REDUCTION OF PLANTAR HEEL PRESSURES: INSOLE DESIGN USING FINITE ELEMENT ANALYSIS

[1] Steven Goske, [2]Ahmet Erdemir, [2,3]Marc Petre, [2,4]Sachin Budhabhatti and [2,5]Peter R. Cavanagh
[1]Dept. of Biomedical Engineering, Saint Louis University, [2]Dept. of Biomedical Engineering, Cleveland Clinic Foundation,
[3]Dept. of Biomedical Engineering, Case Western Reserve University, [4]Dept. of Chemical & Biomedical Engineering,
Cleveland State University, [5]Dept. of Orthopaedic Surgery and Orthopaedic Research Center, Cleveland Clinic Foundation
e-mail: cavanap@ccf.org, web: www.lerner.ccf.org/bme/cavanagh

INTRODUCTION

Plantar loading of the heel during daily locomotion can result in high local pressures that need to be relieved in the case of heel pain [1]. In-shoe interventions are commonly used to reduce plantar heel pressures by using custom or off-the-shelf insole products, e.g. [2]. The design process for these products is often intuitive in nature and does not always rely on scientifically derived guidelines [3].

Finite element analysis provides an efficient computational framework to investigate the performance of a large number of designs for optimal plantar pressure reduction. The objectives of this study were to develop a finite element model of the heel pad and footwear and to explore the insole design space in order to quantify the effects of i) insole conformity, ii) insole thickness, and iii) insole material on pressure relief.

METHODS

A 55 mm thick plane strain model of the heel pad was developed. Heel geometry was obtained from MRI of the right heel of a healthy adult male (23 years, 89 kg, 1.88 m). Bone was assumed to be rigid; soft tissue was modeled as incompressible hyperelastic. A barefoot simulation was conducted during which the heel was loaded vertically to simulate maximal loading of the heel at first step of walking. This simulation provided the baseline peak pressure that needed to be relieved by insole intervention. Barefoot pressure measurements validated model predicted peak heel pressure. For simulations regarding insole design, footwear was included into the model (Fig. 1). A 20 mm thick midsole was modeled as Firm Crepe (compressible, hyperfoam) and the shoe sidewalls were modeled as stiff leather (linearly elastic).

Three insole design variables were investigated: conformity (flat, half, full); thickness (6.3 mm, 9.5 mm, 12.7 mm); and compressible hyperfoam material (Microcel Puff [hard], Microcel Puff Lite [medium], Poron Cushioning [soft]). All simulations were conducted using ABAQUS (Abaqus, Inc.) and percent reduction in peak heel pressures was calculated compared to model prediction of peak barefoot pressure.

RESULTS AND DISCUSSION

Conformity had the most profound effect in pressure reduction (Table 1), possibly due to larger contact surfaces. Thickness was also influential in reducing plantar heel pressures (Table 1). Material had a limited effect; pressure reduction slightly improved while using a softer material. It was possible to reduce peak heel pressure by 15-24% (compared to barefoot condition) by simply using a flat insole. Through careful selection of insole properties, it was possible to increase this reduction up to 44% when compared to barefoot values.

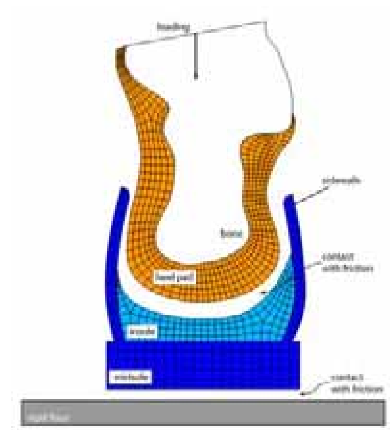

Figure 1: Plane strain model of the heel pad, insole and the remaining components of the shoe.

Table 1: Percent reduction in peak heel pressures (for each insole) compared to barefoot peak pressure (435 kPa).

Conformity		Material	Thickness (mm) 6.3	9.5	12.7
Flat	Material	Microcel Puff	15.2	20.5	23.0
		Microcel Puff Lite	16.3	20.7	23.9
		Poron Cushioning	16.8	20.7	24.1
Half		Microcel Puff	26.7	28.7	31.3
		Microcel Puff Lite	26.2	29.7	34.7
		Poron Cushioning	25.1	28.5	33.8
Full		Microcel Puff	37.5	38.9	40.7
		Microcel Puff Lite	37.9	40.7	43.7
		Poron Cushioning	35.6	38.9	43.4

The finite element analysis allowed a cost-effective investigation of multiple insole design criteria to reduce plantar heel pressures. The approach also advanced previous modeling studies of the heel/footwear, e.g. [4], by adapting a plane strain approach in order to capture heel anatomy and representation of the various components of the shoe.

REFERENCES

1. Alridge T *Am Fam Phys* **70**, 332-338, 2004.
2. Ashry HR, et al. *J Foot & Ankle Surg* **36**, 268-271, 1997.
3. Ulbrecht JS, et al. *in Kominsky SJ,* 29-45, 1994, Mosby Year Book, St. Louis, MO.
4. Verdejo R and Mills NJ *J Biomech* **37**, 1379-1386, 2004.

ACKNOWLEDGEMENTS

This study was funded by the NIH Grant # 5R01 HD037433.