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An anatomical and histological study of the structures surrounding the proximal attachment of the hamstring muscles

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ABSTRACT

Introduction: The proximal attachment of hamstring muscles has a very high incidence of injuries due to a wide number of factors and its morphology may be one of the underlying factors as scientific literature points out. The connective tissue component of the attachment of hamstring muscles is not well known. For this reason the aim of this study is to describe the anatomy and histology surrounding the proximal attachment of the hamstring muscles (PAHM) and its direct anatomic relations.
Methods: Forty-eight cryopreserved lower limbs have sequentially been studied by means of dissection, anatomical sections and histology.
Results: All specimens studied presented an annular connective tissue structure that resembles a retinaculum, which covers and adapts to the attachment of hamstring muscles on the ischial tuberosity.
Conclusion: The results show how this retinaculum is continuous with the long head of biceps femoris muscle, however there is a layer of loose connective tissue between the retinaculum and the semitendinosus muscle. Furthermore, this structure receives expansions of the anterior epimysium of the gluteus maximus muscle (GIM).

1. Introduction

"The hamstrings" is a colloquial term used for the muscles found in the posterior compartment of the thigh. They include the biceps femoris, the semitendinosus and the semimembranosus muscles. The ischial tuberosity is the proximal attachment of the hamstring muscles (PAHM) except for the short head of the biceps femoris, which arises from the linea aspera of the femur. These muscles are hip extensors and knee flexors (Beltran et al., 2012) and are key muscles for gait and running.

Hamstrings injuries are common in many sports, especially when rapid acceleration and running at maximum speed are needed (Hoskins and Pollard, 2005; Opar et al., 2012). As a percentage of total hamstring injuries, the prevalences are 12%–16% in football (soccer) (Arnason et al., 1996; Hawkins et al., 2001) and 11% in cricket (Stretch, 2003). In addition to their high incidence, these injuries are also associated with a high recurrence rate (Arnason et al., 1996; Woods et al., 2004); for example, football has a rate, of approximately 16% (Ekstrand et al., 2011). Injury severities range from a minor inflammation to a muscle strains (Opar et al., 2012), and rehabilitation can be prolonged and complicated by the high incidence of recurrence (Orchard and Best, 2002; Woods et al., 2004).

Hamstrings injuries may affect any of the components of the muscle group (Garrett et al., 1989; Pomeranz and Heidt, 1993; Woodley and Mercer, 2005). However the PAHM or the proximal muscle-tendon-bone unit is the site most frequently injured (De

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Smet and Best, 2000; Askling et al., 2007b). Moreover, the biceps femoris is consistently the most commonly injured of the three muscles (Thelen et al., 2005; Askling et al., 2007a; Sato et al., 2012).

A multifactorial etiology has been proposed based on the biomechanics and morphology of the PAHM (Beltran et al., 2012; Sato et al., 2012), but the evidence is often inconclusive or contradictory (Orchard and Best, 2002). In addition, it is possible that the biceps femoris muscle is predisposed to injury due to its myofascial attachments (Hoskins and Pollard, 2005). It is equally important to study the anatomy and morphology of the connective tissue around the PAHM given the argument that a better knowledge could improve our understanding of hamstring injuries and improve the available treatments (Culav et al., 1999; Sato et al., 2012). However, no published studies have described the fascial elements or connective tissue around the PAHM.

This study aims to examine the anatomy and histology of the PAHM in detail, specifically its surrounding connective and fascial tissue, and its direct anatomic relations in order to broaden our existing knowledge of the anatomy in this region.

2. Material and methods

We examined 48 cryopreserved hemipelvis and their corresponding thighs; 11 males and 13 females, with a mean age of 78 years (range 58–88). The body donor program of the Faculty of Medicine (Bellvitge Science Heath Campus), University of Barcelona, provided all specimens. None of the cadaveric specimens used for this study had evidence of traumatic injuries or surgical scars. We assigned each specimen a number (1–48) as it was processed. The analysis involved two stages: an anatomical study followed by a histological study.

2.1. Anatomical study

2.1.1. Dissection procedure

We dissected 26 bilateral lower limbs from 13 cadavers (4 males and 9 females) in the prone position. Dissection proceeded in a proximal distal direction, from the gluteal to the popliteal region. Two longitudinal incisions were performed. The first was made through the midline of the lumbar and sacral spine, superficial to spinous process and the median sacral crest of the sacrum. The second incision passed from the posterosuperior aspect of the thigh to the popliteal region. Three transverse incisions were then performed. The highest incision was made at the level of iliac crest, the middle incision at the level of the gluteal sulcus and the lowest incision at the level of the femoral condyles. The skin and subcutaneous adipose tissue of the superficial fascia were removed in layers, exposing the deep gluteal fascia and the fascia lata, which are continuous. The gluteus maximus muscle was detached from the midline and put aside laterally.

At this point, the PAHM was exposed and the surrounding connective and fascial tissue surrounding were studied. All connective tissue measurements were taken using a tape measure. The length of the connective tissue was measured from the lateral border of the long head of the biceps femoris to the medial border of the semitendinosus muscle. The width was measured from the upper transverse fibers to the lower transverse fibers that form the connective tissue of this region.

2.1.2. Anatomic sections

Anatomic cross-sectional cuts were performed on 22 bilateral specimens from 11 cadavers (5 males and 6 females). Successive cross-sections were taken using an anatomical saw at the level of the proximal hamstring tendon attachment in three different planes: eight specimens were sectioned in the transverse plane, eight specimens in the frontal plane and six specimens in the sagittal plane. We took photographs during these procedures using a digital camera (CANON 911).

2.2. Histological study

We obtained six connective tissue samples from the proximal attachment of the hamstring tendon at the ischial tuberosity and the gluteus maximus muscle (sample size 2.5 × 1.5 cm) from previously dissected specimens (3 males and 3 females). All samples were immediately fixed using a 4% formaldehyde solution and embedded in paraffin before obtaining 7 μm thick slices for histological examination. The slices were stained with hematoxylin-eosin to observe the structure and distribution of the connective tissue of interest. The thicknesses of the dense connective tissue samples were recorded at different points in the histological slice. All slices were analyzed and measured using a Leica DMD108 digital micro-imaging instrument (Leica Microsystems).

3. Results

3.1. Dissection study

Stratigraphic dissection of the gluteal and posterior thigh exposed the superficial fascia (subcutaneous adipose tissue) and the deep fascia underneath. The deep fascia surrounding the gluteus maximus muscle, the gluteal fascia, continued distally as the fascia lata. The latter covered and compartmentalized the thigh muscles. The hamstring muscles were present in the posterior compartment.

The gluteus maximus muscle also had its own fascia, an epimysium which was a continuation of the connective tissue that embedded the different muscle fascicles (the perimysium and endomysium) and emerged on the anterior aspect of the gluteus maximus muscle. At this point, the epimysium of the gluteus maximus was continuous with the perineal fascia.

The gluteus maximus muscle covered the ischial tuberosity and 4–6 cm of the PAHM. When detaching the gluteus maximus muscle, a fascial expansion was observed from its anterior aspect that expanded to the PAHM (Fig. 1). Laterally, the fascial expansion split to form a canal that surrounded the sciatic nerve and the posterior femoral cutaneous nerve (Fig. 1).

During detailed dissection, we observed the attachment of the sacrotuberous ligament on the proximal portion of the ischial tuberosity together with, the PAHM more distally. Superficial to these attachments, an annular-like shape composed of dense connective tissue with transversally distributed fibers was observed, close to the anterior structures (Figs. 2 and 3). This structure anchored directly to the lateral and medial aspects of the ischial tuberosity, thereby covering the insertion of the sacrotuberous ligament, the origin of the tendon of the long head of the biceps femoris, the semitendinosus muscle and the semimembranosus tendon (Fig. 2). The annular-like structure resembled a rectangular strap or retinaculum, and measured (means) 5.6 ± 0.45 cm long by 4.1 ± 0.16 cm wide. In the most superior and superficial aspect of the annular-like structure, we also observed the attachment of the fascial expansions from the anterior epimysium of the gluteus maximus muscle (Fig. 1).

When removing the annular-like structure, its the deep lateral aspect was continuous with the biceps femoris epitenon, while the deep medial aspect was easily detachable from the epimysium of the semitendinosus because of a lax connective tissue layer was between them.

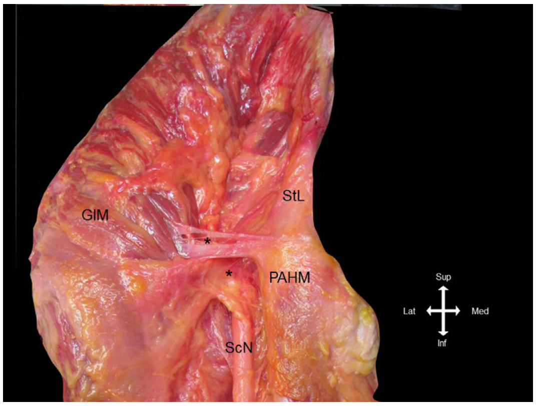

Fig. 1. Proximal attachment of the hamstrings (PAHM). The gluteus maximus (GlM) muscle has been detached from midline and put aside laterally. Fascial expansions from the gluteus maximus (*) to the PAHM form a tunnel-like structure around the sciatic nerve (ScN). Sacrotuberous ligament (StL).

3.2. Anatomic sections

Successive transverse, sagittal and coronal anatomical cross-sections revealed the presence of an annular-like structure that encompassed the PAHM confirming the findings of the detail dissection. In addition, fascial expansions were observed from the anterior aspect of the gluteus maximus epimysium to the annular-like structure (Fig. 4).

Transverse cross-sections at the level of the ischial tuberosity showed fascial expansions interspersed with adipose tissue. These came from the anterior aspect of the gluteus maximus epimysium, surrounding the sciatic nerve and the posterior femoral cutaneous nerve (Fig. 5).

3.3. Histological study

The histological analysis evidenced an annular-like dense connective tissue structure that was consistent with a retinaculum (Fig. 6A). Transverse slices showed that a layer of dense connective tissue, with transverse collagen fibers and adjacent loose layers of connective tissue formed the retinaculum. This structure covered the distal sacrotuberous ligament and the PAHM. Successive slices showed that the deep lateral aspect of the retinaculum adhered tightly to the superior and lateral aspects of the long head of the proximal biceps femoris epitenon (Fig. 6B and B′). There was a layer of connective tissue between the deep medial aspect of the retinaculum and the epimysium of the semitendinosus (Fig. 6C and C′). The retinaculum enveloped and adapted to the morphology of the proximal hamstring attachment. The retinaculum thickness was 925 ± 123 μm.

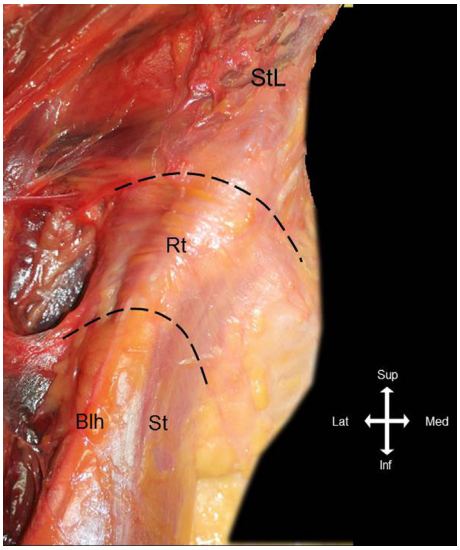

Fig. 2. A retinaculum-like structure (Rt: limited by the dotted lines) superficial to the proximal attachment of the hamstrings (Blh, biceps femoris long head and ST, semitendinous) and the sacrotuberous ligament (StL).

Superficial to, and independent from, the retinaculum was a more dense and irregular layer of connective tissue belonging to the anterior fascia of the gluteus maximus (Fig. 6B′ and C′).

4. Discussion

In this study we demonstrated the presence of an annular structure that was constant, dense, and composed of connective tissue, with similar anatomical and histological properties to a retinaculum. The structure covered the origin of the PAHM, and the distal attachment of the sacrotuberous ligament. Superficially, this retinaculum-like structure receives loose connective tissue expansions from the epimysium of the gluteus maximus, which was uncovered when placing its muscle aside. These expansions also extend laterally to the PAHM to embed and compartmentalize the sciatic nerve and the posterior femoral cutaneous nerves. We are not aware of any reports of either the annular structure or the tissue expansions in the existing literature.

Anatomically, various structures hold tendons in position and have different names depending on their location, such as retinaculum, fibrous pulleys, annular ligaments or fibrous sheaths (Benjamin et al., 2008). Similarly, various texts define retinaculum as a structure that contains or holds in place a tissue, organ or tendon (Glanze et al., 1993; Moore and Dalley, 2006); additionally, they prevent tendons from bowstringing, contribute to force transmission and may contain muscles and nerves (Kumka and Bonar, 2012). Based on these principles, the structure we found surrounding the PAHM in the current study is consistent with a retinaculum-like structure. In general, a retinaculum serves to provide a smooth surface for tendons to contact and slide longitudinally when their associated muscle contracts (Benjamin, 2009). However, in contrast to similar anatomic structures, the retinaculum surrounding the PAHM adheres very closely to the attachments of the hamstring muscles (especially the tendon of long head of biceps femoris). Its function is therefore more that of an anchoring structure than one that enables tendon sliding.

The histological study of the annular retinaculum confirmed that it was formed by dense connective tissue, which is compatible with the typical histological pattern of a retinaculum (Klein et al., 1999; Stecco et al., 2010). However, it differed from a typical retinaculum (Benjamin, 2009) in that no fibrocartilage present within the dense connective tissue, on the surface exposed to the PAHM. We hypothesize that this lack of fibrocartilage is a direct consequence of it having a containing and anchoring function, rather than being an enabler of longitudinal sliding. In addition, its annular shape and disposition support the hypothesis that the retinaculum is responsible for anchoring the sacrotuberous ligament and the PAHM, specifically the proximal attachment of the long head of the biceps femoris. Thus, the structure probably has a direct role in force transmission during muscle contraction, establishing a synergy between the gluteus maximus muscle and the long head of the biceps femoris.

Due to their high incidence, several studies have attempted to identify mechanisms how and why hamstring injuries occur (Verrall et al., 2003; Gabbe et al., 2005). However the evidence so

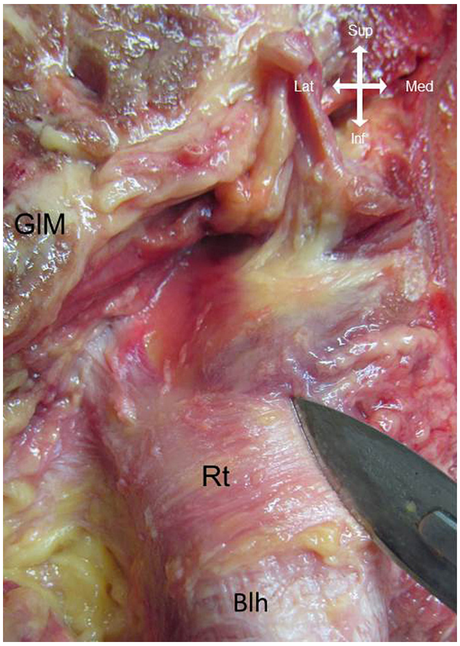

Fig. 3. Transverse fibers of the retinaculum (Rt) in relation to the biceps femoris long head (Blh).

far remains inconclusive or contradictory (Orchard and Best, 2002; Orchard, 2002). The anatomical morphology and distribution of the hamstring muscle complex has been pointed out as a key factor in the injury process (Kumazaki et al., 2012), mostly at the proximal aspect (Beltran et al., 2012; Sato et al., 2012), which motivated the present study. The tight adherence of the retinaculum to the PAHM, may explain the high incidence of lesions in this area.

It is well known that the proximal attachment of long head of biceps femoris is the most frequently injured tissue in the hamstring muscle complex (Woods et al., 2004; Thelen et al., 2005; Brooks et al., 2006; Thelen et al., 2006; Askling et al., 2007b). The anatomical and histological findings of the current study could suggest a role for the described retinaculum in injuries to the proximal hamstring muscle complex specifically in the common injuries to the tendon of the long head of the biceps femoris. The long head of biceps femoris muscle and the semitendinosus muscle have a proximal common tendon however the long head of the biceps femoris has a stronger adherence to the retinaculum compared to the adherence of the semitendinosus muscle to the retinaculum (Fig. 6). Therefore a shear stress during muscle contraction could act on the PAHM and may explain the high injury rate of the proximal attachment of long head of biceps femoris. Moreover, the gluteus maximus fascial connections, which are superficial and perpendicular to the retinaculum (Fig. 4) could also play a role in the aforementioned injury mechanism of the long head of biceps femoris.

Both the gluteus maximus muscle and specific pelvic positions are involved in the sciatic neuropathy (Singh and Jolly, 1963; Martin et al., 2011). Fibrotic bands of connective tissue around the sciatic nerve at the level of the proximal hamstring complex may compress the nerve, producing a compressive neuropathy (Puranen and Orava, 1991; McCrory and Bell, 1999). These fibrotic bands can be removed through arthroscopic surgery (Martin et al., 2011, 2012). The location of the fibrotic bands is consistent with the location of the epimysial expansions from the gluteus maximus to the sciatic nerve found in the present study, which expand around the nerve forming a nerve tunnel.

Given that the present study was performed on cadaver specimens, it has several limitations. For example, we were unable to assess muscle contraction to evaluate force transmission and the previous habits of the donors were unknown (sports involvement, active/passive job, etc …). However the present results have evidenced different types of muscle-retinaculum attachments at a histological level that will most likely transmit force in a different way. Recent studies have observed that understanding the anatomy of the

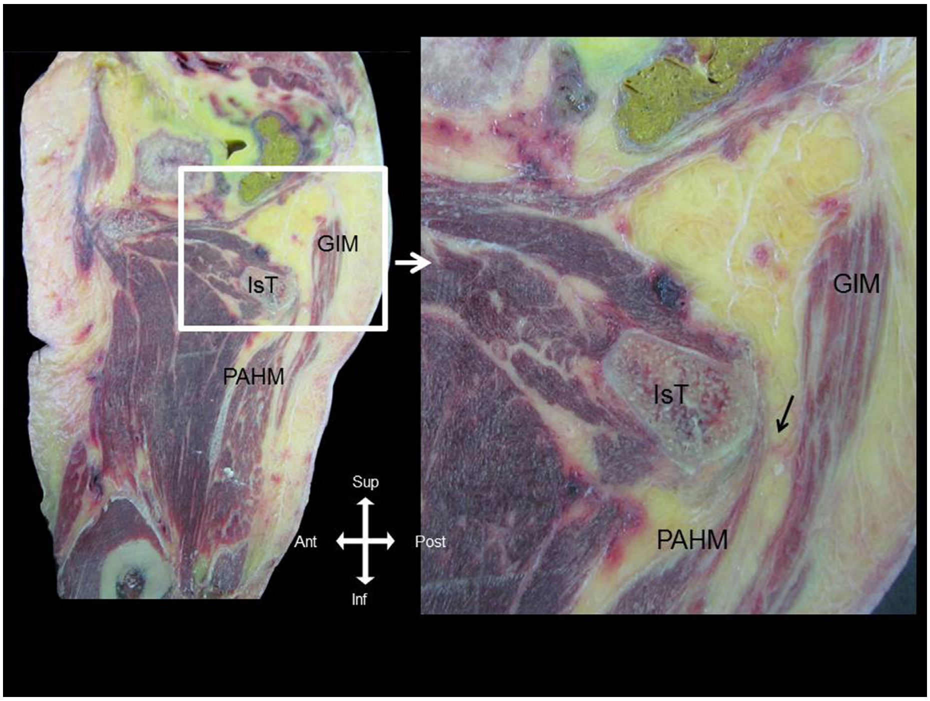

Fig. 4. (A). Sagittal section of the pelvis. (B) Detail of sagittal section of the pelvis. A. Gluteus maximus muscle (GlM) expansions (black arrow) to the proximal attachment of the hamstrings Fig. 1 (PAHM) and retinaculum. Ischial tuberosity (IsT).

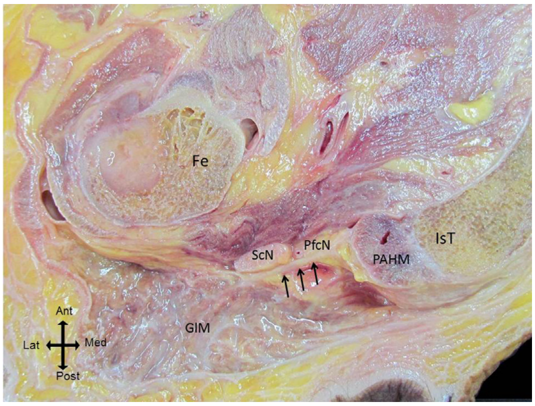

Fig. 5. Transverse section of the pelvis at the level of the ischial tuberosity (IsT) showing the tunnel for the sciatic nerve (ScN) and the posterior femoral cutaneous nerve (PfcN). The posterior border of the sciatic nerve tunnel is formed by the fascial expansion of the gluteus maximus (arrows). Femur (Fe), proximal attachment of hamstring muscles (PAHM) and gluteus maximus muscle (GlM).

hamstring muscle complex is critical to understanding the mechanisms through which they sustain injury and in determining appropriate treatment strategies (Sato et al., 2012). At the present a wide range of manual therapy, rehabilitation and physiotherapy that focus on global or fascial approaches is available to treat muscle injuries (Pilat, 2003; Myers, 2009). In addition, neuropathies can be treated by mobilization of the soft tissues surrounding nerves (Butler and Jones, 1991; Barral and Croibier, 2009). The anatomical and histological results of this study could explain the efficacy of these therapies through their effects on the retinaculum and its fascial relations. For this reason, it is important to understand the role of the annular retinaculum structure described in this study as part of the proximal hamstring muscle–tendon complex. This could have major relevance in the biomechanics of the lower limb and in understanding of the mechanism and progress of hamstring injuries.

Further studies are necessary to demonstrate force transmission between the gluteus maximus and the retinaculum to explore the possible consequences on the proximal hamstring muscle–tendon complex and to design interventions aimed at lowering such force transmission.

In conclusion, the current study confirms the presence of an annular retinaculum-like connective tissue structure, superficial to

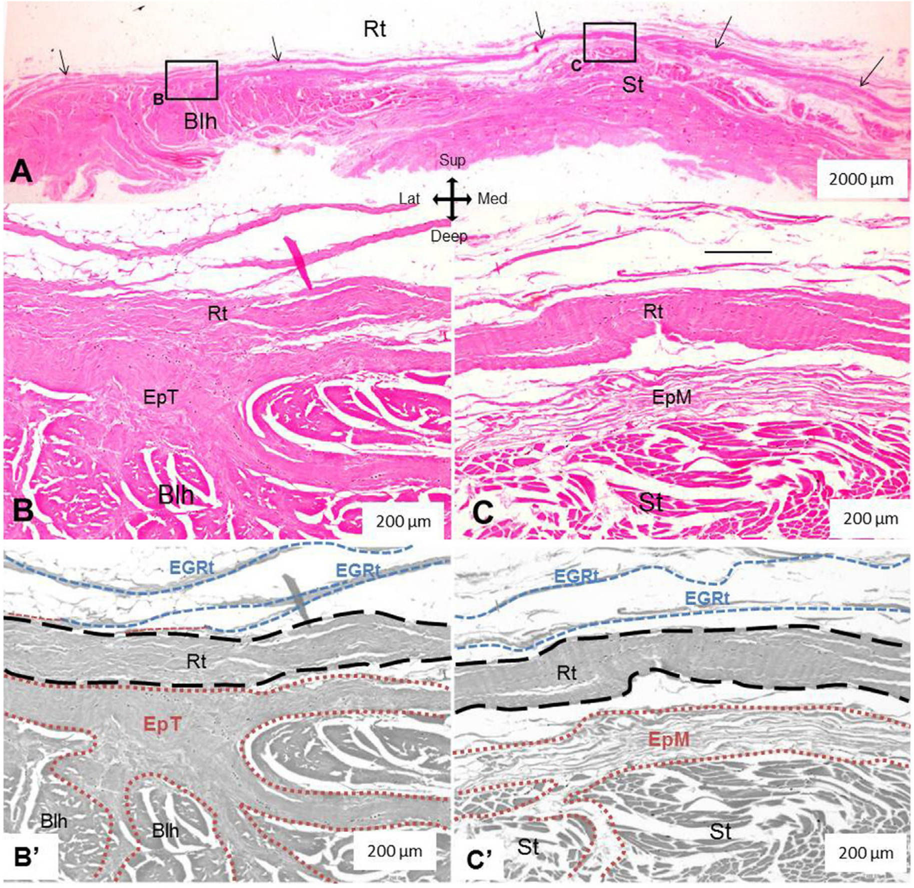

Fig. 6. Image A Low magnification image of the retinaculum (Rt and arrow) stained with hematoxylin-eosin. It covers the proximal biceps femoris long head tendon (Blh) and the proximal semitendinous muscle (St). Frames show magnification points corresponding to images B and C. Image B is a magnification showing the lateral aspect of the retinaculum (Rt) superficial to the tendon of the long head of the biceps femoris (Blh). Note a very slight difference between the retinaculum (Rt) and the connective tissue density of the epitenon (EpT), which suggests the presence of two different but tightly bound structures. Image C is a magnification showing the medial aspect of the retinaculum (Rt) superficial to the semitendinous muscle (St). Note the different collagen fiber density between the retinaculum (Rt) and the proximal semitendinous epimysium (EpM). Semitendinous muscle (ST). Image B′,C′ Superimposed diagram over images B and C showing the limits of the different structures described. Retinaculum (Rt, back dotted line), expansions of the gluteus maximus epimysium to the retinaculum (EGRt, blue dotted line), epitendon (EpT, red dotted line), semitendinous muscle epimysium (EpM, red dotted line), tendon of the long head of the biceps femoris (Blh), and the proximal semitendinous muscle (ST). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the PAHM that is reinforced by expansions of the anterior epimysium of the gluteus maximus muscle.

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