MUSCLE FORCES - BONE DEFORMATIONS
A NOVEL APPROACH TO DETERMINE MUSCLE FORCES CORRESPONDING TO MEASURED TIBIA DEFORMATIONS

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Introduction

Bone deformation induced by muscle contractions are thought to play an important role for adaption of bones. Past simulation studies to determine bone forces during locomotion focused on an inverse dynamics approach, mostly without consideration of these substantial deformations. However, latest studies have shown that both muscle forces and corresponding deformation of the bone are required for maintenance of bone [Ducos M., 2013].

A recently completed study at the German Aerospace Centre (DLR) produced *in vivo* data of tibia deformation during various activities (e.g. walking, running, hopping) [Yang P.-F., 2013]. Utilizing this data, we have begun the development of a computer program which inversely calculates the muscle forces corresponding to tibia deformation.

Methods

The basic concept is the combination of an operating software (MATLAB) forwarding input to a Finite Element model (ANSYS) and processing the results with an optimization algorithm.

A 3D geometry (CAD) of the tibia and the muscle attachments has been created and the directions of the forces are defined on basis of the muscles' anatomical location.

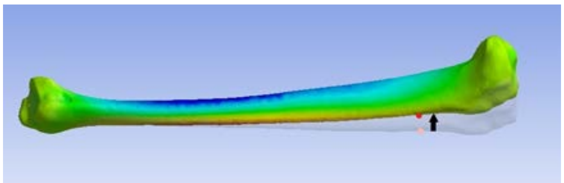

Figure 1: CAD model of tibia (ANSYS) – displacement (↑) of measurement point (red dot)

Following the assumption of small deformations, a linear displacement behaviour of the bone is presumed. Based on the superposition principle, the displacements for n forces can be summed up to form one equation:

$$\sum_{i=1}^{n} (\vec{f}_i * fmp_i) * D_i = \vec{u}_{calc} \quad (1)$$

where f is the directional vector, *fmp* the magnitude, D the deformation matrix and u_{calc} the calculated displacement vector for one single point of the geometry (see figure 1). Hence, the deformation matrix for each muscle force on its own is determined via FEM and the force vectors are normalized.

The now calculable displacements are compared to the measured ones and the difference is minimized by a constrained nonlinear optimization algorithm:

$$\left|\vec{u}_{calc} - \vec{u}_{meas}\right| \rightarrow min! \quad (2)$$

Results

The optimization algorithm, satisfying specified boundary conditions, is searching for a fitting solution for the under-determined muscle force equation. In a regular FEM simulation the displacement induced by 10 forces has been calculated. Our program was then able to reconstruct the displacement with a precision of 10^{-7}mm.

Discussion

The program can reconstruct muscle contraction patterns for given deformations. Future work will make them comparable to realistic patterns measured with EMG. Yet, the results are biased due to the simplified material properties implemented in the CAD model. Also, only the displacement of one point is taken into consideration, whereas the *in vivo* data provides three, enabling a more realistic deformation. Enhancing the program will bring further insight in the biomechanics of human locomotion and the mechanisms triggering bone remodelling.

References

Ducos, M. *et al*, in preparation, 2013.
Yang, P.-F. *et al*, in preparation, 2013.