Design of Insole using Image Base Analysis

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Human beings are engaged in a sort of activities, such walking and running, which induce high transient forces to the foot, resulting in elevated local stresses. Such forces are believed to be the etiological cause for numerous pathologies including degenerative joint disease, low back pain, plantar fasciitis, Achiles tendonitis, muscle tears, stress fractures, and overuse diseases. The human body has two natural ways to minimize the noxious effects of these forces: correct joint alignment and viscoelastic materials present in it. Thus construction of appropriate footwear appears like a promising alternative which would build a third line of defense against such forces. This theory is supported by the belief that viscoelastic materials can attenuate the magnitude of these forces.
Key words: Human Foot Model, Finite Element Method, Footwear Biomechanics.

1. Introduction

A variety of over the counter and custom products have been used for footwear's manufacture, aiming magnitude reduction of such forces. However, the design of footwear components, as insole, midsole and walls do not follow scientific principles, rather intuition. Moreover, the understanding of relative contributions of the footwear design variables such geometry and material properties on transient forces attenuation are still in its infancy. In this panorama, computational models of foot-footwear interaction are favorable options to simulate it, since the design space can be systematically searched to optimize the product (Goske, 2006). In the universe of biomechanical variables we opt for peak plantar pressure. This variable was chosen to evaluate the efficacy of designs variables because of the widespread clinical and experimental use (Cavanagh et al. 2000) of this quantity and its links to diseases. The study aims to investigate the effect of insole design variables on peak plantar pressure. The parameters in question are: conformity and material. It has also been reported in literature that the peak plantar pressures has differences patterns and values depending on the various activities that are imposed to the foot, thus the best way to start a study is with a simple case. We chose balanced standing position on insole as a beginning.

2. Research Design

In order to find meaningful insight into this effect, the following strategy was adopted: Image Analysis, Finite Element Analysis and Plantar Pressure Measurements. The global approach to this problem can be seen in the figure 1 below.

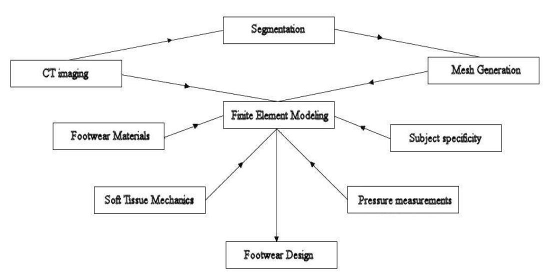

Fig.1 Methodology.

2.1 Acquisition and Segmentation

The Finite Element model was constructed based on a right foot of a 40-year-old male subject, without any foot pathology. The CT scan images were acquired using a TOSHIBA/Aquilion scanner with series of 277 scans taken at 1 mm interval in the transverse plane; its resolution was 512 by 512 pixels and each pixel length 0.976 mm. The data were a courtesy of the Alive Human Body Team at RIKEN. Using a edition program, the segmentation of the different structures of the foot was performed, and the volume rendering was performed. To improve accuracy, I used three different segmentation techniques in sequence: thresholding, region growing and polylines curves. After segmentation, the volume generated (volume rendering) was delimited by a 2D triangular mesh. This mesh was exported to a preprocessor software (Hypermesh 8.0, Altair Engineering Inc., 1995-2006) which was used to create the 3D solid mesh (tetrahedral elements) directly from the triangular mesh.

2.2 Finite Element Model

A geometric, detailed 3-D finite element model of the human foot, based on CT scan, was developed to estimate the peak plantar pressure. A net normal vertical force of 350N was applied on 40 nodes on the talus' throclea for the tibia, and 175 N was applied on 10 nodes on the triceps surae insertion. The inferior surface of the insole were fixed throughout the analysis, while the points of load application, i.e., the 50 nodes mentioned above, were allowed to move in the vertical direction only. Besides that, the bottom faces of each insole, used in simulation, were constrained. The region between the plantar region and the insoles were modeled as contact regions with coefficient of friction 0.6 (Cheung, 2005).

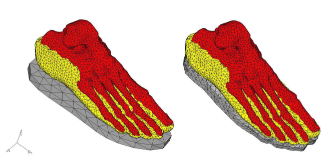

Fig.2 Finite Element Model.

2.3 Plantar Pressure Measurements

In order to validate the model that was build, one experiment was performed to acquire the peak plantar pressure. Four activities were recorded: barefoot standing position, balanced standing position, walking and running. For the three last activities the subject was shod. The measurement system was the Tekscan F-scan that allows measurement of vertical ground reaction force, pressure, peak pressure, contact area, and gait cycle timings (Woodburn *et al.*, 1996).

3. Results and Discussion

Even though the predicted plantar pressure distribution pattern was, in general, comparable to the F-scan measurement, the predicted values of peak pressure were higher than the F-scan measurements, consequently the data will be compared qualitatively. The first footwear design variable tested (conformity) proved to have a great influence on the plantar pressure distribution and peak plantar pressure values. The data obtained on this study showed a tendency of peak plantar pressure decrease for three of the foot regions: rearfoot, forefoot and phalanges. However the behavior was opposite for one of the foot regions: midfoot. For rearfoot region the biggest amount of reduction, while supported by a soft material, was about 41% (simulation result) and 63% (experimental result) when compared with barefoot condition. Some other researchers, such as Lobmann et al. (2001) and Bus et al. (2004), reported reductions up to 23% and 60%by simply using insoles that conform to the heel. The decreases between flat and conforming insole for the rearfoot region were 27% and 21.5% (simulation results), for rigid material and soft material, respectively. From the experimental data, comparing two different conditions, the reduction ranges from 0.2% to 9.4%. Probably the main reason for the small decrease observed, when compared to simulation results, is that for the experiment, conform insoles were in fact half conformed to the heel, a shape that is not so effective in plantar pressure reduction, as observed by Goske *et al.* (2006). Going to the next region, the amount of the decrease was 29.5% and 40.7%, for rigid material and soft material, respectively, on the forefoot region (simulation results). Experimental data showed reduction ranging from 31.4 % to 11.6%, for rigid and soft material, respectively. The next region: phalanges, showed reductions of 22.6% and 33.5%, for rigid material and soft material, respectively (simulation results). Experimental data showed reduction of 62.6% to 43.7%, for rigid and soft material, respectively. Simulation and Experimental results for these three regions are depicted in Fig 3 and Fig 4, respectively.

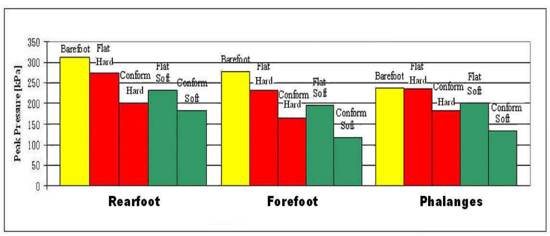

Fig.3 Simulation results for design variables.

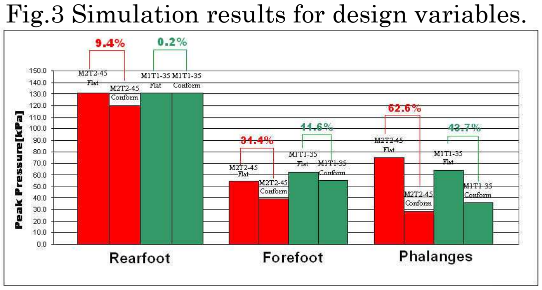

Fig.4 Experiment results for design variables.

On the other hand, midfoot region presented an opposite behavior: an increase in plantar pressure. The amount of this increase was 71.1% and 7.8%, for rigid material and soft material, respectively (Fig 4). Experimental data showed increase ranging from 38.3% to 23.0%, for rigid and soft material, respectively (Fig 5). This increase in peak pressure was expected, because midfoot region is fully supported while wearing conform insoles.

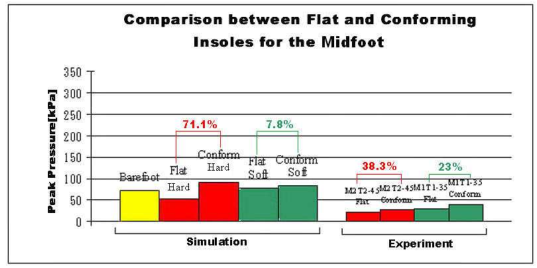

Fig.5 Simulation and Experimental results for midfoot region.

The second footwear design variable analyzed was material. Simulation and experimental results showed a trend that softer materials can reduce peak plantar pressure. The decrease is calculated comparing soft and rigid material, while keeping the same geometry. Simulation data showed a decrease in peak plantar pressure: 14.5%, 15.4%, -46.4% (anomalous result) and 15.1%, for phalange, forefoot, midfoot and rearfoot, respectively, for a flat insole. For a conform insole the order of the decrease was 26.5%, 28.8%, 7.7% and 8.7% for phalange, forefoot, midfoot and rearfoot region, respectively. Experimental data presented decrease of order of 7.8%, 19.9%, 7.1% and 4.5% for phalange, forefoot, midfoot and rearfoot region, respectively, for a flat insole. For a conform insole this order was 26.4%, 11.2%, 21.2% and 9.9% for phalange, forefoot, midfoot and rearfoot, respectively. Cheung and colleagues (2005) found that conform, soft insole reduced the peak plantar pressure by 40.7% and 31.6% at the metatarsal (forefoot) and heel region, respectively, compared with those under a flat, rigid insole. Comparing these two conditions in our case study we have 33.2% and 43.2%.

4 . Conclusion and Future Considerations

To simplify the analysis in this study, we assigned homogeneous and linearly elastic material properties to the model. The use of linear elasticity for the material used during the simulation may under or overestimated the real values for peak plantar pressure. That is a far approach from the real situation, thus the inclusion of nonlinear properties seems like a promising and natural path for a future work. The current finite element model, joints of the foot were not considered. As consequence, ligaments and cartilage, structures with major function in joint stability and constraint, were not considered either. Therefore, this assumption potentially overestimates stiffness, consequently overestimating peak plantar pressure. The model did not account for the surface interactions between bony, ligamentous and muscles structures. This kind of structural simplification would have influence on peak plantar pressure, however for the condition studied (balanced standing position), its effects are expected to be minimal. Only the Achilles'tendon loading was considered, whereas other intrinsic and extrinsic muscle forces were not simulated. Consequently, the exclusion of muscles leads to prevent accurate force application, which leads to erroneous stress and strain distributions. Again here we have to say, this issue is a promising topic for a future study. The finite element analysis and experimental data indicated that conformity is an important factor in peak plantar pressure reduction. Data indicate that the geometry (conformity) of the insole has an important role on peak plantar pressure decrease. This phenomenon can be seen in all areas of the foot with an exception to midfoot region. For phalanges, forefoot and rear foot simply changing the geometry of the insole from flat to conform produces reductions, supported by enough body of evidence (experimental and simulation data), allowing us to claim that conformity is an important peak plantar pressure decrease factor for three of the foot's region: rearfoot, phalanges and forefoot. The remainder region, midfoot, conformity acts as a peak plantar pressure increase agent. For the second variable studied, like was observed to the first variable, all region of the foot showed influence of it. Opposite to conformity, this effect seems to do not have any relation with the region observed, i.e., it seems more like a global behavior, where all regions present a decrease of peak plantar pressure inversely proportional to hardness. Our claim for this variable is that the values of peak plantar pressure are directly proportional to insole material hardness, with enough body of evidence (experimental and simulation data) to corroborate with this theory. Finally it can be said, supported by finite element prediction and experimental data, that both a softer material and a conform insole have a role in the reduction of peak plantar pressure. These insoles aided in assimilating the plantar pressure in a more uniform manner than a rigid, flat insole. Consequently, this kind of design would be a good adopted strategy to prevent many diseases associate with transient forces experienced by the foot during daily activities.

References

1) Sarang Lakare, "3D Segmentation techniques for medical volumes", *Research proficiency exam* (2000).
2) Geffen A., Ravid M., Itzchak Y., Arcan M., *Journal of Biomechanics Engineering* **122** (2000) 630-639.
3) Goske S., Erdemir A., Petre M., Budhabhatti S., Cavanagh P.R., *Journal of Biomechanics* **39**(2006) 2363-2370.
4) Cheung J., Zhang M., *Medical Engineering and Physics* (2007).