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HIP

A qualitative and quantitative analysis of the attachment sites of the proximal hamstrings

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Abstract
Purpose Proximal hamstring tears represent a challenge. Surgical repair of such tears has been reported utilizing both open and endoscopic techniques. It was hypothesized that the proximal attachments of the hamstring muscle group could be reproducibly and consistently measured from pertinent bony anatomical reference landmarks.
Methods Fourteen fresh-frozen, human cadaveric specimens were dissected, and measurements were taken regarding the proximal attachments of the hamstring muscle group in reference to bony landmarks. A highly precise coordinate measuring device was used for three-dimensional measurements of tendon footprints and bony landmarks, and relevant distances between structures were calculated.
Results The semitendinosus and long head of the biceps femoris shared a proximal origin (conjoined tendon), having an oval footprint with an average area of 567.0 mm^2 [95 % CI 481.0–652.9]. The semimembranosus (SM) footprint was crescent-shaped and located anterolateral to the conjoined tendon, with an average area of 412.4 mm^2 [95 % CI 371.0–453.8]. The SM footprint had an accessory tendinous extension that extended anteromedially forming a distinct footprint. A consistent bony landmark was found at the medial ischial margin, 14.6 mm [95 % CI 12.7–16.5] from the centre of the conjoined tendon footprint, which coincided with the distal insertion of the sacrotuberous ligament.
Conclusion The conjoined tendon was the largest attachment of the proximal hamstring group. Two other distinct attachment footprints were identified as the SM footprint and the accessory tendinous extension. The sacrotuberous ligament insertion served as a bony landmark. The anatomical data established in this study may aid in better restoring the anatomy during repair of proximal hamstring tears.

Keywords Proximal hamstring · Anatomy · Anatomical landmarks · Endoscopy · Hip arthroscopy

Introduction

Hamstring injuries are among the most common muscle injuries seen in sports [1, 2, 18, 20, 29, 41]. Injury most commonly occurs during eccentric muscle contraction due to the muscles' potential for rapid and extreme lengthening [29, 47]. Hamstring injuries are 2.5 times more common than quadriceps injuries and account for 17 % of all injuries in the Union of European Football Associations soccer players and up to 50 % of strain injuries in sprinters [13, 14, 27, 28, 46].

Previous literature has determined that the biceps femoris (BF), specifically its long head, is the most frequently injured of the hamstring muscles [8, 21, 40, 42, 46]. However, these studies grouped hamstring muscle injuries as a whole and did not explicitly address proximal injuries. De Smet et al. [24] in their detailed report differentiated proximal tendon injuries from

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intramuscular tears and demonstrated that the BF was the most commonly injured muscle in each category. Interestingly, there was no mention of associated semitendinosus (ST) injury, given that both muscles share a common tendinous origin. These findings are confirmed in a study by Kouloris et al. [34] although, once again there is no mention about the presence of combined proximal lesions. Notably, there is conflicting information in the literature regarding which is the second most commonly injured proximal muscle [10, 11, 16, 23]. It is possible that this inconsistent information is a result of an incomplete knowledge of the anatomy of the proximal hamstring attachment. This assertion is supported by Batterman et al. [8] who reported that the pennation angle at which the ST inserts into the common tendon makes this muscle especially vulnerable to strains.

A system for the classification of proximal hamstring avulsions has been devised by Wood et al. [45]. This system describes five types of avulsions, which can be identified on the basis of the anatomical location of the injury, the degree of avulsion (incomplete or complete), the degree of muscle retraction (if avulsion is complete), and the presence or absence of sciatic nerve tethering. Bierry et al. [12] and Miller et al. [39] have outlined the radiologic and surgical anatomy of the proximal hamstring attachment and its relationships to surrounding structures. Despite these descriptions, the location of the origin of these tendons is commonly misrepresented in illustrations, which perhaps contributes to the confusion surrounding which specific tendons are injured [19, 43].

Several studies have been published reporting the use of open surgical techniques to repair the complete proximal hamstring avulsion [7, 17, 20, 30, 32, 33, 35, 38]. Recently, it has been postulated that endoscopic repair of proximal hamstring injuries may represent a safe, reliable, and less invasive alternative to open surgery [25, 26].

The purpose of this study was to precisely define the footprints of the proximal hamstring origin and identify clinically and surgical relevant landmarks. It was anticipated that this information would not only assist in endoscopic navigation, but would also refine the specific imaging diagnosis of which tendon is injured in a proximal hamstring disruption and thus aid in planning a more anatomical repair.

Materials and methods

Specimens and anatomical dissection

Dissections were performed on 14 non-paired, fresh-frozen human cadaveric hemi-pelvises (median age 59 years, range 47–65; 12 males and 2 females; 8 left and 6 right hips) with no evidence of prior injury, degenerative change, or femoroacetabular impingement (FAI). Standard anatomical nomenclature was used with the hip described in the prone position. The gluteus maximus was reflected medially from its insertion on the femur to expose the deeper muscles. The semimembranosus (SM), ST, and long head of the BF muscles were followed proximally to delineate the conjoined tendon of the long head of the BF and the ST. The SM tendon, anterolateral to the conjoined tendon, was identified in addition to its accessory tendinous attachment. The angle between the taut accessory tendinous attachment and the extended main SM tendon was measured with a goniometer with 1° increments. A qualitative assessment of each hamstring muscle and the relationship to the surrounding structures was made in a systematic manner.

The superior and inferior gemelli, quadratus femoris, obturator externus and internus were dissected away so as to allow access for an osteotomy of the ischium. The sacrotuberous ligament was incised at its mid-point, and an osteotomy was performed starting at the lesser sciatic notch extending to the inferior pubic ramus. The origin of the proximal hamstrings and adductor magnus muscles was preserved on the ischium. The ischium was rigidly mounted in a clamp for measurement. The tendinous origin of each muscle was removed sequentially. The border of the footprint of each hamstring tendon was marked with a stylus using india ink. In addition, the footprint of the accessory attachment of the SM was marked, along with the direct muscular insertion of the ST. The footprints were immediately measured with a coordinate measuring device by measuring along the border of the india ink outline.

Data collection

A coordinate measuring device (MicroScribe MX, GoMeasure3D, Amherst, VA) with a previously determined accuracy of 0.113 mm was used for manual collection of anatomical locations with a needle-point stylus tip [31]. The same individual performed data collection for all specimens using a fixed number of points spaced approximately 1–2 mm apart for circumferential footprint measurements along the border of the muscular footprints. Points on the ischium were collected to determine a relevant coordinate system describing the anatomical superior–inferior and medial–lateral directions. The most superior point of the footprint of the conjoined tendon and the most distal point on the ischial tuberosity were used to define the superior–inferior axis. The medial–lateral axis was identified as a line extending from the medial bony prominence of the ischium, corresponding to the distal attachment of the sacrotuberous ligament, to the lateral-most bony margin of the ischial tuberosity.

Statistical analysis

The footprint area of each muscular insertion was calculated using Heron's formula with the average footprint centre used as the primary reference point for each insertion. Area and distance measurements are reported as averages with the 95 % confidence interval; for distance measurements, the primary direction was reported for each three-dimensional distance.

Results

Individual soft tissue and osseous structures of the proximal hamstring insertion are described below. For each subsection, a qualitative description of the specific structure is provided followed by quantitative measurements.

Relevant bony landmarks

A bony prominence was identified on the medial aspect of the ischium, which marked the location of the distal attachment of the sacrotuberous ligament. The prominence was palpable and the fibres of the sacrotuberous ligament were visible. This bony landmark marked the most medial border of the footprint of the conjoined tendon of the long head of the biceps and the ST. The distance from this bony prominence to the centre of the SM and conjoined tendon footprints was 23.1 mm [95 % CI 20.7, 25.6] and 14.6 mm [95 % CI 12.7, 16.5], respectively. The most distal point of the ischial tuberosity was completely covered by the tendons and was not palpable, so it did not provide a useful landmark. The most proximal footprint point was continuous with the inferior gemellus muscle and therefore was not recommended as a landmark for surgical navigation.

Semimembranosus

The SM tendon originated on the lateral aspect of the ischium, anterolaterally to the footprint of the conjoined tendon of the long head of the BF and ST. From its origin, it coursed medially, anterior to the conjoined tendon, to follow a path on the medial aspect of the posterior thigh (Figs. 1, 2). The quadratus femoris muscle origin was immediately anterior (deep) to the anterior margin of the SM footprint. The inferior border of the inferior gemellus crossed the superior margin of the SM footprint.

An accessory tendinous extension of the SM was noted in every specimen. The angle of approximately 105° was created between the main tendon of the SM and the accessory tendinous extension (Fig. 3). The accessory tendon inserted on the inferior surface of the ischium and was intimately related to the muscle fibres of the adductor magnus. A distinctive footprint for the accessory tendon was present in all specimens.

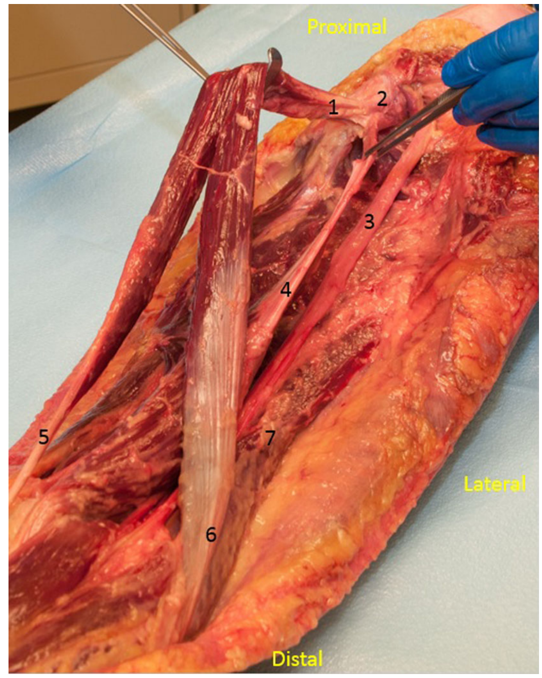

Fig. 1 Right side, posterolateral panoramic view: this shows how the SM tendon has the most lateral footprint and then crosses deep to the biceps to insert in the medial tibia. *1* Conjoined tendon, *2* ischial tuberosity, *3* sciatic nerve, *4* SM, *5* ST, *6* BF distal tendon, *7* BF short head

The footprint of the SM represented 42.6 % [95 % CI 39.2, 46.0] of the area of the proximal hamstring footprint on the ischium. The accessory tendon footprint was inferior to the most inferior margin of the SM footprint (Fig. 3); the shortest distance between these structures was 9.3 mm [95 % CI 6.8, 11.8]. The footprint morphology and dimensions are listed in Tables 1 and 2.

The conjoined tendon of the biceps femoris and semitendinosus

The conjoined tendon consisted of the long head of the BF tendon, laterally, and the ST tendon medially (Figs. 1, 2). The division of the long head of the BF and the ST was clearly visible distal to the origin. The long head of BF coursed parallel to the SM tendon and was identifiable as a distinct tendinous structure. The tendon fibres at the conjoined tendon footprint were intimately related and confluent with the distal attachment of the sacrotuberous ligament (Fig. 4). The ST, on the other hand, originated as a short tendon with an abundance of muscle fibres proximally. The muscle bellies separated approximately 9.5 cm from the proximal origin. Additionally, the ST had a distinctive muscular attachment, medial to its tendinous

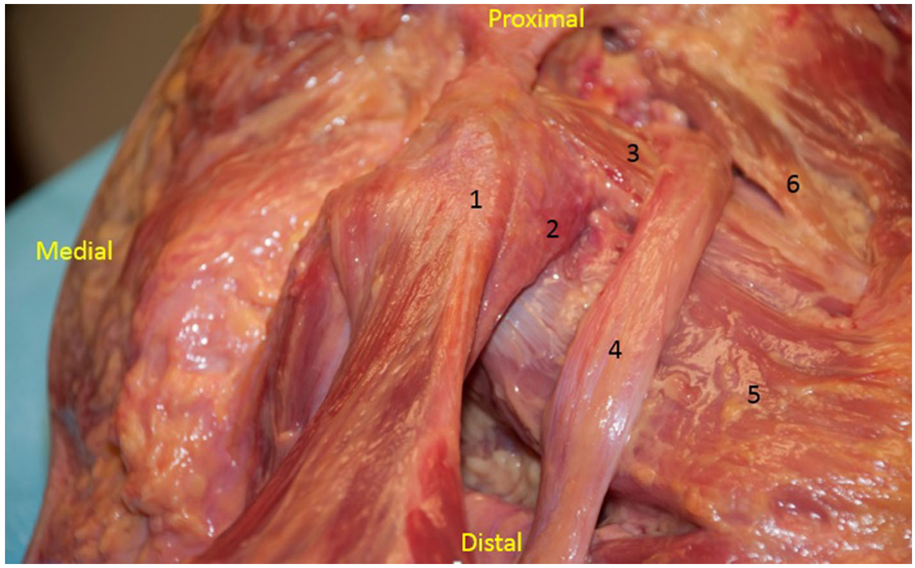

Fig. 2 A close-in posterior view of the right side. The conjoined tendon lies medial and posterior to the SM tendon. *1* Conjoined tendon, *2* SM tendon, *3* inferior gemellus, *4* sciatic nerve, *5* quadratus femoris, *6* piriformis

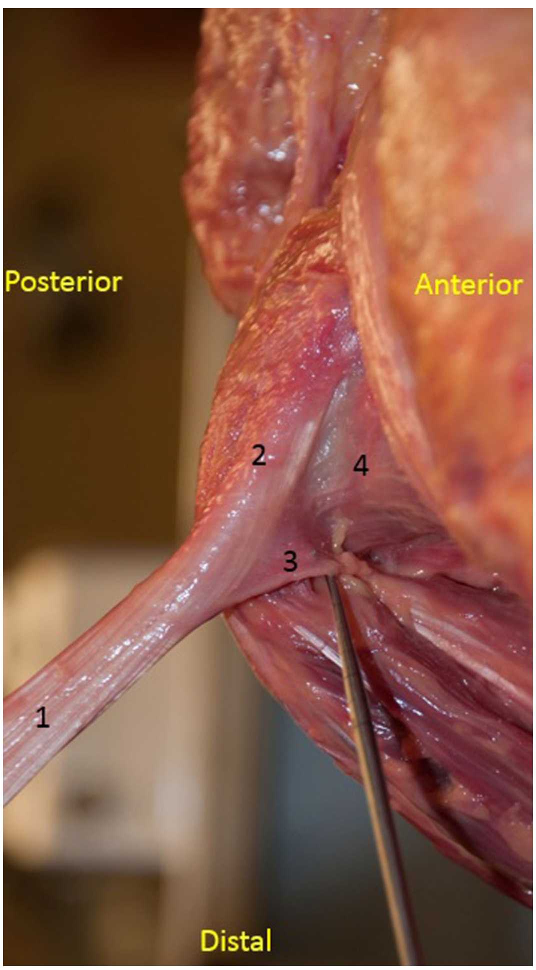

Fig. 3 Right side, lateral view. SM origin demonstrating the presence of the accessory tendinous extension. *1* SM tendon, *2* SM main footprint, *3* tendinous extension, *4* quadratus femoris

Table 1 Surface areas and morphology of the proximal hamstring footprints

Structure	Mean [95 % CI] footprint area (mm^2)	Shape
SM	412.4 [371.0,453.8]	Crescent
Tendinous extension of SM	11.8 [10.2,13.4]	Rectangular
Conjoined tendon	567.0 [481.0,652.9]	Ovoid
Muscular attachment ST	194.7 [154.3,235.0]	Triangular

Table 2 Footprint linear dimensions

Footprint	Mean [95 % CI] superior-inferior length (mm)	Mean [95 % CI] medial-lateral width (mm)
SM	32.6 [30.6, 34.6]	14.8 [12.8, 16.7]
Conjoined	36.2 [33.4, 39.1]	20.8 [17.3, 24.3]

attachment, which extended anteriorly and medially along the inferior aspect of the ischial tuberosity (Fig. 5). The medial aspect of the conjoined tendon footprint was marked by the presence of a medial bony prominence, which corresponded to the distal attachment of the sacrotuberous ligament. This point also represented the termination of the lesser sciatic notch. The origin of the inferior gemellus was closely related to the superolateral margin of the conjoined footprint.

The footprint of the conjoined tendon represented 57.4 % [95 % CI 54.0, 60.8] of the total proximal hamstring footprint. The morphologies and dimensions of the conjoined tendon and ST tendon are found in Tables 1 and 2.

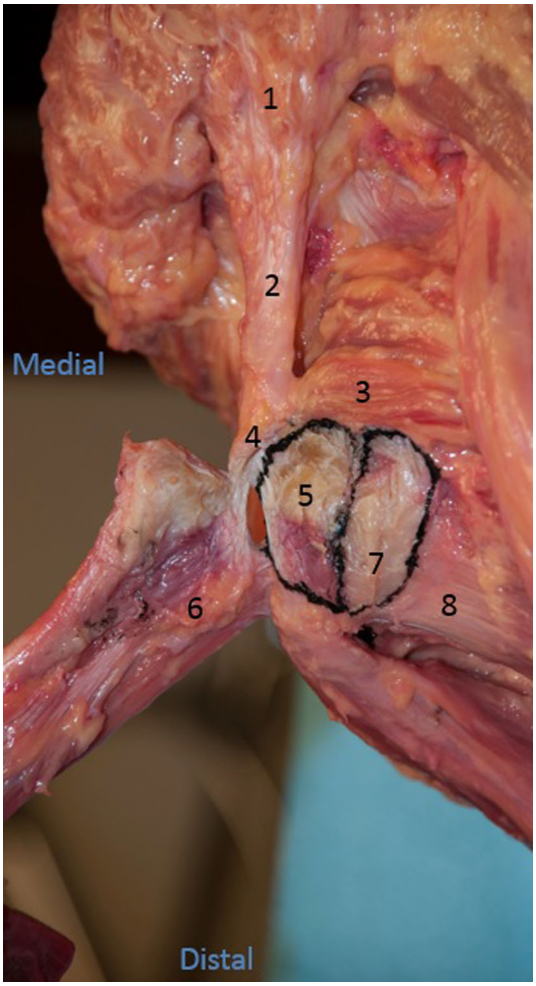

Fig. 4 Right side, posterolateral view. The footprints of SM and the conjoined tendon. The conjoined footprint is closely related to the sacrotuberous ligament at its superomedial border. *1* Sacrum, *2* sacrotuberous ligament, *3* inferior gemellus, *4* medial bony prominence, *5* conjoined footprint, *6* conjoined tendon (reflected), *7* SM footprint, *8* quadratus femoris

Discussion

The most important finding of this study was that it provided a comprehensive qualitative and quantitative anatomical analysis of the proximal hamstring insertions. Specifically, the relationship of the medial border of the conjoined tendon footprint with the medial bony prominence at the ischium, which represents the attachment of the sacrotuberous ligament, was identified. In addition, an accessory tendon contributing to the origin of the SM tendon was identified. To our knowledge, this is the first time this accessory tendon has been described. It is anticipated that data presented in this study will enhance the current knowledge on the anatomy of the proximal hamstrings and provide useful endoscopic landmarks and references to assist in endoscopic navigation and a subsequently more anatomical repairs.

As the diagnosis and treatment of proximal hamstring injuries increase, precise knowledge of the proximal hamstring anatomy is essential. Surgical exposure and visualization in this region, whether open or endoscopic, is frequently limited, which increases the importance of referencing precise osseous landmarks. When endoscopic surgery is carried out, identification of the injured structure attachments can be impaired by the presence of a large haematoma, scar tissue, the ischial bursa, and a variable and unpredictable amount of remnant tendinous tissue. Therefore, soft tissue reference points may be unreliable. Unless there is an avulsion fracture, an osseous landmark will be at a predictable location and can aid in surgical navigation.

The identification of relevant landmarks is extremely useful not only for navigation but also for interpretation of surgical findings, such as reaching an accurate diagnosis about which tendon or tendons are damaged and deciding

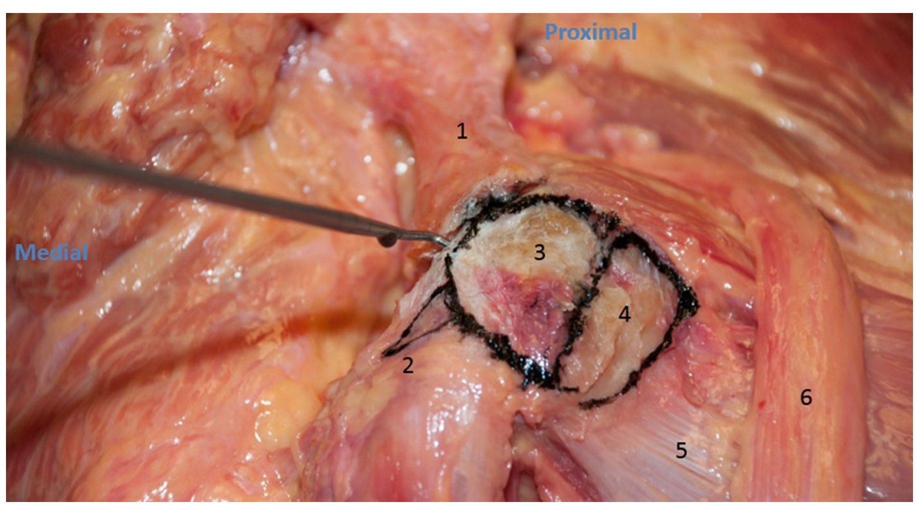

Fig. 5 Right side, posterior view. The probe marks the medial ischial prominence, which is the medial border of the conjoined tendon footprint and the distal insertion site of the sacrotuberous ligament. The triangular footprint of the ST direct muscular attachment lies inferior to this point. *1* Sacrotuberous ligament, *2* ST direct muscular attachment, *3* conjoined footprint, *4* SM footprint, *5* quadratus femoris, *6* sciatic nerve

the number and location of suture anchors for restoration of the footprint. Also, one should be able to correlate the surgical findings with preoperative magnetic resonance imaging scan or ultrasound which Bedi et al. [9] used to evaluate the proximal hamstring function after graft harvest.

The findings of this study clearly describe the footprint of the SM tendon, which is crescent-shaped and located lateral and anterior to the ovoid-shaped conjoined tendon. A key distinguishing feature to differentiate between the two tendons, aside from their location, is the presence of an accessory tendon contributing to the SM. This accessory tendon formed an angle of approximately 105° with the main SM tendon. It is hypothesized that this structure acts to dissipate the force in the main tendon, which may contribute to its pull out strength and perhaps explain why the SM is often reported as the least frequently injured hamstring muscle [24, 36, 38, 46].

Recently, Askling et al. have reported that for proximal hamstring injuries, isolated proximal SM tendon injuries often require a more prolonged recovery time than proximal BF injuries and may even jeopardize an athlete's career [4–6, 15, 22, 37]. It has been postulated that this difference in recovery time might reflect a better overall healing capacity of the BF tendon compared to the SM tendon. However, it may now alternately be explained by load redistribution to the accessory tendon when a partial tear of the main tendon is present. This would alter the angle of pull, thereby elevating the proximal portion of the main tendon and preventing the requisite contact for healing. Moreover, this alternate theory may account for the successful treatment of partial SM tears with a tenotomy followed by suturing the cut tendon to the biceps femoris, thereby eliminating the counter pull exerted by the accessory tendon [37].

Previous studies have provided descriptions of this regional anatomy. However, to the authors' knowledge, this is the first study to provide a comprehensive description of bony footprints with reference to anatomical landmarks for endoscopic navigation. Batterman et al. [8] published an anatomical study of the same region, based upon dissection of embalmed cadavers. The descriptions provided relate to the angle of pennation of the various muscle groups, which are interpreted as possible predisposing factors for muscle strains. Although useful in its findings, this work provided no quantitative measurements of the tendons' footprints. Sato et al. have also contributed to the knowledge in this area. In their study, again using embalmed cadavers, they commented on the common origin of the long head of BF and ST. The findings of our study corroborate this description and also describe a reproducible palpable bony prominence as a landmark where the conjoined tendon meets the sacrotuberous ligament. Notably, Sato et al. [44] also recognized that the medial aspect of the ST has a direct muscular insertion on the ischium. Finally, Miller et al. [39] have provided the most comprehensive report of the proximal hamstring anatomy to date. The focus of their study was to report specific measurements such as tendon lengths and the distance to inferior gluteal and sciatic nerves to assist in the surgical technique. The footprints' shapes were simplified and depicted as roughly oval, with a crescent-shaped SM footprint and an ovoid conjoined tendon origin. The findings of this present study similarly describe the overall shape of the footprint. This study adds to this knowledge by providing further information on the additional elements noted in association with the footprints, such as relations to a bony landmark and the relations to the surrounding musculature (quadratus femoris, inferior gemellus, and adductor magnus).

It is acknowledged that there are limitations to this study. Only 14 fresh-frozen cadaveric specimens were used, which may not account for all anatomical variation in the general population. However, previously published anatomical studies using fresh-frozen specimens utilize similar specimen numbers [3, 31]. The median age of the specimens was 59 years. Due to age-related muscle atrophy, our findings may not be representative of the younger athletic population, which often requires treatment for proximal hamstring tears.

Conclusion

The correct identification of the proximal hamstring tendons might be complicated by the fact that the SM has the most lateral footprint, while it crosses anterior (deep) to the conjoined tendon to insert on the medial tibia. The footprint of the conjoined tendon is the largest and represented the origin of two muscles, the long head of the BF and ST. The medial bony prominence of the ischium delineated the medial margin of the footprint attachment. The SM originated anterolateral to the conjoint tendon footprint and was augmented by the presence of an accessory tendon.

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