INTRODUCTION
The biceps femoris long head, one of the muscles of the hamstrings group, is one of the most commonly injured lower-limb muscles. Previous studies have suggested that aponeurosis morphology influences injury susceptibility in muscle [1]. In that study, a model of the biceps femoris long head muscle predicted that the width of the muscle’s proximal aponeurosis greatly affects localized tissue strains and therefore injury susceptibilities. However, it is currently unknown how much variability in aponeurosis morphology exists in the normal population. In the present work, we used magnetic resonance imaging (MRI) to characterize how muscle volume, proximal external tendon cross sectional area, and proximal aponeurosis width of the biceps femoris long head muscle vary across a group of healthy subjects.

METHODS
Eighteen volunteers (nine male and nine female, height range: 157.5-195.6 cm, weight range: 54.4-102.1 kg, age range: 21-39 years) were scanned on a 3T Siemens Trio MRI Scanner. The subjects were imaged head first in the prone position with the knee and hip extended, with three coils: one body coil was placed on the hip, one body coil on the knee, and one flex coil was wrapped around the subject’s thigh. A proton density turbo spin echo protocol was used with the following imaging parameters: TE/TR/α: 29/6000/120°, imaging matrix: 512×512, field of view: 250mm×250mm, slice thickness: 5mm, spatial resolution: 0.488mm×0.488mm. Axial slices were obtained from the origin of the biceps femoris at the ischial tuberosity to the insertion on the fibula.

MR images were imported into Materialise Mimics 13.1 medical contouring software. The biceps femoris long head (BF lh) was segmented, along with this muscle’s proximal tendon and aponeurosis. Additionally, the semimembranosus, semitendinosus, and biceps femoris short head muscles were segmented. All segmentation was completed by one person.

Lengths and volumes of the muscles and tendons were found using the software’s 3-D reconstruction feature. The muscle volume was plotted against the whole hamstring volume for each subject (Fig. 2). These data were then used to find a gross cross-sectional area (CSA) for each muscle and tendon:

$$\text{CSA} = \frac{V_m}{L_m},$$

where \((V_m)\) is the volume measured for each muscle and \((L_m)\) is the superior-inferior length measured parallel to the axis of the MRI scan. The physiological cross-sectional area (PCSA) for the BF lh was calculated as:

$$\text{PCSA} = \frac{(\text{CSA})(L_m/L_{f^0})}{},$$

where \((L_m/L_{f^0})\) is the muscle length to optimal fiber length ratio taken from literature [2].

Figure 1: Axial MR image. The BF lh has been segmented (green). This slice was determined to be the representative slice. The BF lh proximal aponeurosis width (blue) was also calculated.

From each subject’s image set we chose a representative slice, defined as the most distal slice at which the proximal BF lh aponeurosis was external of the BF lh (Fig.1). From this slice, we determined the width of the BF lh’s proximal aponeurosis (Fig. 1).
RESULTS

87% of the subjects’ BFhl volumes could be predicted by a linear function of hamstring volume (Fig. 2a). 82% of the subjects’ BFhl PCSAs could be predicted by the summed hamstring CSAs (Fig. 2b). The BFhl volume as a percentage of the whole hamstring volume (mean ± SD) was 0.275±0.034 while the BFhl PCSA as a percentage of the summed hamstring CSA was 0.312±0.035.

The relationships for tendon and aponeurosis measurements compared to BFhl PCSA show much less correlation. Average external tendon cross-sectional area exhibited a weak correlation with BFhl PCSA (R²=0.52) (Fig. 2c). Proximal aponeurosis width showed no effective correlation with BFhl PCSA (R²=0.005) (Fig. 2d).

CONCLUSIONS

Previous studies have found that muscles in a given muscle group scale linearly in volume and in PCSA with one another [4]. In this study, we also found that the volumes of the BFhl of healthy subjects scale linearly with whole hamstring volume and that BFhl PCSA is likewise scalable with hamstring CSA.

However, we observed that proximal external tendon and aponeurosis morphologies are variable across healthy subjects. It is commonly assumed that the average cross-sectional area of the tendon scales with the muscle PCSA [3]; however, we found only a weak correlation between tendon cross section and muscle PCSA.

It has been suggested that proximal aponeurosis morphology affects strain distributions within the muscle and therefore may be an indicator of muscle injury susceptibility [1]. In this study, we found a range of aponeurosis morphologies among 18 healthy subjects. This suggests that hamstring tissue strains and injury susceptibility may vary substantially across a normal population. A related study [5] explores the relationship between aponeurosis dimensions and localized strains in the muscle using functional MRI.

REFERENCES


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