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Biceps femoris and semitendinosus tendon/aponeurosis strain during passive and active (isometric) conditions

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ABSTRACT

The purpose of this study was to quantify strain and elongation of the long head of the biceps femoris (BFlh) and the semitendinosus (ST) tendon/aponeurosis. Forty participants performed passive knee extension trials from 90° of knee flexion to full extension (0°) followed by ramp isometric contractions of the knee flexors at 0°, 45° and 90° of knee flexion. Two ultrasound probes were used to visualize the displacement of BFlh and ST tendon/aponeurosis. Three-way analysis of variance designs indicated that: (a) Tendon/aponeurosis (passive) elongation and strain were higher for the BFlh than the ST as the knee was passively extended ($p < 0.05$), (b) contraction at each angular position was accompanied by a smaller BFlh tendon/aponeurosis (active) strain and elongation than the ST at higher levels of effort ($p < 0.05$) and (c) combined (passive and active) strain was significantly higher for the BFlh than ST during ramp contraction at 0° but the opposite was observed for the 45° and 90° flexion angle tests ($p < 0.05$). Passive elongation of tendon/aponeurosis has an important effect on the tendon/aponeurosis behavior of the hamstrings and may contribute to a different loading of muscle fibers and tendinous tissue between BFlh and ST.

1. Introduction

Hamstring muscle strains are common in various sports that require sprinting or excessive stretching (De Smet and Best, 2000; Connell et al., 2004; Hoskins and Pollard, 2005; Malliaropoulos et al., 2010). Hamstring injuries in sprinting most commonly involve the proximal musculotendinous junction of the long head of the biceps femoris (BFlh) (De Smet and Best, 2000; Connell et al., 2004; Malliaropoulos et al., 2010). Nevertheless, the factors that lead to a higher injury rate of the proximal region of the BFlh compared to the rest hamstrings are yet unclear (Battermann et al., 2011; Bennett et al., 2014).

Hamstring injury most likely occurs during the late swing phase of the sprinting cycle (Thelen et al., 2005; Schache et al., 2010). This is accompanied by approximately 2–3% greater BFlh stretch than the semitendinosus (ST) (Thelen et al., 2005). A recent study showed that the BFlh is required to exert proportionally more force in a lengthening muscle contraction relative to the remainder hamstrings primarily as a consequence of having to lengthen over a greater distance within the same time frame (Dolman et al., 2014). It appears, therefore, that higher BFlh injury susceptibility may be due to a different BFlh architecture than the other hamstring components (Thelen et al., 2005; Dolman et al., 2014; Fiorentino and Blemker, 2014).

A few research studies examined the differences in passive mechanical properties between individual hamstring components (Magnusson et al., 2000a,b; Kumazaki et al., 2012; Umegaki et al., 2015a,b). Magnusson et al. (2000a,b) reported a higher strain of the whole muscle–tendon unit (MTU) of the ST compared with the BFlh during a passive stretching maneuver. Kumazaki et al. (2012) found a higher lengthening of the ST compared with BFlh as the knee was passively extended. However, when change in total muscle length was expressed as a percentage of fascicle length, the decrease of total muscle length per fiber length was larger in BFlh than in ST. In a recent study, BFlh shear elastic modulus was higher (approximately 65%) than that observed for the ST (Umegaki et al., 2015a,b) indicating a higher passive elongation of the BFlh fibers compared with the ST fibers. Furthermore, studies have shown that the distal tendon of the ST is 3 times longer that the distal BFlh tendon (Woodley and Mercer, 2005; Kellis et al., 2009, 2010) which might have an effect on their mechanical behavior. These results suggest that passive elongation of the hamstrings is accompanied by a different tendon/aponeurosis mechanical behavior of the individual hamstring components. Nevertheless, such differences have not been previously described.

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A few research studies examined the in vivo mechanical behavior of the hamstring muscles during active contraction (Kellis et al., 2013; Bennett et al., 2014). Particularly, it has been shown that fascicle strain does not vary along the BFlh (Bennett et al., 2014). In contrast, there was a heterogenous tendinous strain along the ST (Kellis et al., 2013). These data, however, are difficult to compare due to differences in mechanical properties between tendon and fascicles (Finni, 2006). Furthermore, no direct comparison between ST and BFlh mechanical properties during active contraction of the whole hamstrings was performed.

The mechanical properties of the MTUs are frequently quantified when the muscle contracts from a fixed joint position (Finni, 2006). However, changes in joint angular position have a significant effect on the mechanical properties and the force-generation capacity of the MTU (Finni, 2006). Such effects depend not only on the change in length of the fascicles and the tendon during contraction but also on the initial (passive) state of the muscle–tendon unit (Herbert et al., 2011). With regards to active conditions, previous studies have shown that with the hip at full extension, contraction of the hamstring musculature is accompanied by higher BFlh muscle activation compared with the ST as the knee extends (Mohamed et al., 2002; Onishi et al., 2002). It was suggested that the BFlh has a higher force generation capacity at longer muscle lengths and the ST at shorter muscle lengths (Mohamed et al., 2002; Onishi et al., 2002). This was attributed to differences in mechanical behavior of passive (elastic) elements and the moment-arms of the muscles (Mohamed et al., 2002; Onishi et al., 2002). However, to our knowledge, these suggestions have not been verified experimentally.

The purpose of this study was to assess the lengths and magnitudes of elongation of BFlh and ST tendon–aponeurosis under passive and active (isometric) conditions using real-time ultrasound (US). We hypothesized that heterogeneity of tendon/aponeurosis strain exists between the ST and BFlh. Particularly three hypotheses were tested (1) that tendon/aponeurosis elongation and strain would be higher for the ST than the BFlh as the knee moved passively from 90° of knee flexion to knee extension (2) at each angular position, hamstring contraction would be accompanied by a higher (active) tendon/aponeurosis strain and elongation by the ST compared with the BFlh and (3) when active and passive strain are added, tendon/aponeurosis strain differences between ST and BFlh would depend on joint angular position tested.

2. Methods

2.1. Subjects

A total of 40 subjects (32 males and 8 females; age 21.3 ± 1.44 years; mass 80.3 ± 3.83 kg; height 1.77 ± 0.03 m) volunteered to participate in this study after signing written informed consent. The participants were healthy and they had no injury of the lower limbs including history of hamstring strain or any other muscle or ligamentous injury of the knee. The study was approved by the University's Institutional Review Board.

2.2. Experimental procedure

The subjects were stabilized on the chair of a Cybex (Humac Norm, CSMI, MA, USA) dynamometer in the prone position. The axis of rotation of the dynamometer was carefully aligned with the lateral femoral condyle. A twin – axis goniometer (Model TSD 130B, Biopac Systems, Inc., Goleta, CA, USA) was used to record knee angular position (0° = full knee extension). Dynamometer moment and knee joint angular position were simultaneously recorded at 1000 Hz.

The testing protocol consisted of two parts. First, five passive extension – flexion trials at a very slow angular velocity ($2^{\circ}\,s^{-1}$) were performed. The range of motion was set from approximately 110° of knee flexion to about 3° hyper-extension. The subjects were instructed to relax as much as possible during the test. Second, the participants performed 5 sub-maximal (warm up) and 3 maximum isometric flexion contractions (MVCs) at 0°, 45° and 90° knee flexion angles in a randomized order. After 10 min of rest, three 10-s ramp isometric contractions guided by an audiovisual signal were performed. Particularly, the participant was instructed to gradually increase the level of effort every 1 s until MVC. To achieve this, the moment curve was displayed on a screen notifying the participant to increase the level of effort, every 10% of MVC.

2.3. Elongation and strain measurement

Tissue movement was recorded using two synchronized ultrasonic (US) devices (SSD-3500, ALOKA, Japan and GE LOGIQ 400 CL PRO, GE Medical Systems, U.K) with a linear array probe of 10 MHz wave frequency and a length of 6 cm (Fig. 1). Muscle–tendon length was measured as the curved path from the distal origin of each muscle to the ischial tuberosity (proximal origin) using a flexible tape. The distal origin of the BFlh was set at the fibular head. For the ST, the distal tendon wraps around the knee and inserts to the fascia cruris (Fig. 1). Therefore, the path of the distal tendon of the ST was identified using transverse and longitudinal scans from the medial condyle to the fascia cruris and the curved path from the medial epicondyle to the fascia cruris was measured using flexi tape. Next, ST length was estimated by adding the distance from the proximal aponeurosis to the medial condyle and from the medial epicondyle to the fascia cruris (Kellis et al., 2009).

Our aim was to examine elongation of the tendon/aponeurosis from the most proximal portion of each muscle–tendon unit. Therefore, starting from the distal origin, the probe was positioned approximately at 60% of whole muscle length. This location allowed visualization of the tendinous inscription of the ST and the most proximal fascicles and intermediate tendon of the BFlh. For both probes, the angle of the probe relative to the mid-thigh line was monitored and care was taken to be standardized across testing conditions using a customized cast (Fig. 1) (Klimstra et al., 2007).

Using video-based software (Max Traq Lite version 2.09, Innovision Systems, Inc., Columbiaville, Michigan, U.S.A) two points were manually digitized (Fig. 2), separately for each muscle US video sequence: First, a reference skin hyperechoic marker to account for any displacement due to probe movement and, second, the intersection point between the superficial aponeurosis and the tendinous inscription (for the ST) and between the intramuscular tendon/aponeurosis and the most proximal fascicle (for the BFlh).

Resting length was measured at 40° of knee flexion (where the passive moment is almost zero (Silder et al., 2007)). The curved path from the distal origin to each of the markers along the skin surface corresponding to BFlh and ST digitized points (Kellis et al., 2009) was quantified using a flexible tape. The distance of each marker from their origin was 272.14 ± 31.3 mm and 209.55 ± 22.8 mm, for the ST and BFlh, respectively. These values corresponded to 62.4 ± 4.1% and 58.3 ± 5.2%, of the ST and BFlh whole MTU length, respectively. Validity and reliability of the US measurements have been reported elsewhere (Kellis et al., 2009, 2012a,b). Since rest length values were taken at 40° degrees, displacement of each tendon/aponeurosis point from 40° to 0° (when MTU lengthened) was considered as positive whilst displacement from 40° to 90° (when MTU shortened) was considered as negative. During ramp contraction, the muscle shortens and therefore tendon/aponeurosis displacement was considered as negative.