Using plantar pressures for improving arch support for shoe customization

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Introduction

The footwear industry is evolving from a labor-intensive work to a knowledge-based manufacturing process, developing customized and personalized products in order to meet the customer needs [1]. Pathologies like high arch and flat foot are widely studied and some orthoses have shown positive results in treatment [1, 4]. The objective of this work was to customize the design of a comfort shoe (Arcopédico), so it could be adapted to three major foot types (pes cavus, planus and normal).

Methods

In this work, a complex geometrical finite element (FE) model of the human foot was used to analyze plantar pressure distributions. This FE model consists in a unified bone structure (tibia and fibula; calcaneus and talus, cuboid, cuneiforms and navicular, all the metatarsals and all the phalanges) assembled with the soft tissue and five springs, simulating the most important tendons in plantar fascia. According to literature [2] and the purpose of the study, bone structure, soft tissue and tendons were considered linearly elastic, isotropic and homogeneous. The shoe sole contour was obtained via 3D laser scan and the surface was transferred to *Solidworks*® software where a computer aided design (CAD) model was developed. The sole object and a rigid support, added to simulate the ground, were incorporated in the FE model [2, 3]. The applied loading and boundary conditions are assumed for a standing orthostatic position. A vertical force equivalent to ½ of the body weight was applied at the inferior rigid support to simulate the ground reaction force [2, 3].

Mechanical experiments (tensile and compression tests) were performed and the original sole material was characterized as linear elastic, with a Young modulus and a Poisson ratio of 8 MPa and 0.4, respectively.

Different sole shoe solutions were evaluated, based on plantar pressure distributions measured experimentally, in order to adapt a universal comfort shoe into a customized shoe, designed to address the three foot types (pes cavus (high arch), normal and pes planus (flat foot)). Therefore, geometrical and material modifications were implemented at the midfoot region and arch support.

The two types of modifications were based on an insert of a different material in the midfoot region, and a longitudinal arch support. The last solution intends to meet the needs of people suffering from pes cavus.

Results

In the FE analysis, the standard condition was considered the one with the original shoe sole. Under the same loading conditions, the plantar pressure distributions for the different sole shoe geometries were very similar, as the peak plantar pressure. However, with a softer insert, the plantar pressure in the midfoot was relieved. The additional arch padding was found to promote an increase of the contact area between the shoe sole and the plantar foot.

Conclusions

Based on the results of simulations, three solutions were chosen, one for each foot type. For planus and normal foot, the original sole geometry was preserved; for the first one, an insert of a softer material was chosen and for the normal foot, to test a different shoe model, it was chosen to product a prototype with a hard insert. The solution for the high arch foot was to produce a shoe sole with a softer insert material and a longitudinal arch support to provide additional cushioning and shock absorption [4].

The authors gratefully acknowledge the funding by QREN/COMPETE, I&D project nº 38415 submitted by ROPAR.

References

[1] Goonetilleke, R. S., *The Science of Footwear,* CRC Press, 2012
[2] Pinto, V. *et al*., *Internal Stresses, Shear Stresses and Plantar Pressures Of 3D Foot Model Using Fem Analysis*, ISB 2011 Brussels
[3] Cheung, J.T. *et al.*, *A 3-Dimensional Finite Element Model of the Human Foot and Ankle for Insole Design,* Arch Phy Med Rehabi 2005
[4] Werd, M. B. and Knight, E. L., *Athletic Footwear and Orthoses in Sports Medicine*, Springer 2010