

REVIEW OF HAMSTRING ANATOMY

– Written by *Stephanie J Woodley and Richard N Storey, New Zealand*

The collective term ‘hamstrings’ refers to three separate muscles located in the posterior compartment of the thigh - biceps femoris (which consists of two components, a long head [BFlh] and a short head [BFsh]), semitendinosus (ST) and semimembranosus (SM) (Figure 1). There are numerous theories on how this muscle group derived its name, but it appears to originate from the early Germanic language as well as the butchery trade. Slaughtered pigs were hung from these strong tendons, hence the reference to ‘ham’ (meaning ‘crooked’ and thus referring to the knee, the crooked part of the leg) and ‘string’ (referring to the string-like appearance of the tendons). From their proximal insertions at the ischial tuberosity, SM, ST and BFlh pass posterior to the hip and knee joints, while BFsh is monoarticular, crossing only the knee joint.

From a clinical perspective, an understanding of anatomy is a fundamental consideration in the diagnosis and management of hamstring injuries. With respect to acute hamstring strain it is well accepted that BFlh is injured most frequently, usually at the proximal musculotendinous junction (MTJ). It also appears that the site and activity associated with strain

may be related. For example, BFlh is usually compromised during sprinting, but slow-speed stretching injuries predominantly affect SM¹. Increasingly, imaging is being employed to confirm the location and severity of hamstring injuries and to inform prognosis, particularly in professional and elite athletes.

With the above factors in mind, the purpose of this paper is to provide an overview of our current understanding of the morphology of the hamstring muscles. Terms used frequently within this review require some explanation. Firstly, a tendon can be considered to consist of two main components:

1. A **free tendon** which, as its name suggests, is purely tendinous, being devoid of any inserting muscle fascicles.
2. A **MTJ** which, in this context, refers to the part of the tendon into which muscle fibres insert (Figure 2).

Secondly, in reference to muscle architecture a **fascicle** is a group of muscle fibres that have distinctive and identifiable attachments; and **muscle volume** and **physiological cross-sectional area (PCSA)** are good anatomical indicators of muscle power.

BICEPS FEMORIS LONG HEAD

This muscle is of particular interest given its susceptibility to injury. Some anatomical parameters that may be relevant when considering strain injuries include its unique muscle architecture and the arrangement of its proximal tendon which it shares with ST, a feature which may explain why injuries to



BFlh is usually compromised during sprinting, but slow speed stretching injuries predominantly affect SM



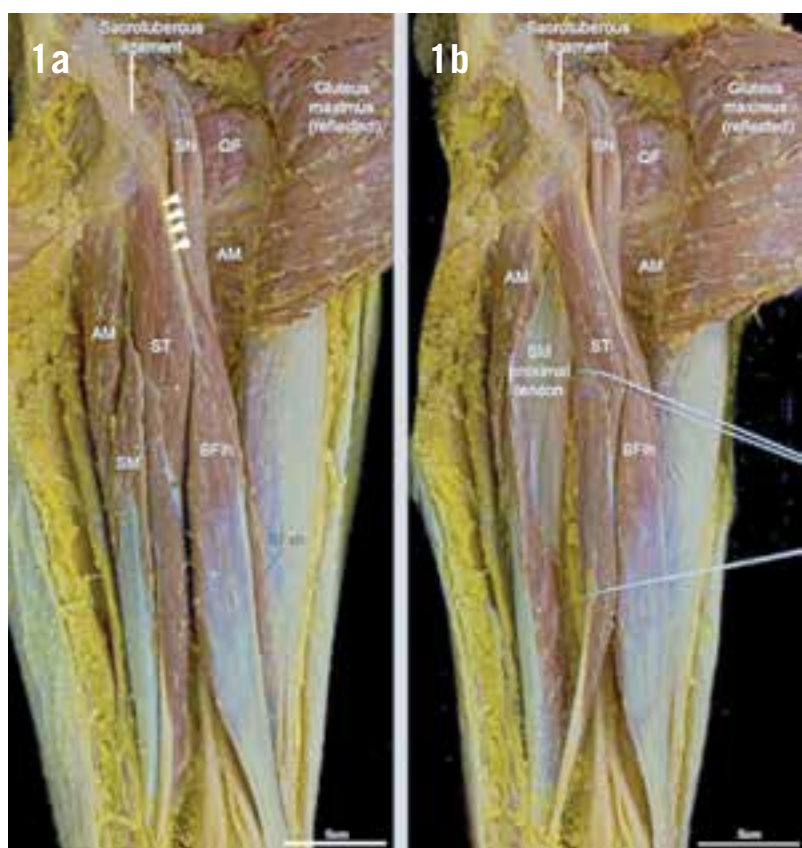
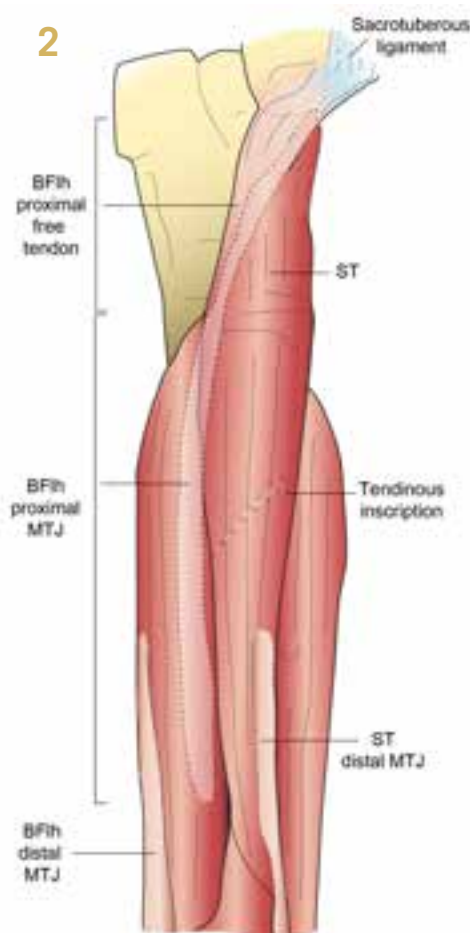


Figure 1: Dissection photograph of the hamstring muscles (right limb, posterior view). (a) Note the proximal tendon of BFlh (arrowheads), the tendinous inscription of ST (*) and the long aponeurotic distal tendons of BFlh and SM. (b) ST and BFlh have been reflected to expose the expansive proximal tendon of SM. AM=adductor magnus, BFlh=biceps femoris long head, BFsh=biceps femoris short head, SM=semimembranosus, SN=sciatic nerve, ST=semitendinosus, QF=quadratus femoris.

Figure 2: A schematic diagram of the hamstring muscles (left limb, posterior view) to demonstrate the proximal free tendon and MTJ of BFlh. Also note the length of the distal MTJs of BFlh and ST. BFlh=biceps femoris long head, MTJ=musculotendinous junction, ST=semitendinosus.



APPROXIMATE PERCENTAGE OF MUSCLE LENGTH

	<i>BFlh</i>	<i>BFsh</i>	<i>ST</i>	<i>SM</i>
<i>Proximal tendon</i>	60	NA	30	73
<i>Proximal free tendon</i>	15	NA	3	25
<i>Proximal MTJ</i>	45	NA	27	48
<i>Distal tendon</i>	60	38	57	60
<i>Distal free tendon</i>	20	2	25	15
<i>Distal MTJ</i>	40	36	32	45

Table 1: Tendon and MTJ lengths of the hamstring muscles as a proportion of muscle length. Data adapted from Woodley and Mercer³ displaying approximate percentages. BFlh=biceps femoris long head, BFsh=biceps femoris short head, MTJ=musculotendinous junction, NA=not applicable (as lacks a proximal tendon of insertion), SM=semimembranosus, ST=semitendinosus.

these two muscles can occur simultaneously. Overall, BFlh is a long, slender muscle and its extensive proximal tendon (including free tendon and MTJ) is longer than that of ST but shorter than that of SM (Table 1).

Proximal insertion and MTJ

The BFlh originates from the lateral quarter of the medial facet of the ischial tuberosity via a thick, round tendon having some connections with a small proportion of the superficial fibres of the sacrotuberous ligament^{2,3} (Figures 1 to 3). Its proximal

tendon is relatively long (24 to 27 cm), extending to occupy approximately 60% of the length of the muscle³⁻⁵. The free part of its proximal tendon extends approximately 6.5 cm distally with its long MTJ (approximately 20 cm in length) spanning 45% of the muscle length to terminate deep within the muscle belly^{3,5,6} (Figure 2 and 4a).

Muscle architecture

The bulky muscle belly of BFlh (30 to 35 cm in length) descends slightly laterally in its course and is bipennate in appearance.

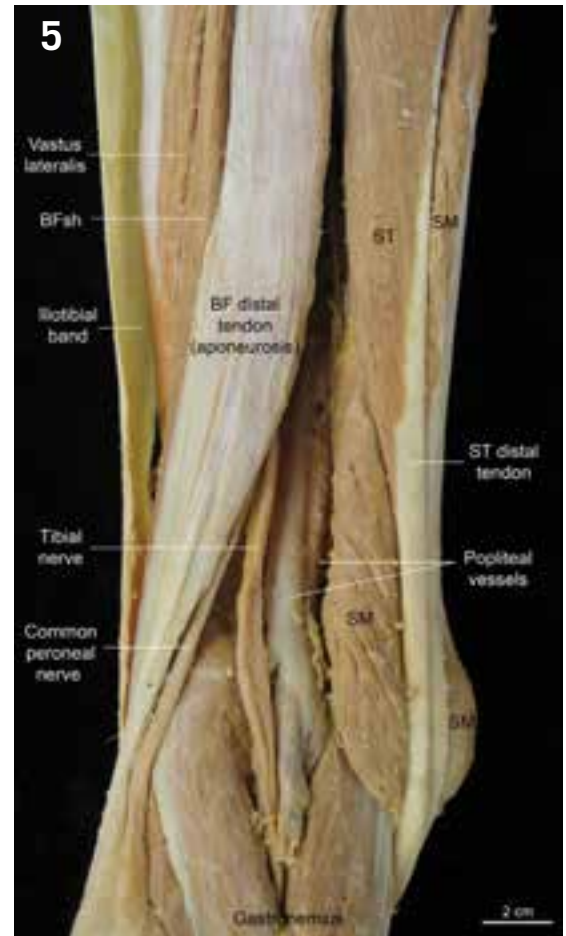
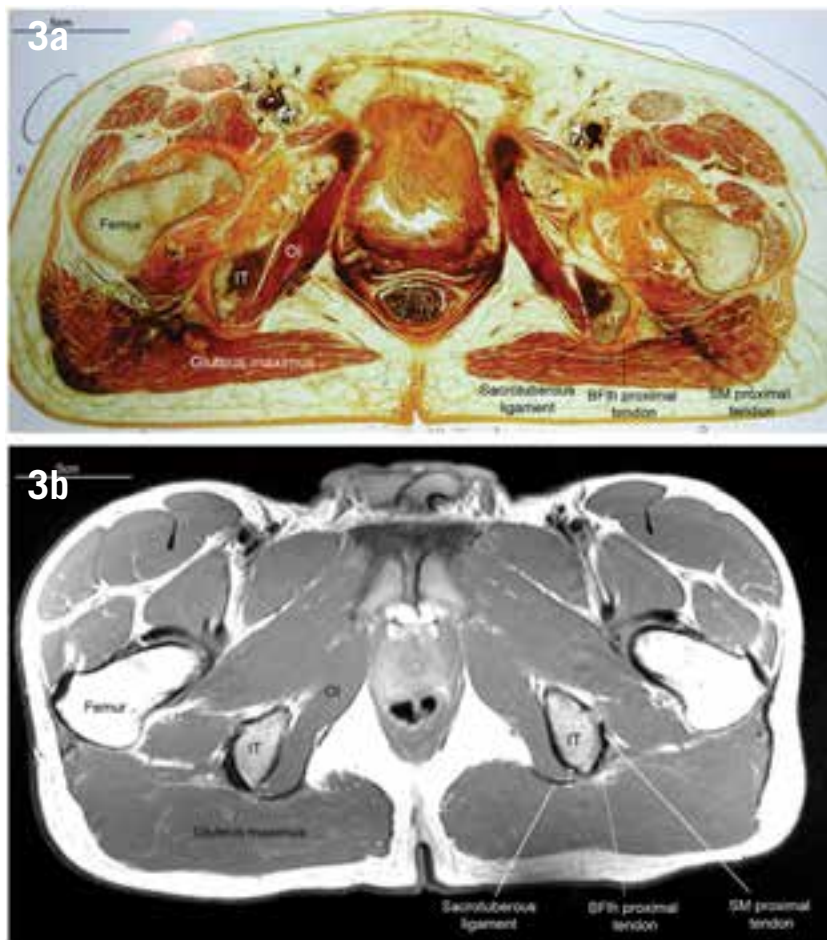


Figure 3: (A) E12 axial slice through a cadaver pelvis. (B) Complementary axial, proton density magnetic resonance image from a young man showing the proximal hamstring attachments and the relationship between BFh and the sacrotuberous ligament. BFh=biceps femoris long head, IT=ischial tuberosity, SM=semimembranosus, OI=obturator internus.

Figure 4: Proton density, coronal magnetic images from a young man demonstrating the long proximal musculotendinous junctions of (A) BFh and (B) SM. BFh=biceps femoris long head, IT=ischial tuberosity, SM=semimembranosus, ST=semitendinosus.

Figure 5: Dissection photograph of the distal hamstring complex (right limb, posterior view). BFsh=biceps femoris short head, BF=biceps femoris, SM=semimembranosus, ST=semitendinosus.



Based on attachment sites and fascicular direction it contains two distinct regions, superficial and deep³. Fascicles of this muscle are longer than those of SM measuring approximately 7 to 9 cm^{3,5,7,8}, but vary in length, being shorter distally compared to proximally⁵. The PCSA of BFlh is the second largest of the hamstring muscles (average value of 10 cm² in cadavers) as is its muscle belly volume (average value of 76 cm³ in cadavers; 260 cm³ in healthy young men). Inferiorly, fascicles insert into the medial aspect of the distal tendon and aponeurosis of BFlh, adjacent to the distal fibres of BFsh^{3,6} (Figure 5).

Distal tendon and MTJ

The distal tendons of BFlh, ST and SM are similar in length. Extending approximately 60% (24 to 34 cm) of the muscle length, the tendon of BFlh is a broad, fan-shaped aponeurosis that covers the entire lateral aspect of the inferior portion of its muscle belly and to a lesser extent the muscle of BFsh^{3,5} (Figures 1 and 5). The distal MTJ of BFlh is also long, occupying 40 to 45% of the length of the muscle. Fascicles from both heads of the muscle are oriented at different angles and therefore at their insertion into the medial surface of the distal tendon, meet at an angle of approximately 45°. The distal tendon of BFlh divides around the lateral collateral ligament, forming two tendinous and three fascial components. Tendinous insertion is into the lateral and anterior aspects of the fibular head and the tibial plateau, while the fascial components mainly attach both heads to the lateral collateral ligament⁸.

Neurovascular supply

BFlh is innervated by the tibial portion of the sciatic nerve, usually via a single muscle nerve that may divide into two primary branches before entering the muscle^{2,5}. However, in some instances it might receive two or three primary nerves¹⁰. The first and second perforating arteries of the deep femoral artery supply BFlh, with accessory vascularisation from the inferior gluteal and medial circumflex femoral arteries (at the ischial tuberosity) and lateral superior genicular artery (distally)¹¹.

Anatomical variation

The proximal tendon of BFlh may be completely separate to that of ST at the ischial tuberosity or receive aberrant muscle slips from the sacrum, coccyx, sacrotuberous

ligament or gluteus maximus^{2,12}. BFsh may contain a tendinous inscription similar to that of ST, displaying separate nerve territories within the muscle².

BICEPS FEMORIS SHORT HEAD

The muscle-tendon unit of BFsh is about 29 cm in length. This muscle is somewhat unique in that it lacks a proximal tendon (and instead arises from bony and fascial attachments) and its innervation differs to the other muscles in this group.

Proximal insertions

Fascicles of BFsh arise directly from the length of the lateral lip of the linea aspera, the upper two thirds of the lateral supracondylar line and the lateral intermuscular septum, spanning a length of approximately 16 cm⁵.

Muscle architecture

The muscle belly of BFsh is relatively thin, but broad and long (26 cm in length) (Figure 5). It consists of two anatomical regions – fascicles in the superficial part are arranged longitudinally, predominantly arising from the lateral intermuscular septum, while those in the deeper distal part originate from all three proximal insertion sites, passing inferiorly at an acute angle. This muscle has the longest fascicle length of all the hamstring muscles (12.4 cm) but is the smallest in area (3.0 cm² in cadavers), suggesting that the magnitude of forces exerted by this muscle are likely to be small^{3,6}.

Distal tendon and MTJ

The distal tendon of BFsh is visually indistinguishable from that of BFlh (Figure 5); its distal MTJ spans 10.7 cm, therefore occupying 36% of the total length of the muscle^{3,6} (Table 1). The distal insertion of this muscle is complex, consisting of six components – a muscular insertion into the tendon of BFlh, an expansion attaching both heads to the posteromedial aspect of the lateral collateral ligament, an insertion confluent with the iliotibial band and three tendinous arms (to the posterolateral aspect of fibular head, joint capsule and the proximal, lateral tibia, respectively)⁹.

Neurovascular supply

The innervation of BFsh differs to the rest of the hamstring muscles. Traditionally, the nerve supply to this muscle is considered to be from a single nerve branch arising

from the common peroneal nerve (Figure 5). However, it is probable that at least two muscle nerves supply the muscle (one to each of the two muscle regions), with one branch originating directly from the sciatic nerve and the other from the common peroneal nerve³. The blood supply of BFsh is from the second or third perforating arteries of the deep femoral artery (superiorly) and from the lateral superior genicular artery (inferiorly)¹¹.

Anatomical variation

BFsh may be completely absent and rarely, the distal tendons of the long and short heads may be partially or entirely separate¹².

SEMITENDINOSUS

Semitendinosus, named in reference to its long cord-like distal tendon, is also distinguished by a tendinous inscription which divides its muscle belly into two separate regions. This division is paralleled by its innervation, with two separate nerve branches supplying the superior and inferior parts of the muscle.

Proximal insertion and MTJ

Semitendinosus is commonly considered to arise from a common origin together with BFlh. However, upon closer inspection it has three distinct areas of insertion:

1. The medial 3/4 of the medial facet of the ischial tuberosity via thick connective tissue,
2. a thin aponeurotic tendon that covers the anterior surface of its muscle and
3. the medial border of the proximal tendon of BFlh, the site which gives rise to the largest number of muscle fascicles^{3,6} (Figures 1 and 2).

Its proximal tendon (approximately 12 to 15 cm in length) and MTJ (11 to 13 cm) are the shortest of all the hamstring muscles, extending approximately 25 to 30% of the length of the muscle (Table 1)^{3,5,6}.

Muscle architecture

The strap-like muscle belly of ST is the longest of all of the hamstrings (approximately 30 cm) and is characterised by a tendinous inscription that divides the muscle into superior and inferior regions. The inscription commences a third of the way down the muscle belly and takes the shape of an inverted 'V' when viewed on the posterolateral surface of the muscle (Figures 1 and 2). This complex three-

dimensional layered structure serves as a staggered insertion site for fascicles which are generally oriented vertically and are of a similar length in both parts of the muscle (8 cm). It may provide added muscle-tendon interface area for its fascicles, reducing force concentration, therefore making it less susceptible to injury. The consistency in fascicle length is mirrored by the identical size of both the superior and inferior regions with respect to volume. With the exception of BFsh, ST has the smallest PCSA (8.08 cm² in cadavers) and volume (both in cadavers [62 cm³] and healthy young men [235 cm³]) suggesting it is capable of producing the least amount of force which may be reflected in lower rates of strain injury^{3,6}.

Distal tendon and MTJ

The long, thin distal tendon of ST (25 to 30 cm in length) lies on the superficial surface of SM and passes along the medial aspect of the knee joint. Its free tendon is the longest of the hamstring muscles, expanding proximally to form a small aponeurosis on the anterior aspect of the muscle thus forming the distal MTJ which occupies 32% of the length of the muscle (approximately 12 cm)^{3,5} (Figure 5). After curving around the medial tibial condyle and passing over the medial collateral ligament of the knee joint, the tendon of ST contributes to the pes anserinus, inserting into the medial surface of the tibia posterior to the attachment of sartorius and distal to that of gracilis. At its termination, it unites with the tendon of gracilis and gives off a prolongation to the deep fascia of the leg and the medial head of gastrocnemius¹¹.

Neurovascular supply

Semitendinosus is supplied by one or two primary muscle nerves from the tibial nerve. Whichever branching pattern is evident, one nerve branch always supplies the superior region of the muscle above the inscription and the other the inferior region below the inscription³. Primarily, blood supply to ST is derived from either the medial circumflex femoral artery or from the first perforating artery; the inferior gluteal and medial inferior genicular arteries may provide an accessory supply¹¹.

Anatomical variation

The muscle bellies of ST and SM may be partially fused and accessory slips can arise from the coccyx, sacrotuberous ligament

or iliotibial band¹². Aberrant fascicles may connect to the fascia on the back of the thigh and rarely, fascicles may arise directly from the femur, a feature present in many birds². Fascicles bridging the tendinous inscription are common.

SEMIMEMBRANOSUS

Semimembranosus is named after its extensive membranous proximal tendon. It is hypothesised that the length of its free tendon together with its tortuous course may render it vulnerable to stretch injuries. This muscle is the largest of all of the hamstrings.

Proximal insertion and MTJ

Semimembranosus attaches to the lateral part of the ischial tuberosity (Figure 3). Its tendon passes deep and obliquely to those of ST and BFlh and rapidly widens to become an expansive aponeurosis characterised by a thick and rounded lateral border and a flattened thin medial membranous edge, such that it is said to resemble the wing of a plane (Figure 1b). On the medial aspect of the thigh its membranous part cups around the strap-like muscle belly of ST, which is positioned superficially. Semimembranosus possesses the longest proximal tendon of all of the hamstring muscles, being approximately 31 cm in length, occupying 73% of the length of the muscle (Figure 4b). Its free tendon constitutes about a third (11 cm) of its total tendinous length with the remaining two-thirds forming the longest proximal MTJ (mean 20 cm) of all the hamstring muscles (Table 1)^{3,6}.

Muscle architecture

Semimembranosus becomes fleshy about mid thigh, distinctly lower than

the other hamstrings. Its muscle belly is formed of three regions, the proximal two are unipennate in arrangement but the distal region is thick and bipennate (Figure 5). In comparison to the other hamstrings, its fascicles are the shortest (5 cm in length) and display the greatest pennation angle, arranged as such for greater force production. Furthermore, SM is the largest of all the hamstrings having the largest PCSA (15 cm² in cadavers) and volume (average value of 104 cm³ in cadavers; 324 cm³ healthy young men). Its muscle belly also has a distinctive groove to accommodate the cord-like distal tendon of ST^{3,6} (Figure 5).

Distal tendon and MTJ

The fascicles of SM insert into a large, broad aponeurosis on the lateral side of the muscle (Figure 1), which tapers to a thick short rounded tendon at its insertion. Its distal tendon (26 cm) is similar in length to that of ST and BFlh but its distal MTJ is the longest of all (19 cm). In effect, the proximal tendon (extending 72% of the length of the muscle) and the distal tendon (extending 60% the length of the muscle) overlap to some extent along the course of the muscle belly (Table 1)^{3,6}. The insertion of this tendon is complex and appears to be comprised of several but variable slips. Consistently, three attachments are described:

1. The posterior aspect of the medial tibial condyle (deep to the medial collateral ligament and separated from it by a bursa).
2. A slip that blends with the popliteal fascia.
3. The oblique popliteal ligament, a reflected slip that reinforces the posterior knee joint capsule¹¹.



The hamstrings are characterised by long tendons and MTJs





Neurovascular supply

SM is innervated by one muscle nerve branch from the tibial division of the sciatic nerve, sometimes arising in common with the nerve supplying the distal compartment of ST. Of its three main branches, one supplies adductor magnus with the two ensuing branches innervating the three regions of SM³. Semimembranosus is vascularised predominantly by the first perforating artery of the thigh but receives contributions from many of the other perforators as well. Its proximal attachment is supplied by the inferior gluteal artery and a branch of the femoral or popliteal artery supplies the distal part of the muscle¹¹.

Anatomical variation

Semimembranosus varies considerably in size and can be absent, duplicated or split. If doubled, it arises mainly from the sacrotuberous ligament; its attachment may extend to the coccyx or have slips that joint with the tendon of adductor magnus¹².

CONCLUSION

In summary, the anatomy of the hamstrings is complex. These muscles are characterised by long tendons and elongated MTJs that overlap within or on the

surface of the muscle bellies. Each muscle is also unique with respect to its architecture in terms of attachment sites, fascicle length, aponeurosis size, PCSA and volume. Research to date suggests that these muscles consist of distinct anatomical regions but further investigation is needed to ascertain the relevance of this structural arrangement to function, injury and rehabilitation. Finally, an awareness of tendon and muscle architecture is important when assessing and treating patients who present with a hamstring injury and should be considered alongside the many other variables that contribute to the clinical picture.

References

1. Askling CM, Malliaropoulos N, Karlsson J. High-speed running type or stretching-type of hamstring injuries makes a difference to treatment and prognosis. *Br J Sports Med* 2012; 46:86-87.
2. Markee JE, Loue JT, Williams M, Stanton WB, Wrenn RN, Walker LB. Two-joint muscles of the thigh. *J Bone Joint Surg Am* 1955; 37:125-142.
3. Woodley SJ, Mercer SR. Hamstring muscles: architecture and innervation. *Cells*

Tissues Organs 2005; 179:125-141.

4. Garrett WE, Rich FR, Nikolaou PK, Vogler JB 3rd. Computed tomography of hamstring muscle strains. *Med Sci Sports Exerc* 1989; 21:506-514.
5. Kellis E, Galanis N, Natsis K, Kapetanios G. Muscle architecture variations along the human semitendinosus and biceps femoris (long head) length. *J Electromyogr Kinesiol* 2010; 20:1237-1243.
6. Storey RN. *The hamstring muscles: proximal musculotendinous junctions*. B.Med. Sci. (Hons) thesis, University of Otago 2012.
7. Barrett B. *The length and mode of termination of individual muscle fibres in the human sartorius and posterior femoral muscles*. *Acta Anat (Basel)* 1962; 48:242-257.
8. Chelboun GS, France AR, Crill MT, Brad-dock HK, Howell JN. In vivo measurement of fascicle length and pennation angle of the human biceps femoris muscle. *Cells Tissues Organs* 2001; 169:401-409.
9. Terry GC, LaPrade RF. *The biceps femoris muscle complex at the knee: its anatomy and injury patterns associated with acute anterolateral-anteromedial rotatory instability*. *Am J Sports Med* 1996; 24:2-8.
10. Seidel PM, Seidel GK, Gans BM, Dijkers M. *Precise localization of the motor nerve branches to the hamstring muscles: an aid to the conduct of neurolytic procedures*. *Arch Phys Med Rehabil* 1996; 77:1157-1160.
11. *Stranding S (Ed). Gray's Anatomy: The Anatomical Basis of Clinical Practice 40th Edition*. Churchill Livingstone, Edinburgh 2008.
12. Bergman RA, Thompson S, Afifi AK. *Catalogue of Human Variation. Urban and Schwarzenberg, Baltimore* 1984.

Stephanie J Woodley B.Phty., M.Sc., Ph.D.
Senior Lecturer
Department of Anatomy
Richard N Storey B.Med.Sci. (Hons),
Fifth year medical student
University of Otago,
Dunedin, New Zealand
Contact: stephanie.woodley@anatomy.
otago.ac.nz