Anatomy of the hamstrings

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Chapter title:

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Abstract

This chapter will provide the anatomical foundation for the content to come in later portions of this book. It will begin with an overview of the proximal insertion sites of the muscles that comprise the hamstring group. The proximal tendons and musculotendinous junctions (MTJs) of semimembranosus, semitendinosus and the long and short heads of biceps femoris long head will then be described, highlighting the differences in structure between each of the muscles. The distinct architectural characteristics of each muscle belly (e.g. size, fascicle orientations within and between muscles) will be outlined, followed by the structure of the distal tendons and MTJs. Finally, a summary is provided of the neurovascular supply of the hamstrings.

Introduction

The posterior muscles of the thigh, semimembranosus (SM), semitendinosus (ST) and biceps femoris (BF) long head (BFlh) and short head (BFsh) are referred to as the 'hamstrings' (Figure 1). The long hamstring muscle group (SM, ST, BFlh) crosses both the hip and knee joints, therefore resulting in hip extension, knee flexion and internal (SM & ST) or external knee rotation (BF); during concentric contraction.

The anatomy of the hamstrings is unique and consistently suggested to be one of the reasons for the high incidence of injuries in this muscle group. The biarticular nature of the long hamstrings [1], the dual innervation of the biceps femoris [2] and the shortness of its fascicles [3] are some factors which have been proposed as reasons why hamstring anatomy influences injury risk. In addition, the intramuscular tendon within biceps femoris is an anatomical feature that is suggested to add an extra layer of complexity when considering rehabilitation approaches [4].

This chapter will outline the anatomy of the hamstrings including their proximal insertion sites and musculotendinous junctions (MTJs), muscle architecture, distal MTJs and insertions and neurovascular supply. Whilst describing the key structural features of the hamstrings, anatomical variations will also be highlighted.

INSERT FIGURE 1A AND 1B HERE

Proximal insertions

Semimembranosus

The proximal insertion of SM is commonly described as the lateral facet or aspect of the ischial tuberosity [5-13], positioned lateral and anterior to the origin of the conjoined tendon of BFlh and ST [9, 12] and posterior (superficial) to the origin of the quadratus femoris muscle [9, 10] (Figure 2 and 3). It is generally accepted that the SM origin is separate to that of the conjoined tendon; however, there is some suggestion that the most proximal part of the SM tendon blends with the conjoined tendon of BFlh and ST [12, 14, 15] or has connections with the BFlh [5-7], separating approximately 3-5 cm from the ischial tuberosity [12, 16]. A common tendon comprised of all three muscles has also been observed as an anatomical variant [17].

In addition to its main proximal tendon, SM has an additional tendinous component that arises from the inferior surface of the ischium and is intimately associated with adductor magnus [7, 9, 10, 15]. This "accessory tendon" has a rectangular-shaped footprint with a mean area of 1.2 cm^2 (95% CI 1.0 to 1.3 cm^2) and forms an angle of approximately 105° with the main proximal tendon [9]. It is hypothesised that this tendinous structure acts to dissipate the force from the main SM tendon, providing a possible reason why SM is not injured as frequently as BFlh and ST [9].

INSERT FIGURE 2A AND 2B, AND FIGURE 3 HERE

The footprint of SM is crescent-shaped [8, 9] or "longitudinal-oval" [17] (Figure 2) with a mean surface area of 41.2 cm^2 [9]. With regard to linear footprint dimensions, nomenclature is variable, but the mean proximal-distal length ranges between 3.1 – 4.5 cm compared to anterior-posterior and medial-lateral dimensions of approximately 1 cm [8, 9, 12, 17] (Table 1).

INSERT TABLE 1 HERE

Semitendinosus and biceps femoris long head

The proximal tendons of the BFlh and ST form a common "conjoined tendon" which originates from the medial facet or posteromedial aspect of the ischial tuberosity (Figures 3, 4 and 5) [5, 10, 11, 13]. The thick, round tendon of BFlh occupies the lateral part of the medial facet [5, 9, 13] and has some connections with the sacrotuberous ligament [7, 9, 10, 15, 18-20]. From a phylogenetic perspective it is suggested that the sacrotuberous ligament represents the upper, degenerated remnant of the BFlh tendon [7], yet the morphological relationship between these two structures is not well defined. In addition to its insertion into the ischial tuberosity, the lateral superficial fibres of the sacrotuberous ligament [19] appear to be confluent with the superficial fibres of the BFlh tendon [10, 19] (Figure 3), but not necessarily in all individuals [19, 20]. Functionally, these connections are thought to be critical when considering transfer of forces across the sacroiliac joint [19, 20], with the sacrotuberous ligament also potentially providing an additional soft tissue anchor for the conjoined tendon that may serve to limit tendon retraction following a hamstring rupture [18].

INSERT FIGURES 4 AND 5 HERE

The origin of ST is positioned medial to that of BFlh and is predominantly muscular [5, 9, 13], occupying a mean area of 19.5 cm^2 (95% CI 15.4 to 23.5 cm^2) on the ischial tuberosity [9] (Figures 3 and 4). Fascicles (a bundle of muscle fibres) of ST also originate from the medial border of the conjoined tendon (which gives rise to the largest proportion of fascicles) and from a short proximal aponeurosis on the anterior aspect of the muscle, which appears to be a medial extension of the BFlh tendon [5, 9, 10, 13, 21, 22].

The conjoined tendon accounts for 57.4% (95% CI 54.0 to 60.8) of the total proximal hamstring footprint [9]. It is oval in shape (Figure 2) with a mean proximal-distal length of between 2.7 ± 0.5 cm and 3.9 ± 0.4 cm. Measures of its anterior-posterior and medial-lateral footprint dimensions are highly variable (Table 1) [8, 9, 12, 17].

A rectangular-shaped retinaculum-like structure, devoid of fibrocartilage, (5.6 ± 0.45 cm long, 4.1 ± 0.16 cm wide and 925 ± 13 µm thick), covering the insertion of the sacrotuberous ligament and origins of the proximal hamstring tendons has been recently described [23]. Composed of transversely oriented fibres, this retinaculum is anchored directly to the medial and lateral aspects of the ischial tuberosity, with its deep fibres strongly adhered to the BFlh epitenon, but separated from the epimysium of ST by loose connective tissue. An additional fascial expansion from the anterior epimysium of gluteus maximus attaches to the superior and superficial aspect of retinaculum. Based on its morphology, it is suggested that functionally this retinaculum anchors the BFlh tendon, rather than enabling longitudinal sliding, and also potentially facilitates the transmission of forces between gluteus maximus and BFlh during muscle contraction.

Biceps femoris short head

The BFsh originates below the distal insertion site of gluteus maximus, commencing approximately 15 cm distal to the ischial tuberosity [13] (Figure 1). Fascicles arise from three distinct locations: (i) the length of the linea aspera [6, 13, 15], between adductor magnus and vastus lateralis [15]; (ii) the upper two-thirds of the lateral supracondylar line [6, 13, 15] to within 5 cm of the lateral femoral condyle [15]; and (iii) the lateral intermuscular septum [6, 13, 15], specifically the distal three-quarters of its posterior aspect [24]. Muscle fascicles inserting into these sites span a mean length of 15.7 cm (range 14.5-17.8 cm) [13].

Proximal tendons and musculotendinous junctions

The tendons of the hamstring muscles can be considered as two distinct components: (1) the 'free' tendon which is devoid of any inserting muscle fascicles and (2) the musculotendinous junction (MTJ), which is the portion of the tendon into which muscle fascicles insert (Figure 6).

Most data on proximal hamstring tendon morphometry are derived from dissection-based research, and although there is some consistency between studies, it should be noted that these parameters are often highly variable between individuals. These differences in size and the amount of free or intramuscular tendon has been hypothesized to influence the susceptibility of a muscle to injury (Figure 2) [10, 25, 26] (Table 2). Little data are available on the three-dimensional morphometry of the MTJs, including their intramuscular portions.

INSERT FIGURE 6 HERE

Semimembranosus

From its origin, the tendon of SM passes medially, lying deep to the conjoined tendon of BFlh and ST as it courses distally. Immediately distal to the ischial tuberosity, the tendon rotates approximately 90° [11, 12], to be oriented in the coronal plane [11]. It then widens becoming broad and aponeurotic

(Figure 5), with a rounded lateral border flattening into a thin membranous projection medially (resembling a "comma-shape" in cross-section) [11, 13].

The proximal tendon of SM is the longest of all of the hamstring muscles, measuring approximately 32 cm and occupying about 75% of the total muscle length [11, 13, 16]. The lateral portion of the tendon extends furthest distally [13] to a point distal to the centre of the muscle belly [6]. The most proximal muscle fascicles of the SM arise from the medial border of the proximal tendon [11] about mid-thigh level [15], distinctly lower than BFlh and ST. As such, the tendon has a substantial intramuscular tendinous component (Figure 6A), with the proximal MTJ accounting for two-thirds of total tendon length (approximately 20 cm, or 48% of total muscle length) [11, 13]. Stretch-induced injury to the SM often involves the proximal free tendon [27, 28], and it could be that the length of this tendon (approximately 11 cm [11, 13]), together with its convoluted course into the muscle belly, predisposes to this type of injury.

Semitendinosus and biceps femoris long head

Immediately distal to the ischial tuberosity the conjoined tendon is round or cresenteric in shape [5, 7, 11, 13], with a cross-sectional area smaller than that of SM (46.8mm^2 compared to 86.2mm^2) [11]. As it passes distally some muscle fascicles of ST muscle arise from its medial, concave border and further distally, BFlh fibres originate from its lateral surface (Figure 5) [7, 10, 13, 29]. The BFlh and ST separate approximately 9-10 cm distal to their origin at the IT [8, 9, 17]. The tendon of BFlh then becomes intramuscular [11] (Figure 6B) forming a small, cord-like tendon with a flat aponeurotic expansion visible on the medial surface of the muscle [5, 6, 13]. The proximal tendon of BFlh is expansive, being smaller than that of SM but larger than ST – it measures approximately 25 cm in length, occupying 60% of the muscle length. Its proximal free tendon is reasonably short (5-6 cm) with a long muscle-tendon component of about 20 cm (extending approximately 45% of the total muscle length). The structure of the proximal BFlh, with the majority of it being composed of tendon, has been proposed to contribute to the greater amount of strain in surrounding muscle during sprinting and as such a purported increases in risk of hamstring injury [26]. Furthermore, disparity in the area of the proximal aponeurosis of BFlh (mean 7.5-33.5 cm^2) is attributed to the variation reported in the length of its proximal aponeurosis (MTJ) [30], which is potentially an important morphological finding as it is suggested that a small [30] or relatively narrow [31] aponeurosis may be a risk factor for injury.

As noted earlier ST has three sites of origin, two from the ischial tuberosity and one common with the proximal tendon of BFlh. This complexity may make the proximal tendon difficult to define, yet measurements are relatively consistent with a mean length of about 12 cm (30% of total muscle length). The free tendinous component is very small (1-2 cm), and ST has the shortest proximal MTJ (formed along the aponeurosis on the anterior aspect of the muscle and the conjoined tendon) of approximately 11-12 cm (occupying 28% of total muscle length) [11, 13, 32].

INSERT TABLE 2 HERE

Biceps femoris short head

Proximally the BFsh originates from the lateral femur with a small amount of tendinous tissue attaching the muscle to the bone. However, none of this tissue runs intramuscularly in the proximal region of the muscle. Therefore, as the fascicles of BFsh arise directly from their proximal insertion sites into this small amount of tendinous tissue, the MTJ is minimal and made up of each individual junction between fascicle and proximal tendon.

Architectural characteristics of the hamstrings

Muscle architecture consists of a range of characteristics that influence how muscles function. These characteristics effect a muscles maximal force output [33], shortening velocity [33] and its susceptibility to injury [3]. The architectural characteristics of muscle consist of two main categories: a) muscle size and b) fibre orientation and length.

Muscle size measures

The muscle size related components of architecture consist of cross-sectional area (CSA) which can be further delineated into anatomical CSA (ASCA) or the physiological CSA (PCSA). These two measures of muscle size are typically taken at a point specific location along the muscle and consider the area of contractile tissue at that site. Whereas the product of a muscles ACSA across its entire length is referred to as muscle volume [34]. The differences between ASCA and PSCA are highlighted below:

ASCA

The ASCA of a muscle is the area of the tissue which can be measured perpendicular to its longitudinal axis, typically expressed in centimetres squared (cm^2) [34].

PCSA

The PCSA is determined from a slice taken perpendicular to the longitudinal axis of the fibres (as opposed to the longitudinal axis for ASCA). As there are differing structural arrangements of muscle fibres (e.g. strap, fusiform, pennate etc), a measure of PCSA is representative of the fibres relative to their orientation within the muscle, which is neglected when using an ASCA measure. It is important to understand this distinction as the force a muscle can produce is relative to its PCSA which is influenced by its pennation angle as well as its CSA [35, 36].

Volume

The volume of a muscle is the circumferential, external area of the tissue which can be measured and is typically expressed as centimetres cubed (cm^3).

Fascicle orientation and length measures

Muscle architectural type is defined by the orientation of the fibres relative to the force-generating axis of the muscle. These different structural arrangements have implications for force-generating capacities (via its PCSA) as well as the shortening velocity of a muscle. The main variable which impacts these structural arrangements is pennation angle. This is the angle at which the fibres (or a bundle of fibres, called fascicles) attach to the tendon aponeuroses. With parallel structured muscles, the fascicles run from origin to insertion therefore resulting in muscle length equalling fascicle length, with small, if any, pennation. Comparably obliquely structured (e.g. unipennate, bipennate) muscles have the fibres inserting at different angles along its length. Therefore, fascicle length in these pennate muscles is determined, simplistically, by the fascicle's angle of insertion into the aponeuroses, as well as the thickness of the muscle. Whilst this is a straightforward concept, throughout the hamstrings there are unique structural arrangements of fascicles across the four muscles.

Within muscle variability in architecture:

Semimembranosus

Based on fascicular orientation, SM is considered to have three distinct regions. Each segment has its own unique fascicular arrangement with the proximal and middle sections being unipennate and the distal portion being bipennate [13]. Despite this difference in structural arrangement, there is a heterogenous fascicular length along the muscle [13]. However, as is the case with the other hamstring muscles, SM displays a variance in fascicle lengths across the literature. Reported fascicle lengths in cadaveric samples range from 5 to 8cm [13, 37-40]. Furthermore, the variability in fascicular lengths along SM lead to comparable differences in pennation angle within the muscle. These range from 15 through to 31° [37-41].

Semitendinosus

Semitendinosus is uniquely structured with a proximal (approximately one third of the muscle) and distal portion (approximately two thirds of the muscle), separated by a tendinous inscription, or raphe (Figure 5 and Figure 7). Both segments of ST have fascicles which are parallel in alignment. This structural arrangement allows ST to have some of the longest fascicle lengths reported in the lower limb (along with sartorius and gracilis) [42]. However, the fascicular arrangement within each segment of ST is not consistently reported in the literature, with large variability amongst cadaveric samples.

Some studies show no difference in fascicle length between the two segments [13], with others reporting longer fascicles moving from proximal to distal [32] and some showing large variability within each segment [43]. Across the literature, the fascicle lengths of ST range from 9 to 24cm [32, 37-43]. These differences highlight the inconsistencies between human cadaveric samples as well as differences resulting from using various methods of assessing living samples (e.g. two-dimensional vs, three-dimensional ultrasound). Therefore, when assessing fascicle length of ST, the standardisation of the site needs to be considered, and consistency is important to enable for accurate comparisons.

INSERT FIGURE 7 HERE

The pennation angle of the ST fascicles also shows large variability between segments because of the difficulty associated with defining the angle of insertion due to its parallel structure. The most common definition of pennation angle in ST is the fascicular insertion relative to the distal tendon [42]. Using this definition, there is a noticeable variance in pennation angle between the two segments with the distal portion having a greater angle than the proximal [43]. Across ST, pennation angle ranges from 0° to 18° [13, 32, 38, 40, 42-44].

Biceps femoris long head

Biceps femoris long head is classified as pennate in structure with fascicles running between the proximal and distal tendon (Figure 5 and 7) ,which covers approximately 60% (Table 3) of the muscle [13]. Generally, the proximal portion of BFlh possesses longer fascicles than the middle and distal segments of the muscle. However, within the literature there is some variability in BFlh fascicle lengths with a range of cadaveric tissue or *in-vivo* samples used. Some reports have found lengths as little as 5 cm with others reporting fascicles of up to 14 cm long [45, 46]..

Like its fascicles, there is some variability in pennation angle along the length of the BFlh, as well as between studies [13, 32, 37]. The proximal region of the BFlh has more pennate fibres than its middle and distal portions [32]. The variance in pennation angle within the literature shows some samples of 0° yet some report angles up to 28° [37, 38, 41]. The difference in the site and mode of assessment, the physical activity status (e.g. recreational or elite) and injury history may all influence the level of variability seen in BFlh fascicle length and pennation angle.

Biceps femoris short head

Due to the lack of a proximal tendinous insertion, the BFsh muscle has fascicles arising from three different locations: the linea aspera, the lateral supracondylar line of the femur and the intermuscular septum which separates BFsh from vastus lateralis. As a result, its fascicular arrangement is variable and can be split into two regions [13]. Typically, the most posterior region of the BFsh possesses longer fascicles than the anterior portion [13]. Across the literature, BFsh possesses fascicles between 10.4 and 14 cm in length [13, 37, 40]. The pennation angle of the BFsh ranges from 10 to 16° [37, 39, 40].

Distal tendons and musculotendinous junctions

The lengths of the distal tendons, free tendons and MTJs are presented in Table 3.

Semimembranosus

The distal tendon of SM commences proximal to the middle of the muscle [6] and forms a large, broad aponeurosis on the medial aspect of the muscle [7, 13]. Semimembranosus has the longest distal MTJ of all the hamstring muscles (mean length 16-19 cm) but, its entire distal tendon is slightly shorter than that of BFlh and ST, measuring approximately 22-25 cm on average and occupying 52-59% of the muscle length [12, 13, 16]. Considering the tendinous morphology of SM, the distal (extending 52-59% the length of the muscle) and proximal (extending 75% the length of the muscle) tendons effectively overlap to some extent along the length of the muscle (Figure 7 and 8). On the posterior aspect of the lower part of SM the tendon tapers to become heavy and rounded near its insertion site [7, 15].

INSERT TABLE 3 HERE

Semitendinosus

The distal tendon of ST is long and thin and lies on the superficial surface of SM (Figure 1, 7 and 8). The tendon commences as a small aponeurosis on the anterior aspect of the muscle at about the mid-level of the thigh [7, 13, 15], forming a MTJ which extends approximately 30% of the muscle length [12, 13]. The free distal tendon is the longest of all of the hamstrings (mean length ranges between 11-19 cm) [12, 13, 40] and its distal portion is often cradled in a trough formed by the superficial surface of SM [13] before it curves around the medial condyle of the tibia, passing superficial to the medial collateral ligament towards its insertion [15].

INSERT FIGURE 8 HERE

Biceps femoris

The distal tendon of BFlh is the longest of all of the hamstrings, measuring approximately 27 cm, extending 60-65% the length of the muscle [12, 13]. The tendon takes the form of a broad, fan-shaped aponeurosis [13, 15] covering the lateral aspect of the lower portion of its muscle belly and some of BFsh (Figure 1, 7 and 8), forming a distal MTJ that extends approximately 40% of the muscle length (18 cm) [13]. The most proximal extent of the tendon originates on the lateral, deep aspect of the muscle belly at about the mid-point of the thigh, narrowing to form a broad flat tendon 7-10 cm proximal to the knee joint [47, 48]. The portion of the distal tendon which is devoid of muscle fascicles measures between 5-12 cm [12, 13, 40, 49].

The deep surface of the distal BFlh tendon also forms an insertion site for the fascicles of BFsh (Figure 1, 7 and 8) [6, 13, 15, 47, 48, 50], which span a length of 10.7 cm (range 9.2-12.8 cm) occupying 36.5% of the total length of muscle and thereby forming the distal MTJ [13]. The fascicles from each head of the BF are oriented differently, and at their insertion into the BFlh tendon, meet at an angle of approximately 45° [13].

Distal insertions

Semimembranosus

The distal SM tendon is an important component of the posteromedial corner of the knee alongside the medial collateral ligament, posterior oblique ligament, and posterior horn of the medial meniscus (Figure 9) [51, 52]. At the knee joint, SM likely functions as an active restraint to valgus (when the knee is extended) and external rotation (with knee flexion) [53]. The anatomy of this region is complex, with differences evident in the number and location of arms attributed to the distal SM tendon, and their relationship to surrounding tissues. Between three to eight different arms of the distal SM tendon have been described [6, 14, 15, 47, 51, 54-56], with [57] providing the most comprehensive account of its insertional anatomy. Of these eight components, three appear to have been consistently identified and agreed upon in the literature: the direct arm, anterior arm, and expansion to the oblique popliteal ligament.

Immediately distal to the joint line, the SM tendon bifurcates into a direct and anterior arm, [57, 58], although this separation may not be distinct [51]. The direct arm is derived from the main portion of the SM tendon [57] and courses distally to attach to a tubercle, sometimes referred to as the tuberculum tendinis [14, 15, 57, 59] on the posterior aspect of the medial tibial condyle [6, 14, 15, 47, 54-56]. This arm is described to expand, forming a broad U-shaped convex attachment, which is located approximately 1 cm distal to the joint line [57].

The anterior (reflected or tibial) arm takes the form of a thick tendinous expansion, originating just proximal to the tibial attachment of the direct arm, within the medial edge of the SM [57]. It runs in an antero-inferior direction, and attaches to the medial tibial condyle, deep to the proximal tibial insertion of the superficial medial collateral ligament [14, 51, 57, 59, 60]. This insertion site is oval-shaped and approximately 1 cm distal to the joint line [51, 53, 57, 59]. The direct and anterior arms of the SM tendon are closely related to the SM bursa, described as an inverted U-shape [61] that forms proximal to the attachment of the direct arm on the tibia [59]. De Maeseneer et al., (2014) state that this bursa covers the medial and lateral aspects of the transition area between the direct and anterior arms, while [59] describe the lateral aspect of the bursa lying between the direct arm attachments to the coronary ligament and tibia, with its medial aspect surrounding the anterior arm.

A thin, broad lateral expansion of the SM tendon [14, 15, 51, 57, 62, 63], with possible contribution from the SM tendon sheath [60, 64] or the capsular arm of the posterior oblique ligament [57, 60], forms the medial aspect of the oblique popliteal ligament. La Prade et al., (2007) report that a “lateral tendinous expansion” from the main SM tendon, arising just proximal to the bifurcation of the direct and anterior arms, also contributes fibres to the oblique popliteal ligament. The ligament, which has a length of approximately 4.5-4.8 cm, courses posterolaterally towards the lateral femoral condyle. Inconsistences are apparent regarding its lateral insertions which include the fabella (when present) [57, 64], the posterolateral joint capsule [57, 62, 64] or the lateral femoral condyle [62]. Additional insertions to the popliteus muscle [57, 64] and the lateral aspect of the posterior cruciate ligament facet on the posterior tibia [57] have been reported, with part of the plantaris muscle also gaining insertion into the lateral aspect of the oblique popliteal ligament [57, 64]. Although not well understood, the oblique popliteal ligament is thought to act as a restraint against hyperextension of the knee joint [57, 65] with the tibial attachment having a potential role in providing rotatory stability [57].

Various other components of the distal SM tendon have also been described. A distal tibial, or popliteal arm, arising from the inferior aspect of the direct arm [51] or the coronary ligaments adjacent to the direct arm [57] forms a fascial expansion over the popliteus muscle [14, 51, 54, 55, 57]. An extension from the SM tendon or tendon sheath [47, 51] to the posterior oblique ligament [51, 54, 57] and an arm to the posterior horn [51] of the medial meniscus [51, 54, 55, 57] via the coronary ligament [51, 57] are also reasonably consistent findings. With respect to the meniscal arm, it is hypothesised that during knee flexion, contraction of SM displaces the medial meniscus posteriorly, thereby protecting it from impingement between the femoral and tibial condyles [54, 55]. An additional, inconstant expansion to the posterior horn of the lateral meniscus has also been described [66] but not identified in more recent studies [51, 57]. A proximal posterior capsular expansion, described by La Prade et al., (2007) located proximal to the oblique popliteal ligament coursing along its superior border, to blend laterally with the posterolateral joint capsule [57] has also been reported.

Semitendinosus

Together with the distal tendons of sartorius and gracilis, ST contributes to the pes anserinus on the anteromedial aspect of the proximal tibia (Figure 9). These three tendons insert in a linear fashion along the lateral extent of the anserine bursa (which separates them from the superficial surface of the distal portion of the medial collateral ligament), with sartorius most proximal, gracilis in the middle and ST most distal [15, 59]. The distal tendon of ST fuses with an aponeurotic membrane from the gracilis tendon [15, 67] and has a mean insertional width of 1.1 (range 0.8-1.6) cm, being wider than the tendons of sartorius and gracilis (0.8 cm) [59].

Nomenclature is variable, but a number of accessory bands or tendons, or tendinous expansions are associated with the tendons that comprise the pes anserinus. Examples that relate to ST include an accessory tendon that arises from its tendon proximal to where it blends with gracilis, which passes on the deep surface of the ST tendon to fuse with the crural fascia [15, 67]. Thin accessory bands of ST may number between two and three, blending with the medial gastrocnemius fascia [68, 69] and the fascia of popliteus [68]. An understanding of normal and potential variant anatomy is critical for surgical harvest of the ST tendon which can be used for reconstructive repair of the patellar tendon or anterior cruciate ligament [69].

[INSERT FIGURE 9 HERE

Biceps femoris

It is generally accepted that the main part of BF tendon inserts into the lateral aspect of the fibular head (Figure 8 and 10) [15, 70-72], and is closely related to, and divided by, the fibular collateral ligament [47, 48, 70-72], with an additional extension to the lateral tibial condyle [15, 47, 48]. However, the detailed anatomy of this insertion site at the posterolateral aspect of the knee is complex, and has been described in a variety of ways, with various names given to different components of the tendon. Slips, extensions or laminae of the BF tendon insert or blend with surrounding tissues including the fibular collateral ligament, crural fascia, iliotibial tract [47, 48, 71, 72], popliteus tendon, and the arcuate ligament [72]. An additional fascial attachment to the lateral femoral condyle approximately 3-4 cm proximal to the where the BF tendon splits has also been described [72].

INSERT FIGURE 10 HERE

A three layer arrangement of the insertions of BFlh and BFsh are reported by Terry & La Prade (1996a, 1996b), which brings together elements from the earlier work of Sneath (1955) and Marshall, Girgis & Zelko (1972). Five attachments of BFlh are described, consisting of two tendinous components (a direct arm and an anterior arm) and three fascial components (a reflected arm, a lateral and an anterior aponeurosis). The reflected arm is the most proximal component and inserts into the posterior edge of the iliotibial tract just proximal to the fibular head. Insertion of the direct arm is into the posterolateral edge of the fibular head. The anterior arm inserts into the lateral edge of the fibular head, and a portion ascends anteriorly forming the lateral aponeurotic expansion that covers the fibular collateral ligament. The medial aspect of the anterior arm is separated from the distal quarter of the ligament by a small bursa, with the lateral portion of the anterior arm continuing distally to terminate in an anterior aponeurosis that overlays the anterior compartment of the leg [50, 58, 73].

The remaining insertions are derived from BFsh, and while Sneath (1955) suggests a three laminar arrangement, Terry and LaPrade (1996a, 1996b) describe six components. The first is a muscular insertion into the deep (anterior) and medial surface of the BFlh tendon (as described above). Muscle fascicles of the BFsh also terminate at two other sites; the posterolateral joint capsule (via the capsular arm which passes deep to the fibular collateral ligament), and to the capsuloosseous layer of the iliotibial tract. The distal BFsh comprises two tendinous insertions, a direct arm to the superficial surface of the fibular head (positioned medially to the lateral collateral ligament) and an anterior arm, which passes deep to the fibular collateral ligament, partially blends with the anterior tibiofibular ligament, and then insert into tibia, 1 cm posterior to Gerdy's tubercle. Finally, a lateral aponeurotic expansion attaches to the posteromedial aspect of the fibular collateral ligament [50, 73].

At the knee joint, the BF tendon acts a dynamic stabiliser to resist anterolateral-anteromedial rotatory instability [72, 73]. Injuries to structures of the posterolateral corner (fibular collateral ligament, popliteus tendon, popliteofibular ligament) alongside the biceps tendon are associated with severe rotational instability [56].

Neurovascular supply

The hamstring muscles are innervated by branches of the tibial division of the sciatic nerve, with the exception of BFsh which is supplied by the common fibular nerve. Arterial supply is predominantly received from branches of the profunda femoris artery (deep artery of the thigh), and venous drainage occurs via tributaries of the profunda femoris vein.

Semimembranosus

Semimembranosus generally receives a single muscle nerve from the tibial division of the sciatic nerve [6, 13, 74, 75] (Figure 11 and Figure 12) and this may sometimes arise in common with the nerve supplying the distal compartment of ST [6, 13, 75]. A branch of this muscle nerve also supplies the posteromedial portion of adductor magnus, either having a shared common trunk of origin [75] or being derived from a proximal branch of the nerve that supplies SM [6, 13]. The number of primary muscle branches entering SM (motor points) varies from 1-5, and this may be due to different interpretations of what constitutes a primary muscle branch [6, 13, 74, 76, 77]. Semimembranosus is usually supplied from all four of the perforating arteries (which arise from the profunda femoris), but predominantly from the first. The inferior gluteal artery may contribute at the proximal attachment of SM, while the distal part of the muscle is supplied by a branch of the femoral or popliteal artery [15].

Semitendinosus

ST usually receives two primary nerve branches from the tibial nerve with one supplying the proximal portion of the muscle (above the tendinous inscription) and the other the distal portion (Figure 11 and Figure 12) [6, 13, 74, 75, 77, 78]. In some instances a single primary nerve branch to ST (which subsequently divides into two) has been identified [13], and one of the nerve branches to ST may share a common trunk with either the nerve to SM [13] or BFlh [75]. The proximal part of ST is supplied by the medial circumflex femoral artery [15, 78] and the first [15] or second [78] perforating arteries; the first [15, 78] and second [78] perforating arteries supply the distal portion. The inferior gluteal artery contributes at the proximal attachment of ST, and an accessory supply is received from the inferior medial genicular artery at its distal insertion [15].

INSERT FIGURE 11 HERE

Biceps femoris long head

Variation is evident regarding the nerve supply to BFlh. There is consensus that a single primary nerve innervates a proportion (or all) of BFlh muscles (Figure 11 and 12) [13, 74, 75, 77-79], but BFlh may also be innervated by more than one nerve [74, 75, 77, 79]. When one nerve innervates BFlh, it may divide into two branches; this pattern was found in a third of specimens studied by Shanahan et al (1993) and in all specimens in three other studies [6, 13, 78]. If BFlh is supplied by two nerves, the second branch may arise separately from, or share a common point of origin with the first. It may also share a common origin with the nerves which supply adductor magnus and SM [75]. The first and second perforating arteries supply BFlh [15, 78] with contributions from the medial circumflex femoral [15, 78], and inferior gluteal [15] proximally; distally the superior lateral genicular artery provides an accessory supply [15].

INSERT FIGURE 12 HERE

Biceps femoris short head

The innervation of BFsh differs to the other hamstring muscles, being derived from the common fibular nerve. Once again, variation is evident in the pattern of innervation with reports of one motor primary nerve most common [6, 24, 75, 77], with two motor nerves supplying BFsh in some instances

[13, 75]. Arterial supply to the superior BFsh is from the second or third perforating artery, with the superior lateral genicular artery supplying the inferior part [15]. Anastomotic vessels between the two heads of biceps femoris are usually present, around the level of where the muscle bellies blend (onto the distal tendon) and mid-way along the length of the BFsh muscle belly [80].

Conclusion

The structure of each of the hamstrings, like any muscle, determines its function [34]. Therefore, the anatomical variables described in this chapter should assist comprehension across the remaining chapters. As an example, the biomechanical demands of running expose the hamstring muscle group to forceful, repetitive lengthening actions [81, 82]. The ability of the hamstrings to perform these actions, and by extension, the likelihood of hamstring injury, will be partially dictated by their structure [81, 83, 84]. Furthermore, architectural characteristics, namely BFlh fascicle length, has been identified as a variable that can modulate the risk of future hamstring injury [3], and the ability to cause adaptation to this structural characteristic may help to guide preventative efforts [85-87]. In addition, damage to different anatomical structures (i.e. MTJ, muscle fibres, free tendon, intramuscular tendon) are factors that may require consideration in the rehabilitation and prognostication of hamstring injury as well as the return-to-sport decision making process [4]. Whilst these present just a few examples of the importance of understanding the anatomy of the hamstrings, it is anticipated that the current chapter provides a foundation to maximise the learnings from the remainder of this book.

Figure captions:

Figure 1A and B:

Illustration (a) and dissection (b) of the right posterior thigh demonstrating the gross anatomy of the hamstring muscle group. The hamstrings consist of semitendinosus (a) and semimembranosus (b) on the medial side and the long head (c and e) and short head (d) of biceps femoris, laterally. Figure 1a printed with permission from Kaeding and Borchers (2014).

Figure 2A, B:

Dissection photograph, posterolateral view of the area of the proximal attachment of the right hamstring muscles. (1) Area of the attachment of the conjoined tendon of the semitendinosus and the long head of the biceps femoris; (2) the proximal attachment area of the conjoined tendon; (3) conjoined tendon of the semitendinosus and the long head of the biceps femoris—cut and rotated 180°; (4) proximal tendon of the semimembranosus muscle; (5) area of the attachment of the semimembranosus muscle; arrowheads—shape of the semimembranosus attachment. Printed with permission from Stepien et al (2018).

Figure 3:

Dissection photograph of the proximal hamstring insertions at the ischial tuberosity (left limb, posterior view). The conjoined tendon (A) arises from the posteromedial aspect of the ischial tuberosity, medial and posterior to the semimembranosus tendon (B) and has some connections with the sacrotuberous ligament (C). Muscle fascicles of semitendinosus (D) originate directly from the ischial tuberosity, the medial border of the conjoined tendon, and an aponeurosis on the anterior aspect of the muscle (not visible). E, quadratus femoris; F, gemelli muscles and tendon of obturator internus; G, piriformis; H, sciatic nerve.

Figure 4:

Dissection photograph, posterolateral view of the posterior thigh of a right thigh. (1) Ischial tuberosity; (2) conjoined tendon of the semitendinosus and the long head of the biceps femoris; (3) sciatic nerve; (4) semitendinosus muscle; (5) long head of the biceps femoris muscle. Printed with permission from Stepien et al (2018).

Figure 5:

The hamstring complex. (1) Proximal tendon of the semimembranosus muscle; (2) distal tendon of the semimembranosus muscle (3) conjoined tendon of the semitendinosus and the long head of the biceps femoris; (4) tendinous inscription (raphe) of the semitendinosus muscle; (5) distal tendon of the semitendinosus muscle; (6) common distal tendon of the long and short head of the biceps femoris muscle. Printed with permission from Stepien et al (2018).

Figure 6:

Proton density, coronal magnetic resonance images from a young man demonstrating the long tendons and musculotendinous junctions of (A) semimembranosus (SM) and (B) biceps femoris long head (BFlh). AM: adductor magnus, IT: ischial tuberosity, ST: semitendinosus.

Figure 7:

Anatomical dissection showing the muscular characteristics of the semitendinosus muscle. (1) Semitendinosus muscle. (2) Raphe. (3) Length of the raphe (range of 5.0 to 9.0 cm). (4) Width of the raphe (3.0 cm maximum). (5) Semitendinosus distal tendon. (6) Long head of biceps femoris muscle. (7) Short head of biceps femoris muscle. (8) Biceps femoris distal tendon. (9) Ischial tuberosity (illustrative representation). (10) Conjoint tendon (Long head of biceps femoris and semitendinosus muscles). Printed with permission from van der Made et al (2015).

Figure 8:

Dissection photograph of the left distal hamstring complex (posterior view). BFlh, biceps femoris long head, BFsh: biceps femoris short head, SM, semimembranosus, ST: semitendinosus.

Figure 9:

Dissection photograph of the medial aspect of the left knee. Note the contribution of the distal semitendinosus tendon to the pes anserinus, alongside the distal tendons of gracilis and sartorius. sMCL: superficial medial collateral ligament.

Figure 10:

Dissection photograph of the lateral aspect of the left knee. Note the distal tendon and insertion of the biceps femoris tendon into the lateral aspect of the head of the fibula.

Figure 11A and B:

Entry points of motor branches to the hamstring muscles [88]. (1) Motor branch to the long head of the biceps femoris muscle; (2) two motor branches to the semitendinosus muscle; (3) motor branch to the semimembranosus muscle. Printed with permission from Stepien et al (2018).

Figure 12 A-C:

Lateral view on the innervation of the hamstring muscle complex [88]. (1) Ischial tuberosity; (2) sciatic nerve; (3) motor branch to the long head of the biceps femoris muscle; (4) recurrent branch to the proximal attachment of conjoined tendon; (5) motor branch to the semitendinosus muscle; (6) motor branch to the semimembranosus muscle; (7) motor branch to the short head of the biceps femoris muscle. Printed with permission from Stepien et al (2018).

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