 50 kPa,

Figure 2: Typical comparison of model and experimental results. Note plug positioning with respect to the pressure distribution.

reduction in edge effect when compared to results for a cylindrical plug of the same plug size. The tapered plug was able to nearly eliminate all edge effects, while successfully reducing the pressure at the site of anatomical interest. The current research demonstrates that plugs should be used with caution, since they have been found to produce unintended edge effects. FEM may be an effective method for testing new footwear designs and reducing the number of experimental measurements.

SUMMARY

The therapeutic effect of midsole plugs in diabetic footwear has been analyzed using both experimental and computational approaches. Cylindrical plugs often cause stress concentrations, sometimes even higher than the original peak pressure. A prototype plug was designed using an FE model, which eliminates stress concentrations and reduces peak pressure.

REFERENCES
