A Finite Element Analysis of foot with hammer toe deformity during walking.

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Summary

A three-dimensional finite element model of a diabetic neuropathic foot with hammer toe deformity was constructed. The geometry of the FE model was formed based on segmentation and reconstruction of MRI images. A multi-body musculoskeletal simulation based on 3D gait analysis was carried out for predicting six muscle forces. Validation of the derived muscle forces were performed using EMG. FE simulations were run at five stages of stance phase of gait. The derived muscle forces and measured GRFs during gait were added to the model as boundary conditions. The validation of FE results indicated a good agreement between simulated plantar pressures (PP) against the measured values from pressure plate. The analyses showed that the presence of hammer toe causes stress concentration on metatarsals. However, the stress concentration seems to shift from the 5th metatarsal to the 3rd metatarsal as the gait progresses from early stance to toe-off.

Introduction

Finite Element analysis can overcome the restriction of experimental methods, by providing a mean to measure internal stresses [1,2].

The aim of this study was to investigate the effects of hammer toe on the internal stress distribution on the bone during walking.

Methods

A participant (male; age: 53 years; BMI: 34 kg/m^2) with diabetic neuropathic diabetic foot with non-deformed right foot and hammer toes deformity in the left foot, participated in this study. Following informed consent, MRI scan and 3D gait analysis were carried out. To predict the muscle forces, 'gait 2392' model in OpenSim software was used [3]. A 3D model consisted of a soft tissue and 30 bony structures were reconstructed based on MRI images using mimics software (Materialise, Leuven, Belgium). The obtained model was then imported to ABAQUS software (SIMULIA, Providence, USA) where the plantar fascia and ligaments were modelled as 2174 truss elements, while 74 layers of cartilage was added to the model. The material properties were assigned based on previous study [1]. The 3D foot orientation angles were obtained from the gait analysis of the participant. As boundary conditions, the GRFs were applied at the COP while the muscle forces (including: lateral gastrocnemius, medial gastrocnemius, tibialis posterior, tibialis anterior, soleus, peroneus longus) were applied at the corresponding insertions points at five stages of stance phase of gait (5%, 25%,50%, 75% and 90%)

Results and Discussion

The FE model showed to be able to predict peak plantar pressure with less than 11% errors. FE results showed internal stresses distribution in bony structures (Figure 1). As shown in this figure, maximum Von-misses (internal) stress occurred at 3rd metatarsal during of late stance phase of gait.

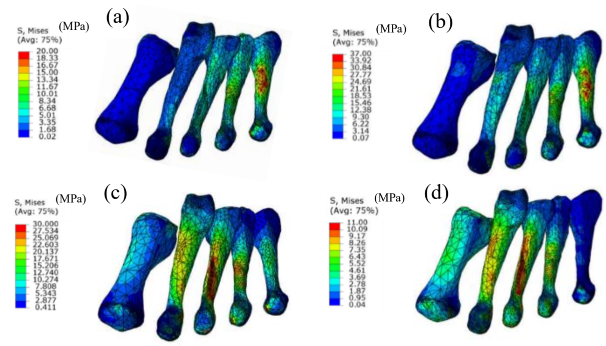

Figure 1: Finite element internal stresses in metatarsals at four walking events. Early stance (a), mid-stance (b), late stance (c) and toe off (d).

Conclusions

In a foot with hammer toe deformity stress concentration appears to be on the 5th metatarsal during the early and mid-stance stages of gait. The stress concentration shifts to 3rd metatarsal during the late stance and toe-off. The findings can have practical implications in clinical management of hammer toe deformity.

References

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