RECTUS FEMORIS FIBER EXCURSIONS PREDICTED BY A 3D MODEL OF MUSCLE

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INTRODUCTION

Computer models of the musculoskeletal system frequently represent the force-length behavior of muscle with a lumped-parameter model (Zajac, 1989). Lumped-parameter models assume that muscle fibers have a simple two-dimensional arrangement and that all fibers undergo the same change in length (or "excursion"). These simplifications may misrepresent muscle fiber excursions and the resulting force-length behavior, especially for muscles with complex architecture. Herzog and ter Keurs (1988) have demonstrated that lumped-parameter models do not accurately predict the *in vivo* force-length behavior of the rectus femoris, a bipennate muscle of the lower limb. In this study, we created a three-dimensional (3D) model of the rectus femoris to determine how a more accurate representation of the fiber arrangement affects the predictions of muscle fiber excursions.

METHODS

3D models of the rectus femoris and the vasti muscles (Fig. 1B) were generated from magnetic resonance (MR) images (Fig. 1A). A representation of the muscle fiber geometry (Fig. 1C) was created by morphing a template fiber geometry to the 3D model. We studied the muscle's action at the knee by prescribing the motion of the tibia relative to the femur according to published kinematic data (Walker et al., 1988). The motions of the patella, the patellar tendon, and the muscles were calculated via simulations performed with NIKE3D, an implicit finite-element solver (Puso et al., 2002). In the simulation, a transversely-isotropic, incompressible, hyperelastic constitutive model was used to describe the stress-strain relationship in the muscle and tendon tissue (Blemker et al., 2004), the bones were assumed to be rigid, and a penalty formulation was used to resolve muscle-bone, muscle-muscle, and bone-bone contact. The simulation results were analyzed in a graphics-based musculoskeletal modeling environment, and the lengths of individual fibers in the rectus femoris were calculated.

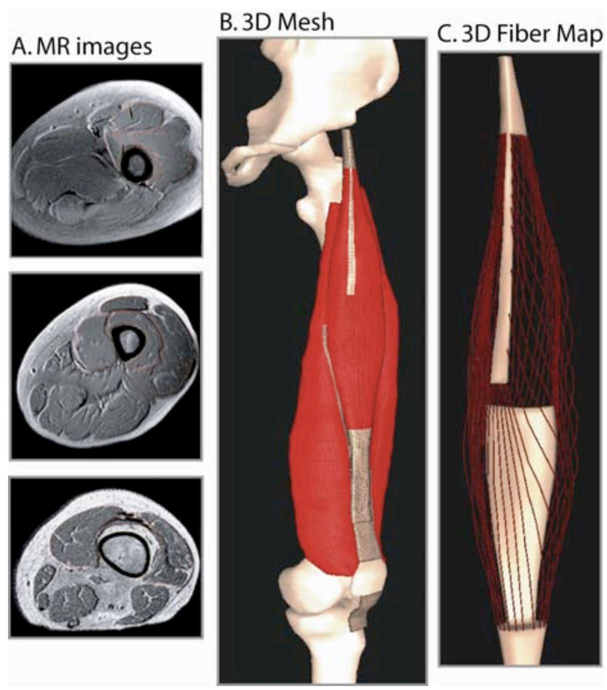

Figure 1: Muscles and bones were outlined in several MR images (A), 3D finite-element models (B) of the quadriceps were generated from the outlines, and 3D representations for the fibers of the rectus femoris (C) and other muscles were created.

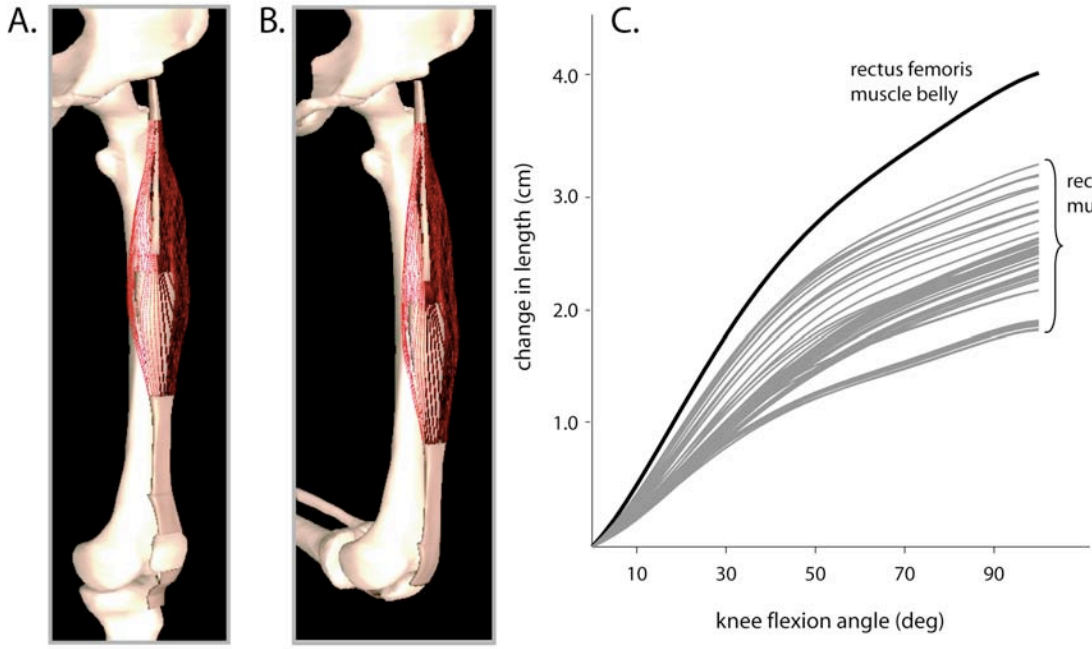

Figure 2: Rectus femoris fiber geometry with the knee extended (A) and flexed (B), and changes in length (C) vs. knee flexion angle predicted by the 3D model.

RESULTS AND DISCUSSION

The 3D model predicted rectus femoris changes in length and moment arms that are consistent with experimental measurements (Buford et al., 1997). The excursions of the rectus femoris muscle fibers varied significantly. Some fibers changed length by 50% less than the muscle belly. By contrast, a lumped-parameter model of this muscle would predict that all fibers excursions are equal and similar in magnitude to the excursions of the muscle belly.

These results indicate that the rectus femoris fiber excursions may be overestimated in lumped-parameter models of muscle. This difference may explain the errors in force-length estimates from lumped-parameter models. More realistic representations of muscle are needed to deepen our understanding of *in vivo* muscle function.

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