THERAPEUTIC FOOTWEAR DESIGN: A FINITE ELEMENT MODELING APPROACH

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INTRODUCTION

Foot ulceration is a common complication among diabetic patients with peripheral neuropathy [1]. Elevated foot pressures can cause skin breakdown that might lead to ulceration (Fig. 1). Therapeutic footwear is a typical intervention for relieving plantar pressures which can lead to ulceration [2], but scientific guidelines for selection of footwear are not well defined [3]. Although some experimental studies have attempted to establish such guidelines, e.g. [4], the systematic testing of multiple design variables is difficult. In practice, footwear selection still relies on the experience of the healthcare provider and on trial-and-error.

Finite element (FE) analysis allows the investigation of complex biological structures under load by discretization of the geometry into small uniformly shaped elements [5]. When boundary conditions, loading and friction at the foot-shoe interface are defined, the models can predict stresses under the foot. This approach permits the examination of a large number of footwear designs without the burden of high-volume experimentation. Once validated, the models can simulate variations in anatomy and footwear: for example, the insole geometry and material can be systematically varied to guide strategies for the prescription of therapeutic footwear. Our objective is to establish an integrated approach and use FE modeling for design of therapeutic footwear.

METHODS

The modeling strategy employed includes representations of foot anatomy, footwear geometry, soft tissue properties, footwear materials, foot kinematics and loading and foot-footwear-ground interactions. Barefoot and in-shoe pressure measurements provide foot loading as well as validation data. Subject specificity is established by optimization protocols to map model predicted pressure measurements to those measured experimentally. Foundations of FE simulations rely on computational and experimental research in the areas listed above; the integrated approach provides the necessary input to develop two- and three-dimensional FE models (Fig. 2).

A variety of design criteria for therapeutic footwear are tested by systematically changing footwear properties (e.g. geometry, material) in FE models. It is possible to identify designs that result in effective pressure reduction overall. Footwear interventions to relieve local pressures under focal areas of the foot (e.g. heel pad, metatarsal head) are also investigated by FE simulations.

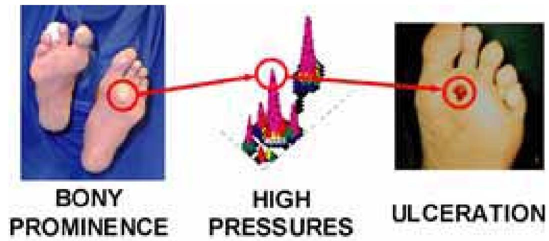

Figure 1: Potential pathway to foot ulceration in diabetic patients with peripheral neuropathy.

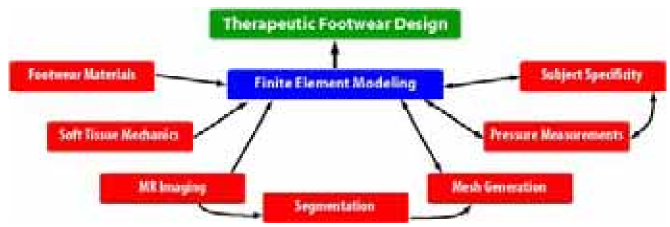

Figure 2: An integrated approach for therapeutic footwear design based on finite element modeling.

EXAMPLES

Simulations using a plane strain model of the second metatarsal region have identified favorable plug designs to relive local pressures underneath the metatarsal head. A plane strain model of the heel pad has provided guidelines on the selection of insole thickness, material and conformity to reduce heel pressures. A three-dimensional model of the first metatarsal and hallux has quantified the influence of material selection on plantar pressure reduction under the first ray.

Among the models under development are a planar heel-pad model to explore shear prediction under the foot; a three-dimensional forefoot model for evaluating load redistribution among the metatarsal heads; and a whole foot model to investigate transfer of forefoot loads to the arch using footwear.

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ACKNOWLEDGEMENTS

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