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Does a Greater Hamstring Muscle Thickness Mean a Greater Aponeurosis Thickness?

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Abstract: The aim of the present study was to assess the association between muscle thickness and the superficial and deep aponeurosis thickness of the hamstrings. Ultrasound images were captured from the semitendinosus (ST) and biceps femoris long head (BFlh) of fifty young individuals (28 males and 22 females). Measurements were taken at six sites along the thigh in prone position. Superficial and deep aponeurosis and muscle thickness were evaluated across the entire length of the ST and BFlh using a computational image segmentation approach, which generated approximately ~360 data points per participant. There was significant interindividual variability in superficial (coefficient of variation, CV: 19.37–31.40%) and deep aponeurosis thickness (CV: 21.22–31.82%). Correlation analysis revealed a limited association between muscle and superficial aponeurosis thickness, with no significant correlations ($r = -0.21$ to 0.22, $p > 0.05$) observed across regions. However, moderate positive correlations were found for deep aponeurosis thickness in the proximal region of the BFlh ($r = 0.43$, $p = 0.002$) and in the middle ($r = 0.34$, $p = 0.014$) and distal–middle region of the ST ($r = 0.35$, $p = 0.022$). No consistent relation between muscle and aponeurosis thickness was observed, suggesting that aponeurosis morphology varies independently of muscle size. This variability may impact the mechanical strain distribution, emphasizing the need for individualized assessments in hamstring injury prediction.

Keywords: hamstrings; ultrasound; aponeurosis; biceps femoris; muscle thickness

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1. Introduction

Hamstring strain injuries (HSIs) are among the most frequent injuries in running-based and high-speed sports [1,2]. These injuries often lead to extended periods away from training and competition, diminishing athletic performance and causing lasting physical and structural changes [3,4]. The biceps femoris long head (BFlh) is susceptible to these injuries, often occurring at or near the musculotendinous junction (MTJ) during high-intensity eccentric contractions [1,2,5]. These contractions are especially prominent during the terminal swing phase of running gait, where rapid muscle lengthening under load places extreme mechanical stress on the muscle–tendon unit [1,2].

Aponeurosis morphology has a critical role in muscle function [6,7]. The aponeurosis is a connective tissue structure responsible for transmitting force from the muscle fibers to the tendon and ultimately to the skeletal system [6,7]. Its morphology (thickness, volume, and width) significantly influences the mechanical strain distribution within the muscle–tendon unit during contraction [6,7]. Abnormalities in these structural properties can lead to localized strain concentrations, particularly near the MTJ, which has been linked with greater risk of muscle injury [6,7]. Specifically, it has been hypothesized that disproportionate dimensions of the aponeurosis, such as a thinner or narrower aponeurosis, exacerbate

strain concentrations, predisposing the muscle to injury during activities involving high mechanical loads [8,9]. Computational modeling and imaging-based assessments have indicated that strain maldistribution is most pronounced in regions adjacent to the MTJ [10–12]. Thus, understanding aponeurosis geometry is pivotal for identifying individuals at greater risk of HSIs.

The relationship between muscle and aponeurosis size is complex and characterized by significant variability [13–16]. Research has shown that the size of the vastus lateralis aponeurosis is directly related to the overall volume of the quadriceps [17]. In contrast, the size of the BFlh aponeurosis did not consistently correlate with muscle size, suggesting that aponeurosis dimensions are not proportionally scaled to the muscle's anatomical cross-sectional area or volume [13,15]. For instance, Evangelidis et al. [13] reported no relationship between aponeurosis area and knee flexor strength or muscle size, highlighting the high variability in aponeurosis-to-muscle area ratios. In contrast, Freitas et al. [14] reported moderate correlations (r = 0.53) between the BFlh muscle volume and BFlh aponeurosis volume. Additionally, Lazarczuk et al. [15] observed a significant positive moderate correlation between BFlh aponeurosis and muscle volume (r = 0.64) in a previously injured limb, but no correlation in uninjured or healthy limbs. These findings emphasize the complex relationship between muscle and aponeurosis dimensions, which is influenced by individual anatomical differences and by structural adaptations that may occur in response to mechanical loading or injury.

Investigations of aponeurosis dimensions have relied predominantly on magnetic resonance imaging (MRI) [13–16]. While MRI remains the gold standard for aponeurosis morphological assessments, its high cost and limited accessibility have constrained its application. However, recently, it has been found that ultrasound (US) is as a reliable and cost-effective alternative for evaluating aponeurosis thickness with relatively low measurement error (standard error of measurement 0.88 to 2.72%) [18].

While previous research has provided insights into the role of aponeurosis morphology in HSIs, several critical gaps persist. Prior studies have primarily focused on male populations [13–16], neglecting potential differences across genders. Furthermore, these investigations have been limited to assessing the BFlh, without considering other hamstring muscles such as the semitendinosus (ST), which may also play a pivotal role in injury risk and prevention. In addition, studies have shown significant variability in architecture along the hamstring muscle–tendon unit [19]. This means that the relationship, if any, between muscle and aponeurotic tissue thickness may vary depending on the region that is selected for analysis. Furthermore, the morphology of the muscle–tendon unit may vary between individuals [13,14], which might also have an impact on the relationship between aponeurotic and muscle tissue thickness. If the thickness of the muscle and aponeurosis tissues varies along the muscle–tendon unit and varies significantly between individuals, then this means that conclusions regarding the relationship between muscle and aponeurosis thickness may largely depend on the measurement method as well as the participant characteristics. Additionally, while some studies use mean values [14,15] for the assessment of aponeurosis dimensions, others [16] have focused on maximum values to identify local peaks. These different methods, combined with significant individual variability, complicate comparisons and interpretations of the relationship between muscle and aponeurosis thickness across the different studies. Identifying such relationships may assist in better understanding if and how muscle morphology correlates with aponeurosis morphology in healthy people and then using this information to examine abnormalities. Therefore, the aim of this study is to investigate the relation between muscle thickness and the thickness of both the superficial and deep aponeurosis layers of young males and females at different measurement locations across the thigh length. It was hypothesized that

there is a significant association in thickness between muscle and aponeurosis tissues across the different measurement sites. Further, it was also hypothesized that the measurement method will significantly influence the observed relationship between muscle thickness and aponeurosis thickness. Finally, large variability between individuals in aponeurosis dimensions was expected.

2. Materials and Methods

2.1. Participants

The study comprised 50 participants, including 28 males (age: 20.3 ± 1.87 years; body mass: 84.5 ± 5.33 kg; height: 1.84 ± 0.06 m) and 22 females (age: 20.5 ± 1.72 years; body mass: 73.4 ± 4.14 kg; height: 1.67 ± 0.07 m). All participants were physically active but did not follow any structured sports or exercise program during the study period. Physical activity was evaluated using the short format of the International Physical Activity Questionnaire [20], with an average energy expenditure of 1766 ± 899 MET·min·week^{-1}. Prior to participation, written informed consent was obtained, and participants confirmed the absence of any prior lower limb injuries, including hamstring- or knee-related muscle or ligament injuries. To standardize conditions, participants refrained from intense physical activity for at least 24 h before their scheduled visits. Ethical approval was granted by the university's Institutional Review Board (ERC-001/2024), and the study adhered to the principles outlined in the Declaration of Helsinki.

2.2. Experimental Procedure

We assessed the variations in thickness of the superficial and deep aponeuroses, as well as the muscle thickness of the ST and BFlh, following methodologies from our recent research [18], which demonstrated high test–retest reliability with minimal measurement error. Participants' hip joints were stabilized in a neutral position with elastic Velcro straps to prevent movement during assessments. Knee angular position was monitored using a twin-axis goniometer (Model TSD 130B, Biopac Systems, Inc., Goleta, CA, USA), with 0° representing full knee extension. All US recordings were obtained unilaterally by a single examiner with over five years of expertise in musculoskeletal US.

2.3. Ultrasound Protocol

A linear-array probe (10 MHz frequency, 6 cm length) connected to a US device (SSD-3500, ALOKA, Tokyo, Japan) was used for imaging. The US settings were kept the same for everyone, with a depth of 80 mm, gain at 59 dB, a dynamic range of 65 dB, and a frequency of 10 MHz. To measure the femur length, we used a precise digital caliper (Model EC10, Tresna, Guilin Guanglu Measuring Instrument Co., Ltd., Guilin, China) that could measure up to 0.005 mm. This measurement was taken from the greater trochanter to the outer femoral condyle. US scans, both longitudinal and transverse, were used to map the path of each hamstring muscle. These scans identified the starting (proximal) and ending (distal) attachment points of the BFlh and ST, which were marked on the skin. The proximal attachment for all muscles was at the ischial tuberosity, while the distal attachment was at the fibular head for the BFlh and the pes anserinus for the ST [21–23]. To take into consideration the intramuscular differences of hamstrings muscles, femur length was divided into six measurement sites (15%, 30%, 45%, 60%, 75%, and 90%) (Figure 1), recognizing that the hamstring muscles exhibit intramuscular variations in both morphological [19] and activation patterns [24]. Axial lines were drawn on the skin with a marker, and the US probe was centered at each marked location.

To ensure consistent imaging, the US probe was positioned perpendicular to the skin and adjusted slightly to improve the clarity of the muscle aponeurosis [18]. Gentle, steady

pressure was applied, along with a water-based gel, to avoid distorting the tissue and to enhance sound transmission. Participants were asked to stay relaxed during the procedure to avoid any interference with the imaging. Two investigators independently reviewed the images to confirm their quality, and any unclear images were retaken.

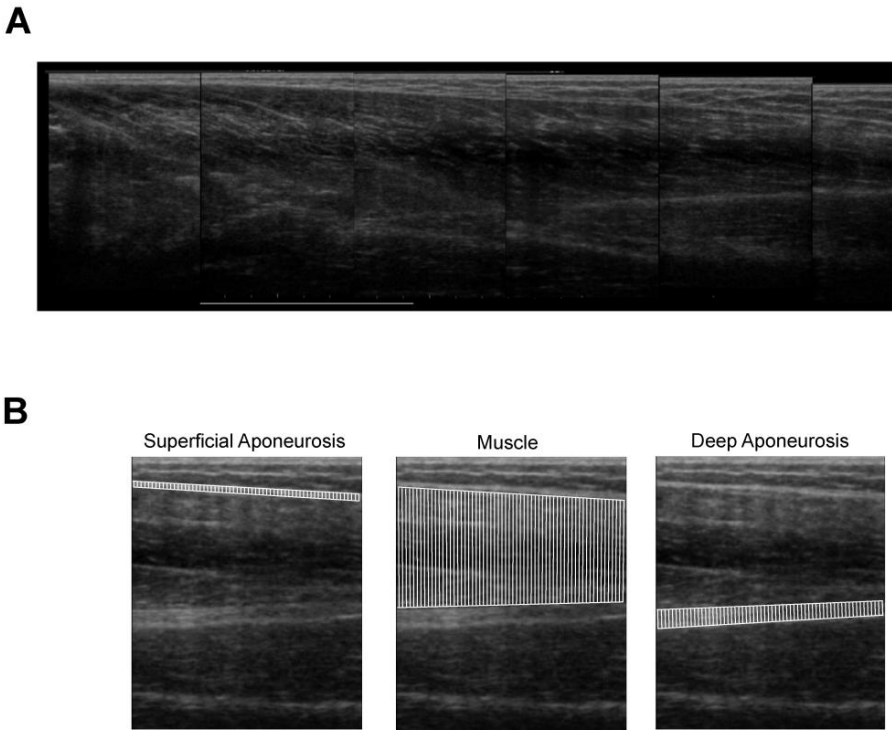


Figure 1. (**A**) Representative examples of a series of ultrasound images obtained at the different measurement sites along the thigh length for the biceps femoris. (**B**) Example of ultrasound images of biceps femoris muscle indicating region of interest as well as the placement of the landmarks to measure muscle and aponeurosis thickness. The fit provided set of landmarks, comprising x- and y-coordinates of 60 evenly spaced pixel points spanning the entire width of the region of interest. The white vertical lines represent thickness measures.

2.4. Image Analysis

A single-blinded examiner (C.S.) analyzed all US images using custom MATLAB scripts (MATLAB 2019b; MathWorks, Inc., Natick, MA, USA). Regions of interest (ROIs) included the superficial and deep aponeurosis and muscle thickness. Landmarks (x- and y-coordinates) were placed at 60 evenly spaced points along the width of each US image, resulting in ~360 data points per participant (6 images × 6 sites per muscle) [18]. Muscle thickness was measured as the distance between the superficial and deep aponeuroses (Figure 1). Aponeurosis thickness was determined as the distance between hyperechoic edges (Figure 1). Measurements were normalized to muscle length, enabling standardized comparisons between participants and muscle groups.

We used two different methods to examine the association between muscle thickness and the thickness of the superficial and deep aponeuroses. Firstly, we divided the muscle into five sections: proximal (15–30% of femur length, near to the hip joint), proximal–middle (30–45% of femur length), middle (45–60% of femur length), distal–middle (60–75% of femur length), and distal (75–90% of femur length, near to the knee joint). For each section, we used two approaches: (1) the first involved calculating the mean thickness of the aponeurosis and muscle within each region (averaging ~72 data points per segment), while (2) the second method focused on identifying the maximum thickness values within each region.

2.5. Statistical Analysis

Data were analyzed using SPSS Statistics for Windows Version 28.0 (Version 25.0, IBM, Armonk, NY, USA). The association between muscle thickness and aponeurosis thickness was investigated with multivariate regression analysis, adjusted for physical activity, body mass, and gender. Product interaction terms between aponeurosis thickness and these confounding variables were also considered in order to investigate the effects of moderators. The model estimated both main effects and interaction terms to test for whether the muscle–aponeurosis association differed by physical activity level, body mass, or gender. The fit of the overall model was determined with R^2, while the alpha level of significance was set at $p < 0.05$. Also, we performed correlation analyses using Pearson's or Spearman's correlation coefficients. Pearson's correlation was used for variables with a normal distribution, as determined by the Shapiro–Wilk test. In cases where the data were non-normally distributed, Spearman's rank-order correlation was applied. The strength of a correlation coefficient was interpreted in the following way: 0–0.10: trivial, 0.10–0.39: weak, 0.40–0.69: moderate, and 0.70–0.99: strong [25]. These analyses were conducted separately for the entire muscle length and for each of the five segmented regions (proximal, proximal–middle, middle, distal–middle, and distal). Additionally, the coefficient of variation (CV) was computed and expressed as a percentage to evaluate the variability in muscle and aponeurosis thickness of the BFlh and ST across the different measurement sites.

3. Results

3.1. Superficial Aponeurosis Thickness

3.1.1. Mean Thickness

The multivariate regression analysis for mean muscle thickness and superficial aponeurosis thickness present trivial to weak relationships for the BFlh (R^2 range = 0.11 to 0.18) and ST (R^2 range = 0.06 to 0.27) after adjusting for physical activity levels, body mass, and gender (Table 1). Additionally, the correlation analyses for the mean muscle thickness and the mean superficial aponeurosis thickness across the five measurement sites are presented in Figure 2. For the BF, none of the regions demonstrated significant correlations (r range = −0.21 to 0.22, $p > 0.05$). Similarly, correlations were not significant in any region (r range = 0.03 to 0.14, $p > 0.05$) for the ST across the different measurement sites.

Table 1. Regression analysis results examining the relationship between muscle thickness and deep aponeurosis thickness, controlling for the confounding factors physical activity, body mass, and gender ($n = 50$).

	Biceps Femoris		**Semitendinosus**	
	R^2	***p***	**R^2**	***p***
Mean Thickness				
Superficial Aponeurosis				
Proximal	0.18	0.27	0.27	0.06
Proximal–Middle	0.11	0.66	0.07	0.90
Middle	0.18	0.28	0.13	0.52
Distal–Middle	0.11	0.61	0.10	0.67
Distal	0.14	0.48	0.06	0.92
Deep Aponeurosis				
Proximal	0.34	0.01	0.23	0.13
Proximal–Middle	0.20	0.18	0.08	0.86

Table 1. *Cont.*

	Biceps Femoris		Semitendinosus	
	R^2	*p*	R^2	*p*
Middle	0.14	0.45	0.10	0.67
Distal–Middle	0.20	0.19	0.20	0.18
Distal	0.16	0.35	0.07	0.93
Maximum Thickness				
Superficial Aponeurosis				
Proximal	0.37	0.01	0.11	0.61
Proximal–Middle	0.26	0.05	0.07	0.84
Middle	0.25	0.07	0.09	0.79
Distal–Middle	0.25	0.08	0.15	0.42
Distal	0.08	0.80	0.08	0.80
Deep Aponeurosis				
Proximal	0.30	0.03	0.14	0.46
Proximal–Middle	0.22	0.15	0.11	0.65
Middle	0.26	0.07	0.24	0.10
Distal–Middle	0.20	0.20	0.24	0.09
Distal	0.16	0.35	0.09	0.80

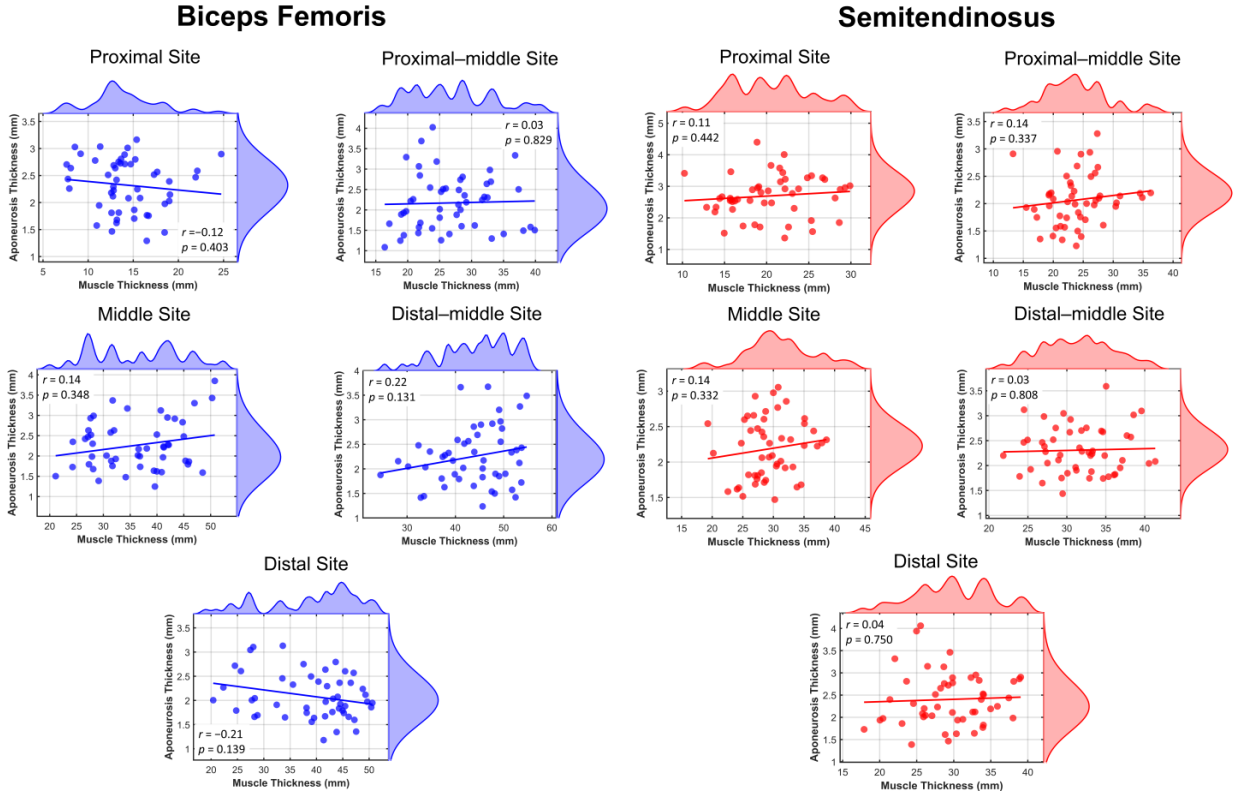


Figure 2. Scatterplots with density distributions showing the relationship between mean muscle thickness (x-axis, in mm) and mean superficial aponeurosis thickness (y-axis, in mm) across different measurement sites for the biceps femoris (blue) and semitendinosus (red) muscles. Measurement sites include proximal, proximal–middle, middle, distal–middle, and distal regions. Each point represents an individual observation (n = 50), with corresponding density plots indicating the data distribution at each site.

3.1.2. Maximum Thickness

The multivariate regression analysis for maximum muscle thickness and superficial aponeurosis thickness indicated trivial to weak relationships for the BFlh (R^2 range = 0.08 to 0.37) and for the ST (R^2 range = 0.07 to 0.15), adjusting for physical activity levels, body mass, and gender (Table 1). Additionally, the correlation analyses for the maximum muscle thickness and the maximum superficial aponeurosis thickness across the five measurement sites are presented in Figure 3. For the BF, the proximal site demonstrated a strong positive association, with a significant correlation (r = 0.47, $p < 0.001$, 95% CI [0.21, 0.66]). No significant correlations were observed for the remaining measurement sites (r range = 0.05 to 0.27, $p > 0.05$). Similarly, for the ST, no significant correlations were observed across all regions (r range = −0.20 to 0.13, $p > 0.05$).

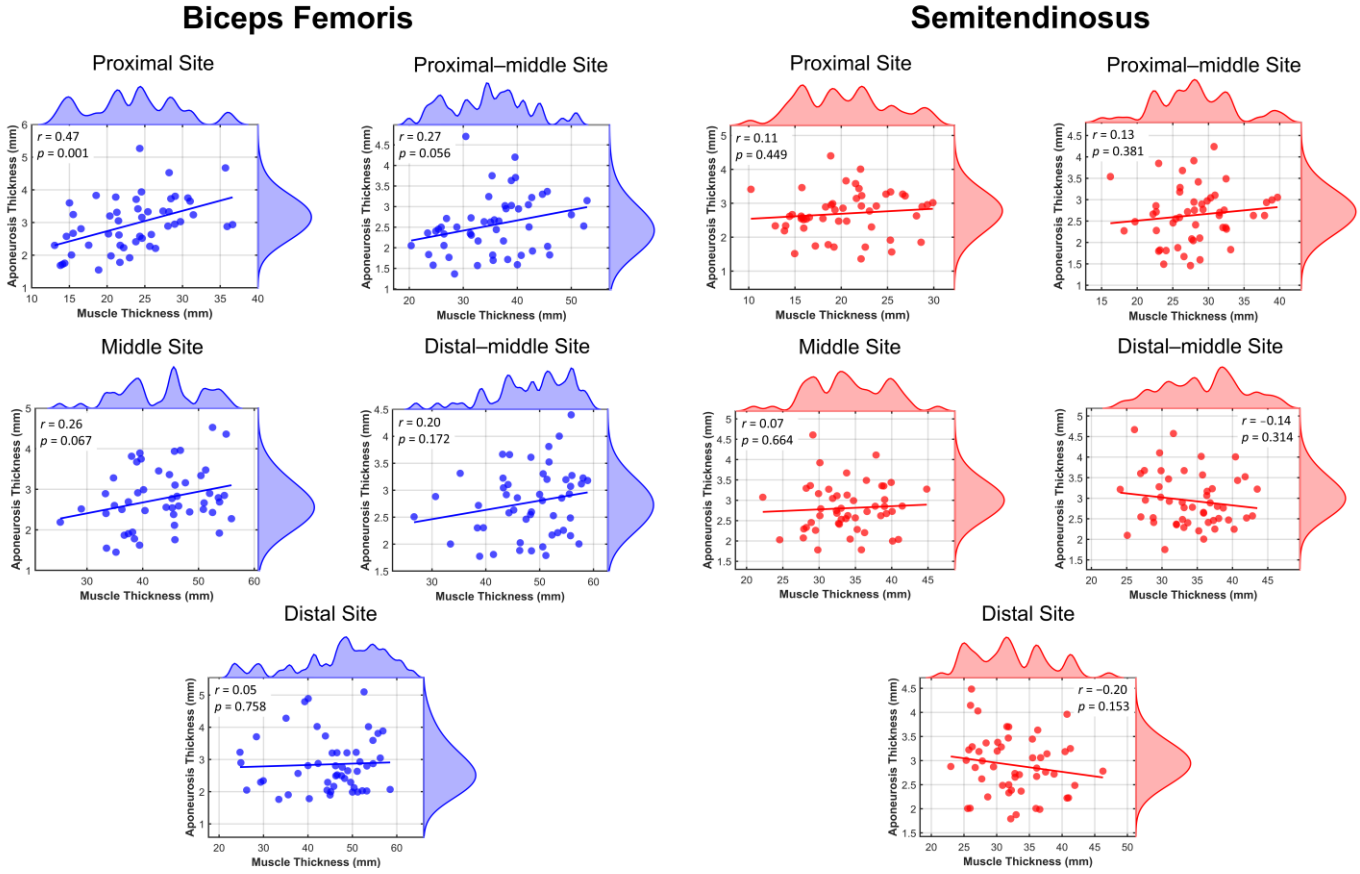


Figure 3. Scatterplots with density distributions showing the relationship between maximum muscle thickness (x-axis, in mm) and maximum superficial aponeurosis thickness (y-axis, in mm) across different measurement sites for the biceps femoris (blue) and semitendinosus (red) muscles. Measurement sites include proximal, proximal–middle, middle, distal–middle, and distal regions. Each point represents an individual observation ($n = 50$), with corresponding density plots indicating the data distribution at each site.

3.2. Deep Aponeurosis Thickness

3.2.1. Mean Thickness

The multivariate regression analysis for mean muscle thickness and deep aponeurosis thickness revealed trivial to weak relationships for the BFlh (R^2 range = 0.14 to 0.34) and for the ST (R^2 range = 0.07 to 0.24), after adjusting for confounding variables (Table 1). Figure 4 displays the correlation analyses for the mean muscle thickness and the mean thickness of the deep aponeurosis across the five measurement sites. For the BFlh, a significant positive moderate correlation was observed in the proximal region (r = 0.43, $p = 0.002$, 95% CI [0.17,

0.63]), while the correlations in the proximal–middle region through to the distal region were not significant (r range = 0.18 to 0.28, $p > 0.05$). For the ST, a significant positive weak correlation was identified in the distal–middle region (r = 0.28, $p = 0.049$, 95% CI [0.002, 0.52]). However, the correlations in the other measurement sites were non-significant (r range = −0.07 to 0.12, $p > 0.05$).

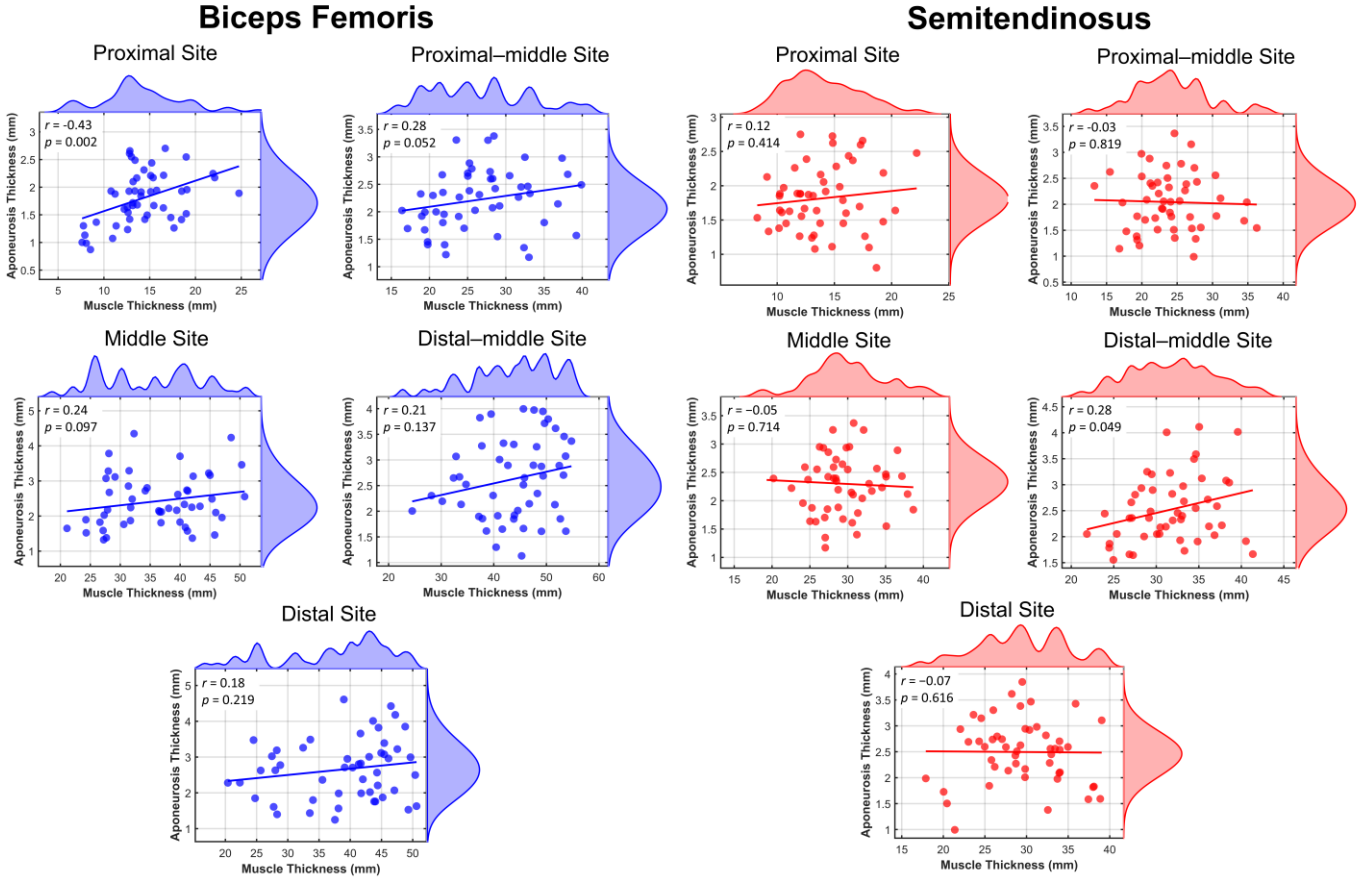


Figure 4. Scatterplots with density distributions showing the relationship between mean muscle thickness (x-axis, in mm) and mean deep aponeurosis thickness (y-axis, in mm) across different measurement sites for the biceps femoris (blue) and semitendinosus (red) muscles. Measurement sites include proximal, proximal–middle, middle, distal–middle, and distal regions. Each point represents an individual observation ($n = 50$), with corresponding density plots indicating the data distribution at each site.

3.2.2. Maximum Thickness

After adjusting for confounding variables, the multivariate regression analysis for maximum muscle thickness and deep aponeurosis thickness revealed trivial to weak associations for the BFlh (R^2 range = 0.16 to 0.30) and for the ST (R^2 range = 0.09 to 0.24). Figure 5 illustrates the correlation analyses between the maximum muscle thickness and the maximum thickness of the deep aponeurosis across the five measurement sites. For the BF, none of the regions showed significant correlations (r range = 0.13 to 0.27, $p > 0.05$). For the ST, significant positive correlations were identified in the middle site (r = 0.34, $p = 0.014$, 95% CI [0.073, 0.568]) and distal–middle site (r = 0.35, $p = 0.022$, 95% CI [0.049, 0.552]). The rest of the measurement sites did not exhibit significant correlations (r range = 0.001 to 0.12, $p > 0.05$).

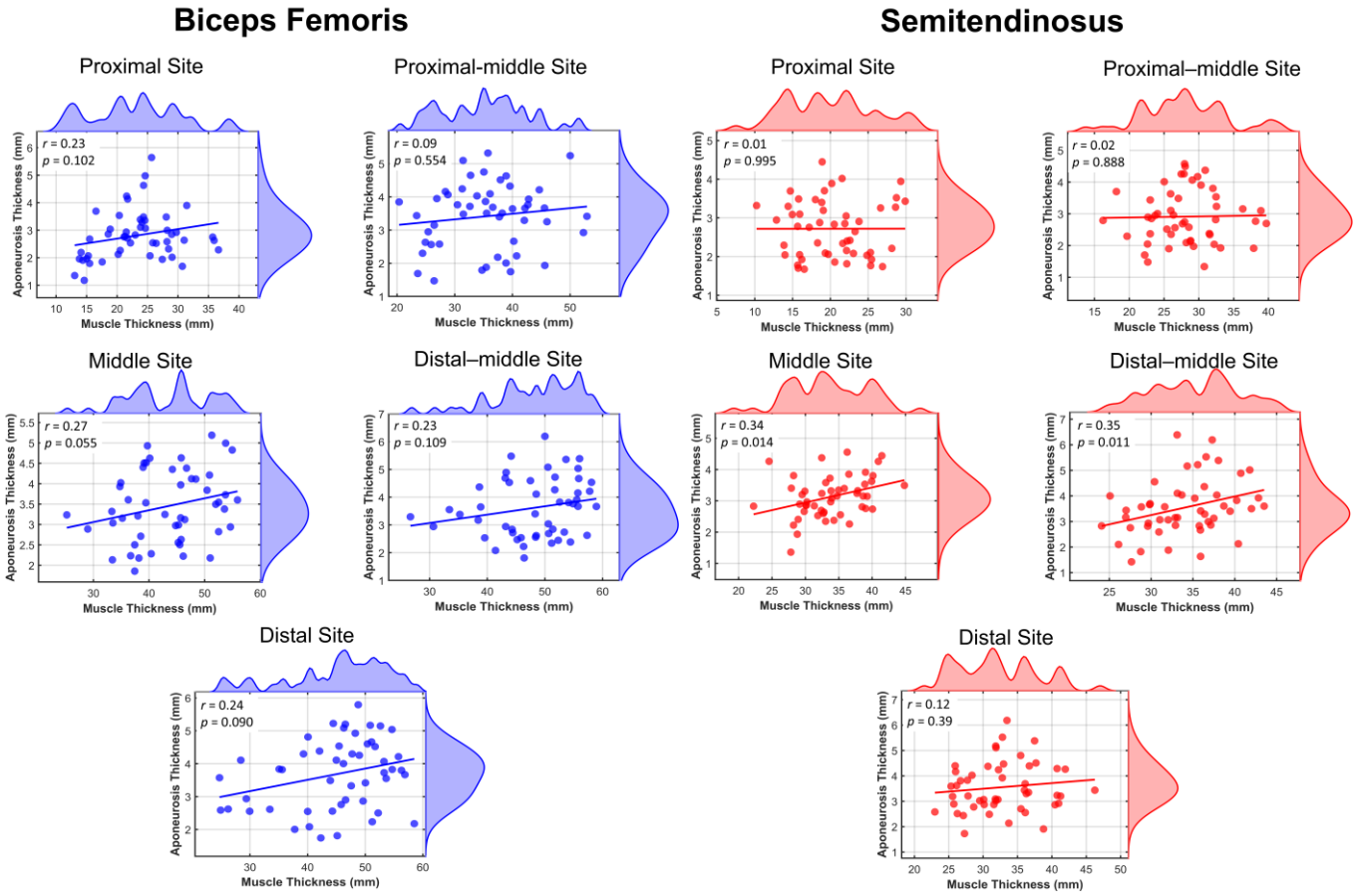


Figure 5. Scatterplots with density distributions showing the relationship between maximum muscle thickness (x-axis, in mm) and maximum deep aponeurosis thickness (y-axis, in mm) across different measurement sites for the biceps femoris (blue) and semitendinosus (red) muscles. Measurement sites include proximal, proximal–middle, middle, distal–middle, and distal regions. Each point represents an individual observation (n = 50), with corresponding density plots indicating the data distribution at each site.

3.2.3. Interindividual Variability in Muscle and Aponeurosis Thickness

The CV for muscle and superficial and deep aponeurosis thickness across the five measurement sites of the BFlh and ST are summarized in Table 2. For mean muscle thickness, the BFlh exhibited a CV range between 16.88% (distal–middle site) and 25.98% (proximal site), while the maximum thickness varied from 15.49% (distal–middle) to 25.90% (proximal site). In the ST, the CV for the mean thickness ranged from 14.53% (middle site) to 22.82% (proximal site), while the maximum thickness ranged from 13.97% (middle site) to 23.56% (proximal site).

Regarding superficial aponeurosis thickness, the BFlh showed a CV for mean thickness of 20.93% (proximal site) to 31.40% (proximal–middle site) and for maximum thickness, 22.71% (distal–middle site) to 28.00% (proximal–middle). In the ST, the CV for mean thickness ranged from 19.37% (middle site) to 24.88% (distal site), while the maximum thickness spanned 21.10% (middle site) to 28.90% (proximal–middle site).

For deep aponeurosis thickness, the BFlh demonstrated a CV for mean thickness of 24.75% (distal–middle site) to 31.52% (distal–middle site), and for maximum thickness, 24.75% (distal site) to 31.82% (proximal site). In the ST, the CV for mean thickness ranged from 23.22% (middle site) to 27.00% (proximal–middle site), while the maximum thickness ranged from 21.22% (middle site) to 31.15% (distal–middle site).

Table 2. Coefficient of variation (%) for the mean and maximum measurements of the muscle as well as the superficial and deep aponeurosis thickness of the biceps femoris long head (BFlh) and semitendinosus (ST) muscles across five measurement sites (n = 50).

Measurement Site	Muscle				Superficial Aponeurosis				Deep Aponeurosis			
	BFlh		ST		BFlh		ST		BFlh		ST	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Proximal	25.98	25.90	22.82	23.56	20.93	27.70	23.33	24.24	24.75	31.82	26.32	26.90
Proximal–Middle	22.70	21.94	20.01	18.10	31.40	28.00	22.54	24.41	30.76	28.78	27.00	28.90
Middle	21.26	17.11	14.53	13.97	26.64	26.48	19.37	21.10	29.86	25.31	23.22	21.22
Distal–Middle	16.88	15.49	14.69	14.40	26.46	22.71	20.07	22.37	31.52	29.12	25.47	31.15
Distal	21.20	19.54	17.45	16.49	22.19	29.69	24.88	21.32	24.75	28.68	24.64	27.25

4. Discussion

This study examined the relationship between muscle thickness and the thickness of both the superficial and deep aponeuroses in the BFlh and ST muscles of young males and females. The results showed no consistent correlation between these parameters across the different measurement sites, suggesting that aponeurosis thickness may not be directly related to muscle thickness in the hamstring muscles even after adjusting for confounding variables such as physical activity, body weight, and gender. The considerable variability in aponeurosis thickness between individuals likely contributed to the low correlation coefficients. Additionally, the correlation remained relatively low even when mean thickness was used instead of maximum thickness.

4.1. No Association Between Muscle and Aponeurosis Thickness

Our results demonstrated limited correlations between muscle thickness and superficial aponeurosis thickness across different regions (Table 1, Figures 2 and 3). In contrast, stronger correlations were observed for the deep aponeurosis, particularly in the proximal region of the BFlh and the distal–middle region of the ST (Table 1, Figures 4 and 5). This challenges the common assumption as well as our initial hypothesis that aponeurosis and muscle morphology are proportionally aligned to accommodate force transmission during muscle contraction [7,8]. Previous studies have indicated that aponeurosis geometry influenced strain distribution during muscle loading. For example, Rehorn and Blemker [9], using computational modeling, demonstrated that thinner or narrower aponeuroses increase localized strain concentrations near the MTJ.

The absence of consistent correlations between muscle and aponeurosis size aligns with the findings of Evangelidis et al. [13], suggesting that the aponeurosis area in the BFlh is highly variable and does not correlate with muscle cross-sectional area or volume. Also, the present findings are in line with the results of Lazarczuk et al. [15], which reported no association between BFlh aponeurosis and muscle volume in uninjured or healthy limbs. However, the present findings are not in line with Freitas et al. [14], who found moderate correlations (r = 0.53) between the BFlh muscle volume and BFlh aponeurosis volume. In summary, these findings emphasize the complex relation between muscle and aponeurosis dimensions (thickness), highlighting the need for further research to better understand their functional and structural interactions.

4.2. Hamstrings' Morphological Characteristics Varied Across Individuals

The present results suggest significant interindividual (CV range 20.93–31–82%, Table 2) variability in aponeurosis thickness, as indicated by the density distribution plots. Similarly, Evangelidis et al. [13] reported up to a fourfold variability in the proximal BFlh

aponeurosis dimensions across individuals, suggesting a high degree of heterogeneity in structural characteristics that could potentially influence hamstring mechanics. This high degree of variability (Table 2) may further influence the overall correlation values between muscle and aponeurosis thickness and could help explain the generally low correlations observed in this study. The present results extend the previous findings by demonstrating that both the superficial and deep aponeuroses exhibit high variability across young males and females at different regions of the hamstring muscles.

The variability observed in this study may reflect both intrinsic factors, such as muscle [19] and tendon architectural differences [21,22], and extrinsic factors, including previous injuries, training background, and adaptive remodeling [13–16]. For instance, Lazarczuk et al. [15] identified significant increases in aponeurosis volume in previously injured limbs, likely due to scar formation or altered loading patterns following injury. From a clinical perspective, this interindividual variability complicates the establishment of universal criteria for aponeurosis size in injury risk prediction. Instead, our findings advocate for personalized evaluations that consider the unique structural and functional characteristics of an individual's muscle–aponeurosis complex.

4.3. Mean vs. Maximum Thickness Assessment

This study's methodological approach provided both mean (Figures 2 and 4) and maximum thickness measurements (Figures 3 and 5) for the superficial and deep aponeuroses. While maximum thickness showed sporadic correlations with muscle thickness, mean values were generally consistent across regions between the two muscles. This discrepancy highlights the importance of capturing both mean and peak values to fully understand the structural characteristics of the superficial and deep aponeuroses. Maximum thickness could potentially reflect localized adaptations or stress concentrations that occur in response to region-specific loading patterns, whereas mean thickness could offer a broader representation of overall aponeurosis structure.

4.4. Practical Implications

The findings of this study have several practical implications. It is highly unlikely that an individual with thicker hamstring muscle tissue will also have thicker aponeurotic tissue, and vice versa, highlighting the importance of evaluating these tissues independently rather than assuming a proportional relationship. The large interindividual variability in the relationship between muscle and aponeurosis thickness suggests that the functional interactions between these tissues cannot be easily explained based on thickness alone. This complexity underscores the need for individualized evaluations, particularly following injury or intervention, as structural changes are specific to the individual being assessed. Clinicians should consider this variability when designing rehabilitation protocols or injury prevention strategies, as personalized assessments can provide better insights into tissue mechanics. From a research and diagnostic perspective, exploring additional factors beyond thickness, such as tissue stiffness or quality, may help to better understand muscle–aponeurosis interactions.

4.5. Limitations

While this study provides valuable insights, some limitations should be emphasized. This study focused on a physically active healthy population, which may limit the generalizability of the findings to elite or injured athletes. The selection of this population was used to attain homogeneity and reduce variations from different training regimens, inactivity, or previous injuries. This approach was essential to accurately focus on the relationship between muscle thickness and aponeurosis structure, providing baseline information for future comparisons with other groups. While US imaging is a reliable and accessible tool

for assessing aponeurosis and muscle morphology [18], its two-dimensional nature and reliance on operator skill introduce limitations. Incorporating advanced imaging modalities, such as MRI or shear wave elastography, could provide further insights into the structural properties of aponeuroses.

5. Conclusions

This study did not identify significant associations between superficial and deep aponeurosis thickness and muscle thickness in the ST and BFlh muscles. However, substantial interindividual variability in aponeurosis thickness was observed. These findings highlight the need for personalized approaches in both research and clinical settings to account for the morphological diversity that may influence muscle–tendon unit function.

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