FLEXIBLE MULTIBODY APPROACH IN MODELING LOCOMOTIVE STRAINS IN HUMAN TIBIA: EFFECTS OF HOMOGENEOUS VS. INHOMOGENEOUS MATERIAL PROPERTIES ON MODEL PERFORMANCE

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INTRODUCTION

Exercise induced bone strains have considerable potential to strengthen the skeleton [1, 2]. Given the invasive nature of direct strain measurement and that only superficial bone sites are applicable to strain measurement [3], there is a need for a tool to be used in estimation of exercise-induced strains at any bone site. For this purpose flexible multibody approach has been incorporated to the strain modeling [4, 5]. The purpose of the current study was to further develop strain modeling by inserting realistic rates of muscular force development (RFD) and incorporating inhomogeneous material properties of cortical bone to the musculoskeletal model.

METHODS

A healthy Caucasian man (52 years, 168 cm, 65 kg) volunteered as subject for the study. He walked barefoot at his preferred velocity (1.6 m/s) on a 10 m long force platform (Raute Inc., Finland), which measured the vertical ground reaction forces (GRF). The gait was recorded with four video cameras at a 50 Hz sampling frequency with 29 visual markers applied on the subject. The three-dimensional motion capture data was applied on a full body musculoskeletal model. The model tried to replicate the motion in forward dynamics simulation. The musculoskeletal model was built on BRG.LifeMODE platform.

Two full body musculoskeletal models were built for simulations. Both models consisted of 18 rigid bodies (head, neck, upper torso, central torso, lower torso, scapulas, upper arms, lower arms, hands, upper legs, lower leg and feet) except for right tibia which was modeled flexible. In the 1st (MRI) model the finite element reconstruction of the right flexible tibia was based on magnetic resonance imaging data. Constant material properties were assigned to each element (longitudinal elastic modulus 20 GPa, transverse 10 GPa). In the 2nd model (CT) the finite element reconstruction of the right flexible tibia was based on computed tomography data (CT). The elastic modules were calculated from the CT values as $1.5 \cdot CT^{1.9}$ for logitudinal and $0.3 \cdot CT^{1.5}$ for transverse direction. The same shear module (longitudinal 5 GPa, transverse 3.5 GPa) and Poisson ratio (0.4) were used for both models.

Hill muscle model was used for both of the models (realistic RFD). In addition, the CT model was run with simple muscle model (no restrictions to RFD) The multibody simulation approach with the floating frame of reference formulation [6] was used to estimate tibial deformations. The different muscle models were compared in terms of the mean squared error (MSE) of the simulated GRF in comparison to the measured GRF.

RESULTS AND DISCUSSION

The MSE of the CT model utilizing Hill muscle model was 12.8 % smaller than the respective error of the simple muscle model (figure 1A). The strain estimates appear to be quite similar between CT and MRI models. The modeled strains at single support and push-off phases of the gait cycle were in line with the Lanyon et al. (1975) [7] i*n vivo* measurements (figure 1B), whereas the strains at the swing phase appear to be overestimated. In conclusion, Hill muscle model appeared more realistic in reproducing GRF. Strain modeling accuracy at long bone shaft is not markedly improved by utilizing CT data over MRI data in tibia FE reconstruction. Because of the radiation dosage associated with CT imaging MRI imaging is seen as more preferable for purposes of modeling long bone shaft strain behavior.

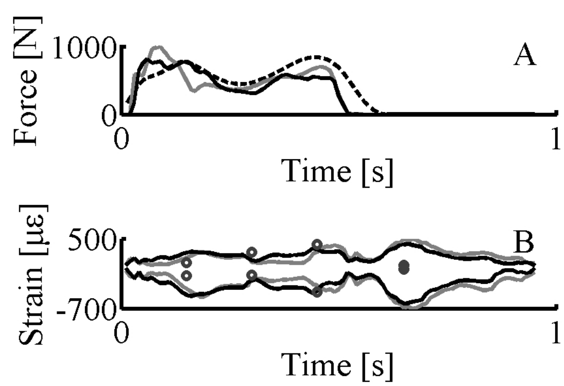

Figure 1: A: measured (dashed line) and model predicted (simple model grey, Hill model black) vertical GRF. **B**: model predicted maximal and minimal strains at the tibial midshaft. MRI model grey, CT model black. Circles are values reported from walking barefoot at 1.4 m/s by Lanyon et al. 1975.

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