ACTIVATION AND APONEURSIS WIDTH AFFECT MEASURED STRAIN IN THE BICEPS FEMORIS MUSCLE

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INTRODUCTION

Acute strain injury remains a prevalent problem in collegiate, professional, and recreational athletics. Hamstrings muscles are commonly the site of acute strain injury in the lower limb. Of the three hamstrings muscles, the biceps femoris long head (BFLH) muscle is injured most often, with injury frequently localized along the proximal aponeurosis [1].

Imaging studies [2] and computational models [3] have shown that strains are elevated in the muscle tissue neighboring the BFLH's proximal aponeurosis, which may explain why injury occurs in this region. Furthermore, the models have demonstrated that the decreasing width of the muscle's proximal aponeurosis [3] and increasing muscle activation level [4] both have the potential to increase the magnitude of the strains that are localized near the proximal aponeurosis. The goals of this study were to use functional MRI to measure mechanical strain *in vivo* in the BFLH muscle and to compare strain in the region surrounding the proximal aponeurosis i) during eccentric contraction and passive motion and ii) for subjects with narrow and wide proximal aponeuroses.

METHODS

Fourteen healthy subjects (nine male, five female) provided informed consent and were imaged in accordance with the University of Virginia's Institutional Review Board guidelines. Subjects were placed in the head-first prone position inside a 3T Siemens Trio MR scanner (Fig. 1A). Right knee flexion-extension was repeated at a rate of one cycle every two seconds and was performed using a MR-compatible exercise device designed to ensure repeatable motion inside the scanner bore as well as to load the hamstrings eccentrically [5]. In a separate acquisition, each subject's leg was moved for them to study the kinematics of passive motion.

High-resolution images were used to define the functional imaging plane through the BFLH's proximal and distal aponeuroses and through the muscle belly (Fig. 1B,C). Displacement ENcoding with Stimulated Echoes (DENSE) images were acquired during 2.5 minutes of repeated knee flexion-extension [6] with the following imaging parameters: 3.125 x 3.125 mm^2 in-plane resolution, 5 mm slice thickness, 51 ms temporal resolution, and 0.08 cycles/mm displacement-encoding frequency.

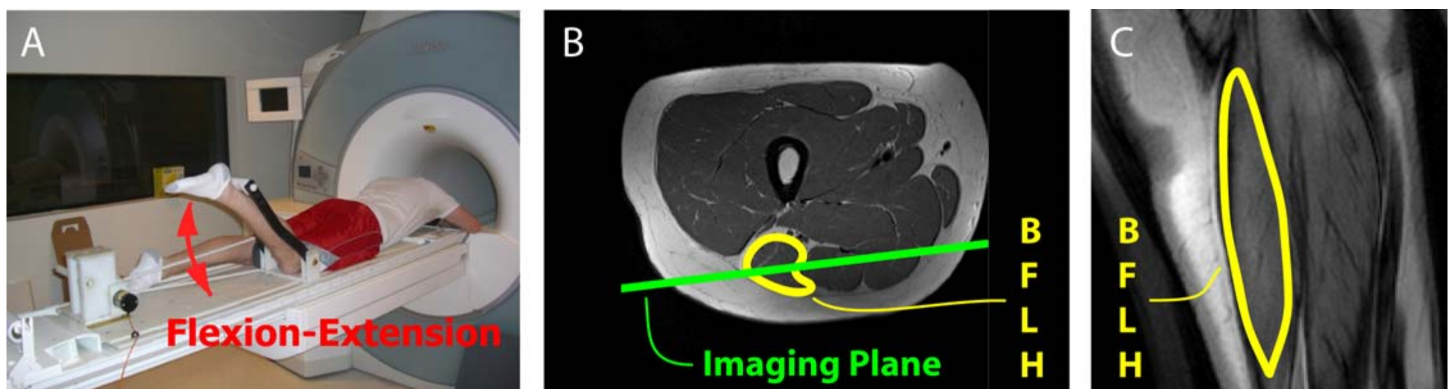

Figure 1. Experimental setup and imaging plane definition. Subjects repeated knee flexion-extension during DENSE image acquisition (A). The functional imaging plane was defined on high-resolution axial images such that it passed through the proximal and distal aponeuroses of the biceps femoris long head muscle (B, C).

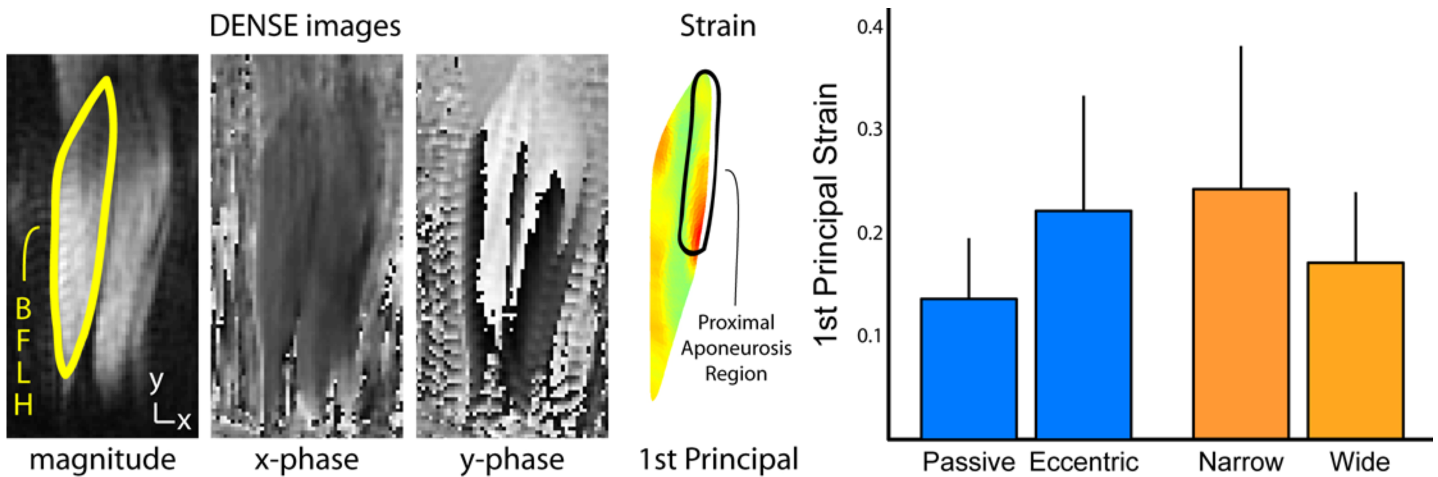

Figure 2. Example images and strain results. Example DENSE magnitude image with the BFLH outlined and phase images (including phase wrap). Lagrangian strain tensors were found at a pixel-wise resolution, decomposed into principal strains, and averaged over the medial third of the muscle adjacent to the proximal aponeurosis. Average 1st principal strains are reported i) during eccentric contraction and passive motion and ii) for subjects with a wide (> 5 mm, N=8) and narrow (< 5 mm, N=6) proximal aponeurosis.

DENSE images were imported into Matlab (MathWorks, Inc., Natick, MA, USA) and analyzed with custom-built software [7]. DENSE phase images (Fig. 2), where image intensity is proportional to displacement, were used to track tissue positions over time. Image data sets with a mean through-plane displacement greater than 20% of in-plane displacement were discarded. Lagrangian strain tensors were calculated at a pixel-wise resolution, and 1st principal strains (most positive eigenvalue) were averaged along the medial third of the muscle adjacent to the proximal aponeurosis (Fig. 2). To compare subjects with different proximal aponeurosis morphologies, subjects were grouped into two categories according to proximal aponeurosis width: wide > 5 mm (N=8) and narrow $\leq$ 5 mm (N=6). Aponeurosis width measurements are described and reported in [8].

RESULTS AND DISCUSSION

Average first principal strain in the region near the proximal aponeurosis was 0.14 ± 0.06 during passive motion and found to be higher (0.22 ± 0.11) during eccentric contraction (Fig. 2). For the group of subjects with a narrow aponeurosis width, average 1st principal strain was 0.24 ± 0.14 and found to be lower for the wider aponeurosis width group (0.17 ± 0.07).

Elevated strains along the proximal aponeurosis during eccentric contraction support the hypothesis that higher strains are present in the region where injury is normally observed. Moreover, the smaller strain magnitudes seen during passive motion illustrate that the kinematics associated with knee flexion-extension cannot be solely responsible for higher strains along the proximal aponeurosis. Thus, muscle activation likely contributes to regions of higher localized strains.

Results comparing subjects with different aponeurosis widths (Fig. 2) confirm previous computational model findings [3] that muscles with narrower widths experience higher localized strains adjacent to the proximal aponeurosis. Therefore, aponeurosis dimensions could potentially serve as a preliminary marker for acute strain injury susceptibility.

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