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Gross anatomical and dimensional characteristics of the proximal hamstring origin

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Abstract
Purpose The current study was undertaken to better define the gross anatomical and dimensional characteristics of the proximal hamstring origin.
Methods Twelve paired whole-lower extremities from six embalmed cadavers were dissected. The gross anatomy of the proximal hamstrings was studied. With the tendons attached to the ischial tuberosity, the width and thickness of each tendon was measured 1 cm distally to their origin, and the distance from the most proximal border of the common origin of the semitendinosus (ST) and long head of the biceps (LB) to their distal junction was assessed. After removal of the hamstring group, the shape, orientation, and dimension of the tendon footprints were determined.
Results One cadaver demonstrated unique anatomy, which was considered as an anatomic variant and was therefore excluded from the study group. The ST and LB had a common origin on the posterolateral aspect of the ischial tuberosity (ST/LB), whereas the semimembranosus (SM) had a separated origin at the anterolateral aspect. The mean distance from the most proximal border of the ST/LB origin to the distal junction was 10.0 ± 1.3 cm. The shape of both footprints was longitudinal-oval, with the longitudinal axes of the SM and ST/LB footprints parallel aligned. Mean tendon width was 3.4 ± 0.5 cm for the common ST/LB complex and 4.2 ± 0.9 cm for the SM ($p = 0.009$). The corresponding values for tendon thickness were 1.0 ± 0.3 cm (ST/LB) and 0.8 ± 0.2 cm (SM), respectively (n.s.). Mean footprint length was 3.9 ± 0.4 cm for ST/LB and 4.5 ± 0.5 cm for SM ($p = 0.002$). The corresponding values for footprint height were 1.4 ± 0.5 cm (ST/LB) and 1.2 ± 0.3 cm (SM), respectively (n.s.).
Conclusion The ST and LB had a common origin, whereas the SM originated separately. The site of origin of both tendons was the lateral aspect of the ischial tuberosity, with the SM footprint lying directly anterior to the footprint of the ST/LB complex. The footprint of the SM was significantly wider than the footprint of the ST/LB. The reported gross anatomic findings and dimensions may aid surgeons in anchor placement at the anatomical attachment site, thereby facilitating anatomic hamstring repair. In addition, the provided data may improve diagnosis and conservative treatment of proximal hamstring tendinopathy, since detailed knowledge about the normal anatomy is crucial for recognizing tendon abnormalities and for several conservative treatment modalities such as shockwave application or ultrasound-guided injections.

Keywords Hamstring tendons · Hamstring avulsion · Hamstring repair · Anatomy

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Introduction

The hamstring muscle group is composed of the semitendinosus (ST), semimembranosus (SM), and biceps femoris muscles [4, 5, 37]. They are important extensors of the hip and flexors of the knee. Except for the short head of the biceps femoris, the site of origin of the proximal hamstrings is located at the ischial tuberosity [4, 28, 33].

Injuries of the proximal hamstring muscle–tendon unit are frequently found in athletic populations [19]. Most injuries are strains of the muscle or the myotendinous junction [11, 15]. A less frequent, but potentially more serious injury pattern is the avulsion of the hamstring origin from the ischial tuberosity [1, 12]. The mechanism of injury is typically forced flexion of the hip with the ipsilateral knee in extension during sports participation or slips and falls during activities of daily living [13, 25, 31]. Conservative treatment of proximal hamstring avulsion injuries often results in poor outcome with persistent pain, decreased function, sciatic nerve symptoms, and inability to participate in sports [14, 20, 31]. Therefore, most authors recommend surgical repair of acute and chronic avulsion injuries [1, 3, 6, 8, 12, 13, 20, 24–26, 32].

Despite a growing number of published studies on surgical repair of proximal hamstring avulsions [2, 6–8, 10, 13, 18, 21, 23, 25, 26, 32, 34], only a few anatomical studies of this region have been conducted with conflicting results [4, 28, 33, 36, 37]. Furthermore, no study so far has reported the dimensional characteristics of the proximal tendons and side-to-side differences of footprint and tendon measurements. The purpose of this study was therefore to better define the anatomy of the proximal hamstring origin by precisely defining the gross anatomical and dimensional characteristics of both the proximal hamstring tendons and attachment sites, and to analyse side-to-side differences. More detailed knowledge about the normal anatomy of this region may aid to improve surgical repair techniques by providing references for suture anchor placement, especially for less-invasive surgical approaches such as newly developed endoscopic repair techniques [16, 17, 27]. Furthermore, this information may also improve diagnosis and conservative treatment of proximal hamstring tendinopathy, since detailed knowledge about the normal anatomy is crucial for recognizing tendon abnormalities and for several conservative treatment modalities such as shockwave or ultrasound-guided injections [24].

Materials and methods

The study was designed to be a descriptive anatomic study. Twelve paired whole-lower extremities from six embalmed cadavers were dissected to characterize the proximal origin of the hamstring tendons. The cadavers were donated to the Department of Anatomy of the Ludwig Maximilians University of Munich for dissection practice and were randomly selected.

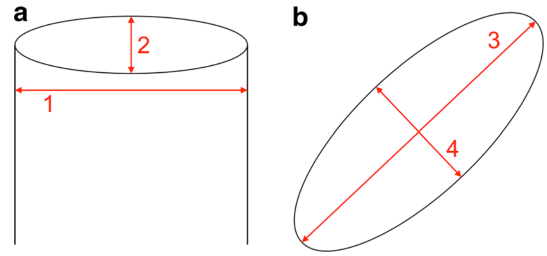

Fig. 1 Measurements of the tendon (**a**) and footprint dimensions (**b**) *1* tendon width, *2* tendon thickness, *3* footprint length, and *4* footprint height. The nomenclature was chosen based on a surgeons point of view with the patient place in the prone position

The mean age of the specimens was 86 ± 7 years. Three of the specimens were male and three were female. None of the specimens had undergone prior surgery in the area of interest nor did they show evidence of proximal hamstring injuries.

The entire skin and subcutaneous tissue was removed. The hamstring muscles were identified distally and marked for later identification. The muscles were followed proximally to expose the hamstring tendons, which were dissected to the level of the bony insertion at the ischium. The gross anatomy of the proximal hamstrings was recorded in each extremity.

All muscles and tendons except the hamstring group were then removed, and the femur was cut at its midportion. The proximal hamstring tendons and the ischium were carefully cleared of all surrounding soft tissue. The width and thickness of the hamstring tendons were measured 1 cm distally to its origin (Fig. 1a). In addition, the distance from the most proximal border of the common origin of the ST/ LB to their distal junction was measured. All measurements were performed by a single observer experienced in proximal hamstring repair using a calliper with an measurement accuracy of 0.1 mm (Mitutoyo, Maplewood, New Jersey, USA).

The hamstring tendons were then dissected free from their respective bony insertion at the ischial tuberosity and the footprint was circumferentially marked with a pen. Finally, the length and height of the delineated footprints were measured (Fig. 1b).

Means and standard deviations were calculated for all measurements. A paired two-tailed *t* test was used to compare the dimensions and side-to-side differences of the SM and ST/ LB complex. The level of significance was set at $p < 0.05$.

Institutional review board approval was not required because the use of cadaveric specimens is exempt at our institution.

Results

In 10 of 12 extremities (five of six cadavers), the anatomy of the proximal hamstring origin was similar, whereas one

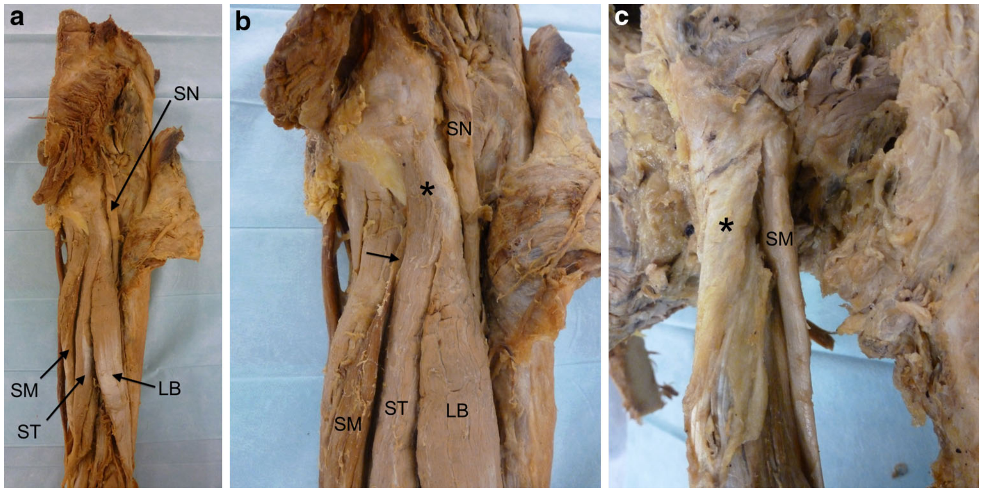

Fig. 2 Representative photographs of the gross anatomic findings before removal of the hamstring muscle group. **a** Poster view of a right lower extremity. **b** Detail view from posterior. **c** Detail view from posterolateral. At the midportion of the limb, the semimembranosus (*SM*), semitendinosus (*ST*), and long head of the biceps femoris (*LB*) can be identified as distinct structures. *ST* and *LB* adjoin each other more proximally (*asterisk*) and attach to the posterolateral aspect of the ischial tuberosity. The SM tendon undercrosses the common tendon of the ST/LB (*arrow*) and attaches to the anterolateral aspect of the ischial tuberosity. *SN* Sciatic nerve

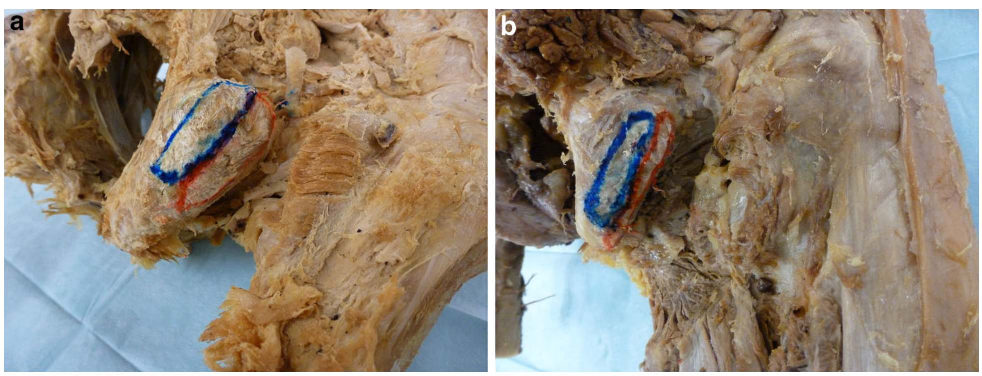

Fig. 3 Representative photographs of the delineated footprints in two extremities. View from posterolateral. *Blue* Common ST/LB complex; *red* SM

cadaver showed a completely different anatomy bilaterally, which has not been described in the literature before. This cadaver was therefore excluded from the study group and the anatomical characteristics of this variant are reported separately below. The following results represent the findings in ten bilateral extremities of five cadavers.

Gross anatomical characteristics

At the midportion of the limb, all three muscles could be identified as distinct structures (Fig. 2a). Further proximally, the ST and long head of the biceps (LB) became a conjoined tendon. The site of origin of the ST/LB complex was the posterolateral aspect of the ischial tuberosity (Fig. 2a, b) with the fibres of the LB running to the superior aspect and the fibres of the ST running to the inferior aspect of the insertion site. The ST mainly consisted of a muscular portion with only a short tendon, whereas the LB had a long tendinous part. The SM undercrossed the ST/LB and attached to the anterolateral aspect of the ischial tuberosity (Fig. 2b, c).

Representative photographs of the delineated footprints are shown in Fig. 3. The SM footprint was located directly anterior to the ST/LB footprint in all extremities. The shape of the SM and ST/LB footprint was longitudinal-oval in all specimens. The longitudinal axes of the SM and ST/LB footprints were parallelly aligned in an inferior-to-superior direction with a slightly anterior tilt.

Dimensional characteristics

The mean distance from the most proximal border of the ST/LB origin to the distal junction was 10.0 ± 1.3 cm (range 8.6–11.7 cm), with a mean side-to-side difference of 0.6 ± 0.5 cm (range 0.0–1.1 cm). The detailed measurements

Table 1 Dimensional characteristics of the proximal hamstring tendons and footprints

	ST/LB	SM	Significance
Tendon			
Width (cm)	3.4 ± 0.5 (2.6–4.1)	4.2 ± 0.9 (3.1–6.2)	$p = 0.009$
Thickness (cm)	1.0 ± 0.3 (0.7–1.5)	0.8 ± 0.2 (0.5–1.0)	n.s.
Footprint			
Length (cm)	3.9 ± 0.4 (3.2–4.7)	4.5 ± 0.5 (3.7–5.3)	$p = 0.002$
Height (cm)	1.4 ± 0.5 (0.9–2.2)	1.2 ± 0.3 (0.8–1.6)	n.s.

Values are shown as mean ± SD (range)

ST/LB common semitendinosus/long head of the biceps complex, *SM* semimembranosus, *mm* millimetre, *n.s.* not significant

Table 2 Side-to-side differences of the dimensional characteristics

	ST/LB	SM	Significance
Tendon			
Width (cm)	0.8 ± 0.5 (0.3–1.5)	0.7 ± 1.3 (0–3.1)	n.s.
Thickness (cm)	0.2 ± 0.2 (0–4.0)	0.2 ± 0.2 (0–0.5)	n.s.
Footprint			
Length (cm)	0.4 ± 0.4 (0–0.9)	0.1 ± 0.1 (0–0.3)	n.s.
Height (cm)	0.2 ± 0.3 (0–0.8)	0.2 ± 0.2 (0.1–0.5)	n.s.

Values are shown as mean ± SD (range)

ST/LB common semitendinosus/long head of the biceps complex, *SM* semimembranosus, *mm* millimetre, *n.s.* not significant

of the tendons and footprints are shown in Table 1. The SM tendon was significantly wider than the common ST/LB tendon. No significant difference for tendon thickness was found. With regard to the footprint dimensions, the SM footprint was significantly longer than the ST/LB footprint, whereas no significant difference was found for footprint height. Overall, the obtained measurements showed considerable inter- and intraspecimen variations, reflected by the observed wide ranges and side-to-side differences (Tables 1, 2).

Anatomic variant

In one cadaver, the SM conjoined the ST/LB near the insertion site, creating a common tendon of all three muscles (Fig. 4a). The main portion of the common tendon attached to the inferolateral aspect of the ischial tuberosity, whereas some superficial fibres of the common tendon complex traversed the ischial tuberosity and attached to its superolateral aspect (Fig. 4b). Overall, the SM part of the common tendon complex could not be distinguished from the ST/LB complex. This anatomic variant was observed bilaterally in this cadaver (Fig. 4c).

Discussion

The main findings of the present study were as follows: (1) With the exception of one specimen, this study confirmed the findings of previous studies that the ST and LB have a common origin from the ischial tuberosity, whereas the SM originates separately [28, 33, 36]. (2) In contrast to the findings of other studies, however, both footprints were located at the lateral aspect of the ischial tuberosity, with the SM footprint located anterior to the ST/LB footprint. (3) Overall, the shape of both footprints was longitudinal-oval, with the longitudinal axes running parallelly in an inferior-to-superior direction. (4) The SM had a significantly wider tendon and a significantly longer footprint than the common ST/LB complex. (5) The footprint size seems to be variable with considerable intra- and inter-specimen differences.

Soft tissue avulsion injuries of the proximal hamstring tendons are becoming more frequently recognized and the available literature supports surgical repair to restore the function of the hamstring muscles [20, 24]. The most commonly used operative technique is open suture anchor repair. Advances in surgical techniques and equipment have also led to the development of endoscopic repair techniques [16, 17, 27]. Regardless of the applied technique, the goal of proximal hamstring repair should be to reattach the avulsed tendon complex to its native footprint in order to restore hamstring muscle function. Therefore, detailed knowledge of the proximal hamstring anatomy is crucial for the surgeon.

There have been varying and conflicting reports on the anatomy of the proximal hamstring origin [1, 4, 5, 12, 22, 28, 30]. Most of these reports are not based on anatomic studies and only reflect expert opinions. Studies on the anatomy of the proximal hamstring tendons are rare [4, 28, 33, 36, 37].

The site of origin of the hamstrings at the ischium has not been described consistently in the available literature. Battermann et al. [4] described 3 different facets of the ischial tuberosity: a small portion of the ST originated from an inferior facet, whereas the main portion originated together with the LB at a medial facet. The origin of the SM was located at a lateral facet. Van der Made et al. [36] divided the ischial tuberosity into an upper and a lower region. The upper region was further divided into a lateral and a medial facet. The lateral facet was the site of origin of the SM and the medial facet of the ST/LB. The origin of the SM was located anterior to the ST/LB origin, with

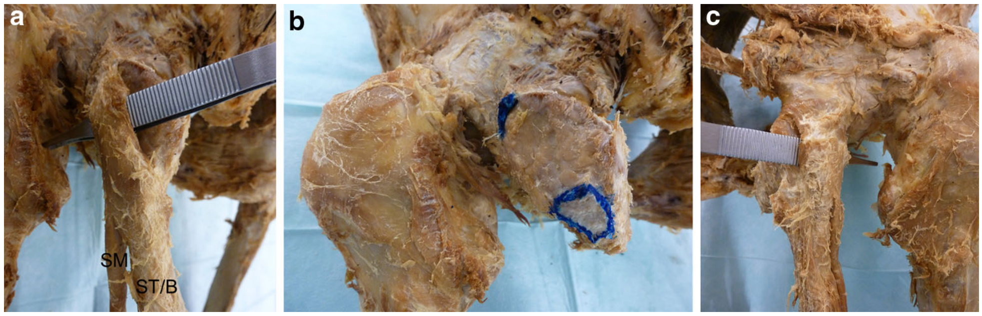

Fig. 4 Anatomic variant. Details are explained in the results section. The forceps is placed underneath the superficial fibres of the common tendon complex, which traversed the ischial tuberosity. The *blue marks* represent the common insertion of all three tendons

Fig. 5 View from posterior after removal of the hamstrings and delineating the footprints. From this view, only the footprint of the common ST/LB complex can be visualized (*blue mark*). The footprint of the SM is located more anteriorly on the lateral facet of the ischial tuberosity

anterolateral positioned variations. Miller et al. [28] found the SM origin located lateral to the origin of the ST/LB. Sato et al. [33] divided the area of the hamstring origin into two parts: the anterolateral part was the origin of the SM and the posteromedial part was the origin of the ST/LB. Since we did not specifically study the bony architecture of the ischium, we cannot confirm or disconfirm the existence of different facets. In our opinion, the varying descriptions are at least partly related to inconsistent definitions of the nomenclature. The site of origin of all three tendons in our study was the lateral aspect of the ischium, which is consistent with photographs provided in other studies [4, 33, 36]. From a surgeons point of view with the patient placed in the prone position, the SM footprint was located anterior to the ST/LB footprint (Fig. 5). The terms anterolateral and posterolateral aspect were therefore used, which were believed to better reflect the surgically relevant nomenclature.

Only two studies have provided detailed measurements of the proximal hamstring origin so far [28, 36]. Miller et al. [28] evaluated the proximal origin of the hamstrings in 14 cadaveric specimens. The mean distance from the most proximal origin site to the separation of the ST/LB was 9.9 ± 1.5 cm, which is comparable to our results (10.0 ± 1.3 cm). The authors described the footprint of the ST/LB as oval, with a mean length of 2.7 ± 0.5 cm and a mean height of 1.8 ± 0.2 cm, while the footprint of the SM was described as crescent shaped, with a mean length of 3.1 ± 0.3 cm and a mean height of 1.1 ± 0.5 cm. These findings are slightly different to ours, since we found both footprints to be longitudinal-oval shaped. Furthermore, the lengths of both footprints in our study were markedly higher, with a mean length of 3.9 ± 0.4 cm for the ST/LB and 4.5 ± 0.5 mm for the SM. Measurements of the footprint heights were comparable in both studies. In a recent study, van der Made et al. [36] studied the hamstring origin dimensions in 56 extremities. The ST/LB origin measured 2.6 ± 0.4 cm medial-to-lateral and 1.8 ± 0.2 anterior-to-posterior. The corresponding values for the SM origin were 1.3 ± 0.3 cm and 1.1 ± 0.5 cm. Remarkably, the SM footprint was considerable smaller ("shorter") compared to our findings and those of Miller et al. [28].

Despite comparable findings in five of the six studied cadavers, one cadaver had a completely different insertional anatomy of the proximal hamstrings. During the dissection process of the first extremity, we thought that the variant anatomy might be the result of an incomplete avulsion injury. However, the proximal tendons did not show any macroscopic signs of injury (e.g. scar tissue, calcification, partial tearing). Since the identical insertional anatomy was also found on the contralateral extremity, we believe that this finding rather represents an anatomic variant. Previously reported variants of the proximal hamstrings have been related to the SM, which has been found to be hypoplastic or absent in some cases [29]. In addition, an accessory SM has been described [9, 35]. However, the variant described in this article has not been reported so far. The prevalence and meaning of this insertional variant remains unknown.

This study has several limitations. Anatomic dissections were performed on embalmed cadavers, and the obtained measurements may vary from those of fresh-frozen specimens. The sample size of the present study is small, which limits the overall validity of our results; however, other anatomic studies had a comparable sample size [28]. The cadavers used were all elderly persons with a high age. Therefore, the obtained measurements may vary from those of younger individuals because of muscle and tendon atrophy as well as tendon degeneration in elder individuals. Future investigations may characterize the anatomy of the proximal hamstring tendons in more and younger specimens. In addition, the anatomical relationship of the proximal hamstring tendons to the sciatic nerve could not be reliable investigation due to the removal of all soft tissue in between both structures and mobilization of the sciatic nerve.

Despite its limitations, the present study may have several implications for clinical practice. The reported gross anatomic findings and dimensions provide useful information, which may facilitate anatomic hamstring repair. In case of isolated avulsion of the ST/LB or SM [25], the course of the tendons has to be respected, with the SM tendon undercrossing the ST/LB. This anatomic relationship between both tendons should be recreated during hamstring repair. In case of an incomplete proximal hamstring tendon avulsion, the insertion site of the avulsed tendon is determined by the yet intact tendon, with the ST/LB footprint lying directly posterior to the SM footprint and vice versa. Since the footprints of both tendons are located at the lateral aspect of the ischial tuberosity, the skin incision has to be placed far enough laterally to allow anchor placement in an appropriate angle. The same is true for portal placement during endoscopic repair techniques. However, the course of the posterior femoral cutaneous nerve must be respected, which runs distally in the midline of the posterior thigh. The provided data about footprint dimensions may assist surgeons in choosing the number of required suture anchors. With regard to the footprint measurements of the present study (ST/LB 39 × 14 mm; SM 42 × 8 mm), we propose to use a minimum of two suture anchors for each tendon/tendon pair in order to reconstruct an appropriate tendon footprint area. For wider tendon dimensions, three suture anchors might be even more adequate for optimal coverage of the native footprint. The findings of the present study may also improve diagnosis and conservative treatment of proximal hamstring tendinopathy. Detailed knowledge about the normal anatomy is crucial in recognizing tendon abnormalities on magnetic resonance imaging as well as ultrasonography. The herein provided detailed description of the normal course and dimensional characteristics of the proximal hamstring tendons may help physicians in differentiating normal from pathologic findings. Furthermore, the presented data may also improve conservative treatment modalities such as shockwave application, ultrasound-guided corticosteroid injection, and platelet-rich plasma injections, which all require knowledge about the detailed anatomy.

Conclusion

This study adds to current knowledge on the gross anatomical and dimensional characteristics of the proximal hamstring origin. The ST and LB have a common origin, whereas the SM originates separately. The site of origin of both tendons is the lateral aspect of the ischial tuberosity, with the SM footprint lying directly anterior to the footprint of the ST/LB complex. The footprint shapes were longitudinal-oval and the mean dimension was 3.9 × 1.4 mcm for the ST/LB complex and 4.2 × 0.8 cm for the SM. Attention has to be given to potential anatomic variants.

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