COMPUTATIONAL PREDICTION OF IN-SHOE PRESSURES WITH AND WITHOUT A METATARSAL PAD

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INTRODUCTION

Poorly designed shoes are believed to be responsible for high plantar pressures that lead to foot ulcers under the metatarsal head (MTH) region of the foot in people with diabetes [1]. Metatarsal (MT) pads can aid in localized plantar pressure relief [2]. However, their experimental evaluation is susceptible to coarse pressure measurements and difficulties in accurate placement. Finite Element (FE) analysis has been widely used to create foot and footwear interventions without the burdens of experimentation [3]. The objective of this study was to use a coupled FE analysis - optimization technique to predict in-shoe pressures and examine the effect of a MT pad, placed inside the shoe, on peak MTH pressures at initiation of late stance. This approach has the potential of optimizing MT pad design as well as evaluating other therapeutic footwear interventions.

METHODS

A PW Minor Shoe (insole and outsole) and a medium size felt MT pad (Hapad Inc.) were digitized using a laser scanner (Roland, CA). FE meshes of shoes and the forefoot were created using TrueGrid (XYZ Scientific Inc., CA. A mesh of MT pad was created using Abaqus. Footwear materials were assigned 2nd order hyperfoam properties obtained from fit to experimental data: soft and hard tissues were assigned incompressible hyperelastic and rigid material properties respectively. Information about the FE model and material evaluation can be found elsewhere [4, 5].

Barefoot plantar pressures of the subject whose FE model was created were collected using an Emed pressure platform (Novel Inc.) and ground reaction forces (GRF) were extracted for the initiation of push-off using a Kistler force plate (Kistler Inc. Zurich). The vertical GRF was applied to the barefoot FE model and the predicted peak pressures under MTH and toes were matched to experimental barefoot pressures using a gradient-based optimization which minimized the difference between the experimental and model pressures by changing bone and foot orientation. Reaction moments for 10 joints (five TMTJ, five MTPJ) and for the whole foot were extracted from this solution. A similar optimization procedure was used to minimize the difference between reaction moments obtained from barefoot simulation and those calculated in the shoe with and without a MT pad (approx. 5 mm proximal to second MT head) by altering the bone configuration. A kinematic constraint between the foot and the shoe was defined such that it allowed the compression of the foot against the footwear but restricted their separation (Figure 1). For evaluation purposes, in-shoe pressures without MT pad were collected using Pedar (Novel Inc.) at a speed of 1.5 m/s [6]

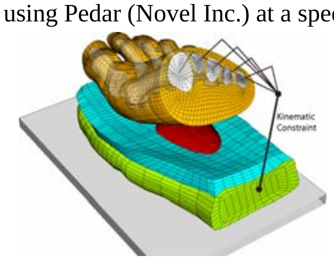

Figure 1: 3D FE model showing kinematic constraint and a MT pad.

RESULTS AND DISCUSSION

Optimization matched the peak barefoot pressures with an RMS error of 150 kPa. On the grid of 5mm by 5 mm (Emed sensor size), peak barefoot pressures under MTH2 for model and experiment were 838 kPa and 840 kPa respectively. The RMS error in joint moments for footwear simulations before and after insertion of a MT pad as compared to barefoot were 1.9 N-m and 2.8 N-m respectively. On a grid of 10 mm by 10 mm (approx. Pedar sensor size), the peak model and experimental MTH2 pressure for the shoe condition were 520 kPa and 277 kPa respectively (Figure 2a). Insertion of a MT pad reduced model peak MTH2 pressures by 18% w.r.t. shoe condition (Figure 2b).

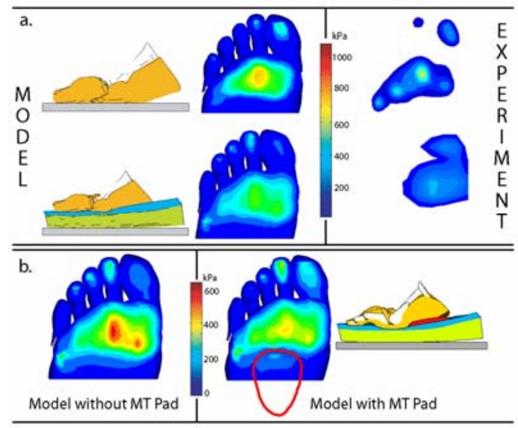

Figure 2: a) Model and experimental pressure distributions b) Peak MTH2 pressure reduction with insertion of MT pad.

The in-shoe model was successfully able to predict the trend in peak pressure reduction as observed experimentally and showed a decrease in peak MTH2 pressures when a MT pad was inserted. Results for MT pad are in agreement with Hayda et al. [2] who showed a 23.1% decrease w.r.t shoe only condition for a similar MT pad conditions. The difference in the actual and predicted in-shoe pressures could be due to measurement resolution, decreased vertical GRF observed during in-shoe experiments, and RMS error due to optimization.

CONCLUSION

This study demonstrates the application of FE modeling for design of therapeutic footwear interventions from barefoot data alone by using MT pad as an example. Future studies will explore the sensitivity of MT pad properties and placement on peak MTH reduction.

REFERENCES

1. Mueller M., *J. Ortho. & Sp. Phy The.* 21, 328-336, 1995.
2. Hayda R. et al., *Foot & Ankle Intl.* 15, 561-566, 1994.
3. Gefen A. et al., *J Biomech.* 122, 630-638, 2000.
4. Budhabhatti S. P. et al., *ISB abstract.* 2005.
5. Petre M. et al., *Comp. Meth. Biomed. Eng.* 231-42, 2006.
6. Budhabhatti S. P. et al., *BioOhio abstract.* 2005.

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