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Muscle architecture variations along the human semitendinosus and biceps femoris (long head) length

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ABSTRACT

The purpose of this study was to examine whether muscle architecture of the long head of biceps femoris (BF) and semitendinosus (ST) muscles varies along their length. The ST and BF muscles were dissected and removed from their origins in eight cadaveric specimens (age range 67.8–73.4 years). One-way analysis of variance designs were used to compare fascicle length (FL), pennation angle (PA) and muscle thickness (MT) between proximal, mid-belly and distal positions. Tendon and muscle length properties were also quantified. For the BF muscle, one-way analysis of variance tests showed a higher PA (23.96 ± 3.82°) and FL (7.12 ± 0.48 cm) proximally than distal positions (PA = 17.78 ± 1.95° and FL = 6.35 ± 0.89 cm, respectively). For the ST, there was a significantly ($p < 0.05$) lower PA (8.81 ± 1.22°) and FL (13.10 ± 1.54 cm) proximally than distally (PA = 14.69 ± 1.09° and FL = 15.49 ± 2.30 cm, respectively). Muscle thickness significantly increased from distal to more proximal positions ($p < 0.05$). These data suggest that the ST and BF architecture is not uniform and that measurement of these parameters largely depends on the measurement site. Modeling these muscles by assuming a uniform architecture along muscle length may yield less accurate representation of human hamstring muscle function.

1. Introduction

The hamstring muscle group consists of four muscles i.e. the semimembranosus, the semitendinosus (ST) and the long and the short heads of the biceps femoris (BF). Fiber arrangement within the muscle as well as changes in muscle and tendon length during human movement largely affect hamstring muscle force generation capacity. Therefore, studying hamstring muscle function *in vivo* often requires modeling of their architectural properties (Thelen et al., 2005; Chumanov et al., 2007) such as tendon and muscle length, fascicle length (FL), pennation angle (PA) and muscle thickness (MT). Such models are applied for the estimation of muscle and tendon length in subjects with cerebral palsy (Arnold et al., 2006), for the examination of hamstring injury potential in athletes (Thelen et al., 2005; Chumanov et al., 2007), for the improvement of ST tendon grafts for surgical reconstruction of anterior cruciate ligament (Pichler et al., 2008) or for the prediction of hamstring muscle forces based on electromyographic signal recordings (Kellis and Katis, 2008).

A factor which may have an effect on architectural parameters is the variability in fiber arrangement along muscle length. It is possible that measurement of PA, FL and MT in more distal positions may differ compared with more proximal positions (Friden et al., 2004). If this is the case, different studies may show different results, depending on the site where architectural variables were measured. To overcome this problem, most studies have reported an average value of FL, PA and MT for each hamstring component (Friederich and Brand, 1990; Chleboun et al., 2001; Woodley and Mercer, 2005; Ward et al., 2009). Although this provides an overall estimate of muscle architecture, potential variability in muscle fiber arrangement along muscle length is not examined. For the hamstring muscles, in particular, such information is necessary as very few studies examined their architecture either *in vivo* (Chleboun et al., 2001; Kellis et al., 2009) or *in vitro* (Wickiewicz et al., 1983; Friederich and Brand, 1990; Woodley and Mercer, 2005; Makihara et al., 2006; Klein Horsman and Koopman, 2007).

Variability in architectural variables along muscle length is of particular importance when using architecture measures from a single site to model and predict the behavior of a specific muscle. For example, *in vivo* examination of muscle architecture is based on sagital ultrasound scans from one particular location of the muscle (Blazevich et al., 2006; Finni, 2006). This information is then scaled to the whole muscle and the behavior is then studied

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at resting and contraction conditions (Finni, 2006). If there are proximo-distal differences along muscle length then studying the behavior of the whole muscle would be site-dependent. In fact, Blazevich et al. (2006) demonstrated that large intra-muscular differences may have a considerable effect on the estimated force–velocity properties of the quadriceps muscles. However, information about architecture variability of the hamstring muscle is scarce. Woodley and Mercer (2005) found that the BF muscle consists of two regions, a surface one and a deeper one, arranged in parallel. For the ST muscle, there were two regions, arranged in series. Although no differences in FL between separate regions were identified, it is not clear whether quantification of architecture using invasive or non-invasive techniques from one site along muscle length would adequately represent the whole muscle–tendon architecture. Chleboun et al. (2001) reported non-significant differences in FL and PA between proximal, middle-belly and distal positions of the BF muscle in one cadaver. However, no data are provided for different parts of the muscle and therefore conclusions regarding variability of architectural arrangement of muscle fibers are not clear. Ward et al. (2009) provided details regarding FL and PA values (among others) for the hamstring muscles (http://muscle.ucsd.edu). They reported considerable variation in FL, especially for the ST muscle. Furthermore, inspection of their data indicates clear proximo-distal deviations in FL and PA of the ST and BF, which suggests that further investigation is necessary.

Variability in architecture along muscle length may yield additional useful information for the function of the ST and BF muscles. This is because, fiber length distribution and properties affect whole muscle excursion while the angle of pull of each fiber relative to the line of action is a primary determinant of whole muscle force (Lieber and Friden, 2000). Such variability has been observed in several muscles, such as the flexor carpi ulnaris and radialis muscles (Friden et al., 2004) or the quadriceps muscles (Blazevich et al., 2006), but data for the hamstring muscles are not yet available. Detailed examination of the architectural arrangement of the fibers along muscle length will allow a better understanding of ST and BF functional properties.

Despite its importance, the hamstring muscle group architecture has not been thoroughly investigated as it is the case with other muscles (Finni, 2006; Kawakami and Fukunaga, 2006). Compared to other muscles, the hamstrings have a distinct architecture. For example, the ST muscle has a parallel fiber configuration while the long head of the BF is pennated. The ST muscle has much longer FL than the rest hamstring heads while it shares a common proximal tendon and origin with the BF (Woodley and Mercer, 2005). Due to the paucity of information in this area, it appears that more evidence on variability of architecture and anatomy of the hamstrings is necessary. Such information is essential to improve understanding of the functional anatomy of these muscles as well as to establish better imaging protocols for investigating their architecture and function. The purpose of this study was to examine the within-muscle architecture of the ST and the long head of the BF in cadavers.

2. Methods

2.1. Cadaveric measurements

Muscle architectural data from the long head of the BF and the ST was obtained from eight legs of four human cadavers (males) with a mean age of 68.3 years (67.8–73.4 years) using dissection.

Each cadaver was embalmed in anatomical position with the hip and knee angles at 0° (full extension) and immersed in 10% buffered formaldehyde for at least 72 h. The skin was incised in the midline and reflected. The underlying subcutaneous tissue and fascia were removed to expose the hamstring and the gluteus maximus muscles. The gluteus maximus was removed with care so that proximal fibers of the hamstrings were not disrupted.

The tendons of the BF and ST were then removed from the proximal and distal attachments. Care was taken to separate the short head of the biceps femoris muscle from the long head at the distal attachment. The muscles were subsequently stored in a fixative consisting of formaldehyde, glutaraldehyde, phenol, ethylene glycol, methanol and ethanol.

The length of each whole muscle–tendon unit was measured using a tape measure (to the nearest millimeter) (Fig. 1). The "pure" tendon length was measured as the portion of the tendon which had no muscle fibers inserting into it (Woodley and Mercer, 2005). Similarly, the MTJ was measured as the part of the tendon into which muscle fibers inserted (either proximally or distally). Pure tendon length plus MTJ length were added to provide an overall measure of the tendon length.

Once the muscle and tendon length were measured, a longitudinal cut following the fiber direction was made through the full thickness of the BF and ST (Fig. 2). Subsequently, the fiber orientation was analyzed at four regions of the muscle. Particularly, starting from the distal end, fascicles were targeted at approximately 20% (distal site), 40% (mid-belly 1), 60% (mid-belly 2) and 80% (proximal site) of muscle length.

Once dissected, the PA was measured at the corresponding locations as the angle between the line marking the outlined fascicle and the deep (for the BF muscle) or surface (for the ST muscle) aponeurosis using a goniometer. For the ST muscle, the PA was measured relative to the superficial aponeurosis, as its fibers originate from three different proximal locations (ischial tuberosity, anterior aponeurosis, common aponeurosis with the BF). To avoid any errors during the measurement session, angle measures were also confirmed by taking pictures of the pennated muscle fibers using a high definition digital camera placed perpendicularly to the muscle. Muscle thickness was measured as the distance between the superficial and deep aponeurosis. For FL measurements, a fascicle from each of the four identified locations of the muscle was teased apart along the length of incision to determine its points of attachment. It was then removed from its superficial and deep aponeuroses. Subsequently, groups of two or three fibers were teased apart from the rest muscle (Chleboun et al., 1997) and their length was measured with a precision caliper (accuracy, 0.1 mm). For the ST muscle, the FL was calculated by adding the proximal and distal parts of the muscle in series. Because the muscles had been fixed, detachment of the fascicles did not change their resting length.

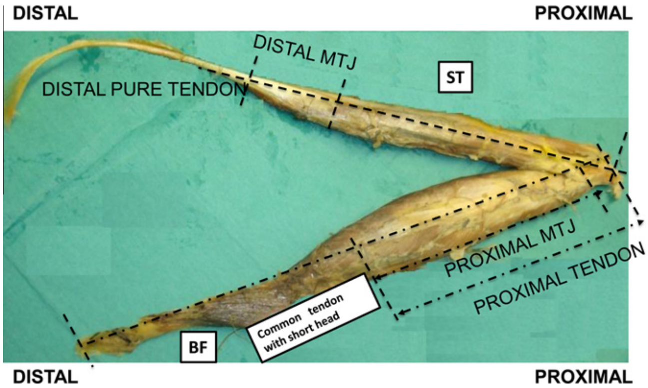

Fig. 1. Determination of the muscle and tendon length of the long head of the biceps femoris and the semitendinosus (posterior view). The common proximal origin of the two muscles is also shown.