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Heterogeneous fascicle behavior within the biceps femoris long head at different muscle activation levels

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ABSTRACT

Magnetic resonance and ultrasound imaging have shown hamstring strain injuries occur most often in the biceps femoris long head (BFLH), and particularly in the proximal vs. distal region of this muscle. Animal research and musculoskeletal modeling (MSK) have detected heterogeneous fascicle behavior within muscle regions, and within fascicles. Understanding architectural behavior differences during muscle contractions may help to discern possible mechanisms behind proximal BFLH injuries. The purpose of our study was to assess the magnitude of shortening of the proximal and distal fascicles of the BFLH under a range of muscle activation levels under isometric conditions using ultrasound imaging (US). Thirteen healthy adults performed targeted sustained isometric contractions while US were taken of the entire BFLH. Measurements of fascicle lengths in both muscle regions were compared at 20%, 30%, 50%, and 67% MVIC. The results showed that while both regions shortened significantly with activation, the proximal fascicles were significantly longer, regardless of activation level (~38%), and shortened significantly more than the distal fascicles overall (~40%), and cumulatively at higher activation levels (30% and above). No significant strain differences were found between the two regions. These data suggest heterogeneous fascicle behavior exists in an absolute sense; however, differences in behavior are eliminated when normalized (strain). Coupled with MSK literature, the absence of regional fascicle strain differences in this study may indicate strain heterogeneity is not detectable at the whole fascicle level. Further knowledge of this commonly strained muscle's regional behavior during dynamic movements could provide evidence of proximal hamstring strain predisposition.

1. Introduction

Hamstring strains commonly occur in sports involving sprinting (Hoskins and Pollard, 2005), and have been found to occur most often in the long head of the biceps femoris (BFLH) (De Smet and Best, 2000; Connell et al., 2004; Malliaropoulos et al., 2010). By pooling together multiple MR imaging studies of the BFLH post injury, it is suggested that the location of injury may be regionally biased with 55% of BFLH injuries occurring in the proximal region compared to 36% in the distal region (Askling et al., 2006; Silder et al., 2008). Hamstring strains, regardless of region, are thought to occur during the late swing phase when the hamstrings undergo active lengthening and are stretched to their greatest extent compared to standing upright lengths (Thelen et al., 2005). Though all of the hamstrings produce their greatest length changes during this time, in this simulation research (Thelen et al., 2005) the BFLH was shown to undergo the most stretch, 9.5%, which was significantly greater than the semimembranosus and semitendinosus, 7.4% and 8.1% respectively, while actively slowing down the movement of the swinging limb. Motion capture of two hamstring strain injuries determined that the injury occurrence was likely during the late swing phase (Heiderscheit et al., 2005; Schache et al., 2010). Collectively, this motion capture and simulation research suggest that the BFLH is most likely injured when it is eccentrically contracting during a lengthened state – the late swing phase of sprinting. Muscle strains during eccentric contractions are generally considered to be the primary determinant of muscle damage (Lieber and Friden, 1993). However, we still do not know why hamstring strains occur more in the proximal region of this muscle. An understanding of the magnitude and timing of region dependent strains the BFLH undergoes during dynamic activities could ultimately allow us to better pinpoint the hazardous conditions that occur within the muscle that cause BFLH hamstring injuries.

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Regional differences in muscle strains have been shown in biarticular muscles across a variety of methodologies (Ahn et al., 2003; Blemker et al., 2005; Silder et al., 2010). The American toad experienced heterogeneous strain within the semimembranosus across varying hopping distances (Ahn et al., 2003). The proximal and central segments of the semimembranosus collectively exhibited higher strain values, ($-11.4 \pm 4.6\%$ to $-15.6 \pm 5.3\%$) that were about 3 times higher than distal segments, strains ($-6.5 \pm 3.2\%$), throughout all hopping distances. Muscle modeling of the biceps brachii found non-uniform, i.e. heterogeneous, strain patterns throughout the muscle during concentric contractions (Blemker et al., 2005). The variation in strain throughout the muscle is believed to be due to the differing fascicle lengths and curvatures located in the biarticular biceps brachii (Blemker et al., 2005). Given that the proximal region of the BFLH has longer fascicles than the distal region (Kellis et al., 2010) it is then plausible that heterogeneous strain behavior would exist within the human BFLH as well. Indeed, regional strain variation has been seen within the most proximal aspect of the BFLH through MRI (Silder et al., 2010). Imaging of the proximal region of the BFLH found larger amounts of tissue strain in the regions closest to the proximal musculotendinous junction, $\sim$15%, compared to more distal regions of the proximal aspect of the muscle, $\sim$11%. Although variation of strain has been observed in animals and predicted through modeling techniques assuming variant fascicle lengths, we do not have evidence of heterogeneous regional (proximal vs. distal) fascicle behavior in the long head of the biceps femoris, the most common hamstring muscle injured during sport-related activities.

We formulated a global hypothesis that heterogeneity of regional fascicle length and behavior exists within the BFLH. The purpose of our study was to assess the lengths and magnitudes of shortening of the proximal and distal fascicles of the BFLH through a range of muscle activation levels under isometric conditions using real-time ultrasound imaging. Based on our global hypothesis, we expected that (1) proximal fascicles would be longer than the distal fascicles, (2) proximal fascicles would shorten more than their distal counterparts, and (3) the relative strain of the proximal BFLH fascicles would be greater than the distal fascicles. Given the regional fascicle and tissue strains from the previous literature, it was thought that greater strain in the proximal fascicles could be a mechanism behind the more prevalent proximal BFLH strains. Examining the behavior between the proximal and distal fascicles within the BFLH in isometric contractions can lend insight of possible differences occurring during the late swing phase of sprinting.

2. Methods

2.1. Subjects

Thirteen recreationally active college students (males=6, females=7, age: 21.6 ± 2 yrs., height: 169.0 ± 10.0 m, and mass: 68.4 ± 13.9 kg.) with no history of hamstring strain injury participated in this investigation. Recreationally active was defined as participating in resistance training at least 3 times per week. All subjects read and signed an informed consent form approved by the University IRB.

2.2. Protocol

Following completion of the informed consent documents, subjects' height and weight were recorded. Subjects were then prepped for electrode placement by muscle palpation of their semitendinosus/semimembranosus (ST/SM), biceps femoris, lateral gastrocnemius, and vastus lateralis, hair shaving, site scrubbing with abrasive cream, and cleaning of site with alcohol wipes. Two electrodes were placed on the muscle belly of each muscle on the right leg, and connected to a Myopac unit (RUN Technologies, Mission Viejo, CA). EMG data was acquired using Datapac Software (RUN Technologies, Mission Viejo, CA) on a laptop. After EMG preparation, subjects lay prone on a custom made platform firmly affixed to a dynamometer chair. The right hip and knee were flexed to 45° with the right shank secured to the dynamometer (Humac NORM Dynamometer, CSMI, Stoughton, MA) and the left leg (hip and knee at 0°) was supported keeping the pelvis balanced. Subjects were then provided an opportunity for familiarity of the target torque conditions portion of the protocol by isometrically contracting their hamstrings while viewing a monitor providing visual feedback.

After ample time was given for familiarity, subjects performed two maximum voluntary isometric knee flexion contractions (MVIC) and the torques and EMG were synchronized with a trigger and recorded using Datapac (RUN Technologies, Mission Viejo, CA). The highest MVIC torque was used as the basis for target torques to be attained throughout the study. Next, neuromuscular activity was measured while subjects performed ramp contractions of 80% MVIC. The ramp contractions were used to determine the activation relationship between the medial and lateral hamstrings, as the BFLH electrode had to be removed so that ultrasound images could be taken of the entire BFLH during the target conditions. Two panoramic ultrasound images were then collected of the entire BFLH on a Logic e Ultrasound unit (General Electric, Wauwatosa, WI USA) using a 13–5 MHz linear array transducer set at a median frequency of 8 MHz, while the muscle was in a passive state. The remainder of the protocol required subjects to attain and hold two isometric contractions for each of the target torque levels of 10%, 25%, 50%, and 75% MVIC for 8 s each, while panoramic ultrasound images of the BFLH were collected. Subjects were allotted 1 min of rest between contractions, and care was taken to ensure that the knee joint center was aligned with the dynamometer head throughout the protocol. The order of target torque conditions was randomized across all subjects.

2.3. Data reduction

All ultrasound images were reduced on the GE Logic e Ultrasound system. For each ultrasound image, the following protocol ensued. First, the full length of the muscle was measured twice on each image using digital calipers, starting at the most proximal point of the muscle before the musculotendinous junction, and ending at the most distal point of the muscle. Though the BFLH muscle has been divided into multiple regions using a variety of techniques (Kellis et al., 2010; Woodley and Mercer, 2005; Rehorn and Blemker, 2010), the current study divided the muscle into 2 regions for the purpose of discerning differences between proximal and distal regions (Fig. 1). Two fascicles were measured in each region of the BFLH, starting at the fascicle's superficial origin and ending at the fascicle's insertion onto the deep aponeurotic tendon (Fig. 2). The concavity of fascicles was tracked as a series of connected lines. Fascicles with more than 75% of length in the proximal half were considered proximal fascicles, and those above 75% of length in the distal half were considered distal fascicles. As the transducer was removed between contractions, measured fascicles are likely not the same fascicles, but are within a specified region of fascicles. It is also important to note the most extreme proximal and distal fascicles were not analyzed in the current study; rather, our definition of "proximal" and "distal" regions was based on the viewable fascicles on the panoramic ultrasound images. The lengths of measured fascicles within each region were averaged to obtain a representation of the respective regional fascicle

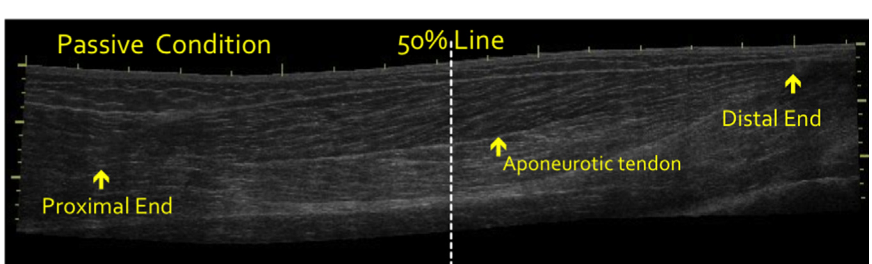

Fig. 1. Schematic of BFLH region measurements. Sample ultrasound image of one subject's entire BFLH. The length of the BFLH was measured, and then divided into equal halves: proximal and distal (yellow line). The left of the image is the proximal region, and the right is the distal region.