BIOMECHANICAL MODELING OF THE FOOT TO STUDY AND PREVENT THE FORMATION OF ULCERS

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Introduction

Most of the foot ulcers are created by compression of the soft tissues (muscles, fat, skin, tendons, and ligaments) by the bones. Such ulcers are treatable when discovered early but can have dramatic outcomes as time passes. Unfortunately, the natural prevention of ulcerations is disturbed when patients are immobilised or cannot feel their extremities (due to nervous disabilities or diabetes). Our group has proposed the “Smart Sock” [Bucki, 2011] which is a 100% textile device made of a network of pressure sensors monitoring the stresses applied around the foot. The idea is to estimate, from these surface stresses, the internal stresses that might be at risk using a patient-specific Finite Element model of the foot. When internal pressures computed by the model reach a critical level, a warning is sent to the patient.

Methods

The FE foot model has been developed using the 3D biomechanical simulation platform, Artisynth (http://www.magic.ubc.ca/artisynth). The model is composed of soft tissues, bones, tendons, ligaments and joints. The soft tissues represent the muscles and fat and are combined in a FE mesh using an incompressible hyperelastic Mooney Rivlin material [Lemmon, 1997]. Each bone segment is modelled as a solid body surface and is rigidly coupled to the soft tissues. Cylindrical pivots connect each bone with its neighbour, to simulate the joint between them. As a real joint, the angle they allow between each bone is constrained. Fig. 1 (left) illustrates the foot model for one of its toes. The main contribution compared to [Chen, 2010] is the integration of realistic joints between bones. The analysis of the constraints resulting from a prescribed load makes it possible to detect where higher pressures appear inside the foot and on its surface and determine if ulcers could be formed.

Results

To study the influence of a compression under the foot, such as the one occurring during gait, a flat rigid body has been brought in contact with the surface of our foot model. To facilitate the readability of the results, only the second toe of the foot is shown here. It includes the soft tissues surrounding this toe, the inner bones (two phalanges, tarsus and metatarsus) and the joints connecting them. The nodes around the metatarsus are fixed to simulate the non-displacement condition applied to the rest of the foot.

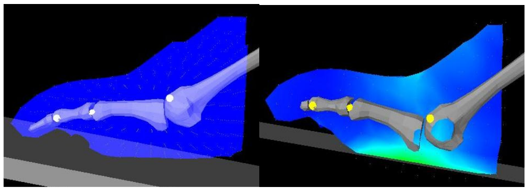

Figure 1: Model of the foot 2nd toe (geometry from www.zygote.com), with surrounding soft tissues (blue), inner bones (gray) and joints (white). Left: no load applied. Right: the flat rigid body below the toe applies a steady load. Internal Von Mises stresses are colour-coded from blue (no stress) to yellow (large stress).

Fig 1 (left) shows the initial state of the toe, before compression. Fig 1 (right) displays the von Mises stresses resulting from the compression. It is clear that the soft tissues are deforming more where the elements are in contact with the rigid body. Moreover the bony structures are also straightening following the strain and the joint constraints.

Discussion

The biomechanical model presented here is improving the state of the art by adding realistic joint constraints. This enhanced anatomical modelling makes it possible to study internal compression and predict ulcer formation with better accuracy. Future works aim at coupling this new model with data provided by the sock sensors and therefore to improve the realism (in location and pressure) of the compression below the foot.

References

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