DYNAMIC SIMULATION AND EXPERIMENTAL VALIDATION OF THE PLANTAR FOOT PRESSURE DURING HEEL STRIKE

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INTRODUCTION

Computational analysis of the foot biomechanics has its advantage in providing an overall stress distribution of the foot. It is also more economical than in vitro cadaver experiments. In the current study, a general mesh generation software, Gridgen V14, was used to establish a three-dimensional hexahedral foot finite element model with detailed joint characteristics and partial plantar soft tissues. In addition, a dynamic finite element analysis software, LS-DYNA 970, was incorporated with the kinematic data from gait analysis for the dynamic simulation of foot motion during heel strike. The pressure distributions at the heel region during heel strike were investigated. Furthermore, in order to validate the analysis results, the plantar pressures of the same subject who provide the foot geometry was measured during heel strike. Both the analysis and measured results showed similar trends and within the same range.

METHODS

A detailed 3-D finite element foot model was created based on the computed tomography images of the left foot of a 24 yr male subject. A finite element mesh generation program (Gridgen V14, Pointwise, Inc., Fort Worth, Texas, USA) was used to generate 10-node hexahedral elements for the bones (12985 elements), cartilages (536 elements) and portion of the plantar soft tissues (6686 elements).(Fig. 1). The material properties for the bone was assumed to be linear elastic while the cartilage and soft tissue were assumed to be visco-elastic. The Young's modulus, Poisson's ratio, density, bulk modulus (short term and long term) were adopted from literature[1,2]. The kinematic data of the foot of the male subject during heel-strike at normal walking speed (1.2 m/s) was obtained using a Vicon-370 motion analysis system. Also, the plantar pressure of the foot was recorded for ten times using a RS-SCAN foot plate system. The vertical and horizontal velocities of the foot (0.6 m/s; 3.12 m/s) were used as loading condition in the simulation. Initial contact angle of the foot with respect to the ground was assumed to be 23° (Fig. 1). A force varying linearly from 0-420 N was applied on the trochlea of talus to simulate the effect of body weight during heel strike. The analysis was performed using LS-DYNA 970（Livermor, USA） on an HP-SPP2200 supercomputer. The stresses in the bone and plantar soft tissues were computed at each of the 100 increments during the simulation time span of 0.048 s.

RESULTS AND DISCUSSION

Analysis results showed that the plantar pressure increased with respect to the time as the foot starting to be in contact with the ground. The plantar pressures at the heel region obtained from the analysis were compared with the measured results using RS-SCAN plate system. Similar trends were found and the peak value for the analysis results at t=0.48 was

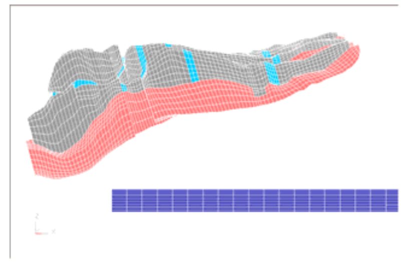

Figure 1: Hexahedral finite element model of the foot bone with plantar soft tissues

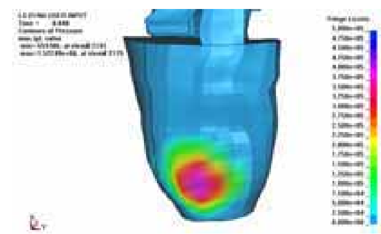

Figure 2: The normal stress of the plantar soft tissue at the heel region at t=0.048s obtained from simulation

found to be 302 KPa. On the other hand, the measured peak plantar pressure was found to be ranging from 248 to 316 KPa (10 measurements). As for the bone stresses, calcaneal stress distribution was transferred gradually from calcaneocuboid joint nearby to posterior calcaneus. Thus, the mean von Mises stress was around 30 ~ 180 KPa. However, anterior and posterior joint surfaces of the subtalar joint sustained compressive stress, and medium joint surface of subtalar joint received tensile stress.

CONCLUSIONS

A 3-D hexahedral finite element model was established and analyzed in this study. The simulation results were validated from plantar pressure measurements. With the application of this model, dynamic finite element analysis for a full gait cycle can be completed in future studies. This model can also provide useful information for footwear and orthosis designs.
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REFERENCES

1. Chen WP et al. *Clin. Biomech.* **16**, 614-620, 2001.
2. Bandak FA et al. *Int J Solids and Structures* **38**, 1681-1697, 2001.

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