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ORIGINAL ARTICLE

Anatomical study of the proximal origin of hamstring muscles

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Abstract
Purpose It is relatively well accepted that the long head of the biceps femoris and the semitendinosus both originate from the ischial tuberosity as a common tendon. However, it is also widely known that the biceps femoris is consistently injured more than the semitendinosus. The purpose of this study was to examine the origins of the hamstring muscles, to find an anatomic basis for diagnosis and treatment of injuries of the posterior thigh regions.
Materials and methods Twenty-eight hips of fourteen adult Japanese cadavers were used in this study. In twenty hips of ten cadavers, the positional relationships among the origins on the ischial tuberosity were examined. In eight hips of four cadavers, histological examination of the origins of the hamstrings was also performed.
Results The origin of the long head of the biceps femoris adjoined that of the semitendinosus. In the proximal regions of these muscles, the long head consisted of the tendinous part; however, the semitendinosus mainly consisted of the muscular part. Some of the fibers of the biceps tendon extended to fuse with the sacrotuberous ligament. The semimembranosus muscle broadly originated from the lateral surface of the ischial tuberosity.
Conclusion The origins of the long head of the biceps femoris and the semitendinosus are found to be almost independent, and the tendon of the long head is partly fused with the sacrotuberous ligament. The high incidence of injuries to the long head of the biceps femoris could be explained by these anatomical configurations.

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Introduction

The colloquial term "hamstrings" refers to four muscles located in the posterior compartment of the thigh: the semimembranosus, the semitendinosus, and the long and short heads of the biceps femoris. The ischial tuberosity is the site of origin of the hamstring muscles except for the short head of the biceps femoris. Hamstring muscle strain is one of the most common injuries in sports medicine [1]. To treat injuries of hamstring muscles, careful consideration of precise location and severity is necessary. The condition of these injuries has been evaluated in detail, because of progress in imaging methods, for example magnetic resonance imaging (MRI) [2–4]. Thus, detailed anatomical information regarding hamstring muscles is critical to understanding the precise situation of such hamstring muscle injuries and determining whether the appropriate treatment strategy includes conservative or surgical treatment.

It is well known that the long head of the biceps femoris and the semitendinosus both originate from the ischial tuberosity as a common tendon [5–8]. However, the positional relationships of the origins on the ischial tuberosity of the hamstring muscles, including the semimembranosus, the long head of the biceps femoris, and the semitendinosus, remain unclear. However, irrespective of the structure of the common tendon, it is widely known that the biceps femoris is consistently the most commonly injured muscle of the hamstrings. For this reason we hypothesized there might be new findings about the origins of the hamstring muscles that were different from anatomical knowledge previously described.

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The purpose of this study was to examine the detailed morphology of the origins of the hamstring muscles to collect basic data as reference information to facilitate diagnosis and treatment of injuries of the hamstring muscles.

Materials and methods

Twenty-eight hips of fourteen adult Japanese cadavers (six males and eight females: mean age 77.3 years old) were used in this study. Of the twenty-eight hips, twenty were randomly assigned to macroscopic analysis and eight to histological examination. Specimens were randomly selected from cadavers used for dissection practice. The cadavers were donated to the Department of Anatomy of the School of Medicine, Tokyo Medical and Dental University.

Cadavers were fixed in 8 % formalin and preserved in 40 % ethanol. For dissection of the hamstring muscles, the surrounding muscles and nerves were precisely identified and carefully removed. Positional relationships among the origins of the hamstring muscles on the ischial tuberosity were meticulously examined. For twelve randomly selected specimens from twenty hips, the muscular portion was removed from the myotendinous units of the hamstring muscles, and the tendons were left attached to the ischial tuberosity to evaluate their specific characteristics. In addition, the relationship between the tendons of the hamstring muscles and the sacrotuberous ligament was also investigated.

Further, we performed microscopic examinations of the relationship between the tendons of the hamstring muscles and the sacrotuberous ligament for eight randomly selected specimens (four right and four left hips: two males and two females). We removed the small region surrounding the ischial tuberosity with the tendons and sacrotuberous ligament as a block. The blocks were wholly decalcified for 1–2 weeks in a solution containing aluminium chloride, hydrochloric acid, and formic acid, as described by Plank and Rychlo [9]. The blocks were then immersed in 4 % paraformaldehyde at 4 °C overnight; the fixed blocks were routinely embedded in paraffin wax. Subsequently, the blocks were serially sectioned (5 μm thickness), and stained with Masson trichrome.

Results

On the ischial tuberosity, the areas of the origins of the hamstring muscles were clearly divided into two parts: the anterolateral part was occupied by the semimembranosus, and the posteromedial part was occupied by the long head of the biceps femoris and the semitendinosus. In the posteromedial part of the origins of the hamstring muscles, the long head of the biceps femoris and the semitendinosus were observed to be tightly adjoined (Fig. 1a). However, it was found that these two muscles could be clearly identified. In the proximal region the long head was composed of the tendinous part. On the other hand, the proximal region of the semitendinosus was composed of the muscular part. The muscle mainly originated from the medial surface of the tendon of the long head of the biceps femoris, and partly from the region just medial to the origin of the long head.

To observe the tendinous portions in the proximal parts of these muscles, we meticulously removed the muscular portions. The long head was composed of the thick and long tendon (Fig. 1b). On the other hand, the semitendinosus contained a thin and short tendon. Both tendons were partly adjoined. Therefore, the origin of the long head of the biceps femoris adjoined that of the semitendinosus. In the proximal regions of these muscles, the long head consisted of the tendinous part, however the semitendinosus mainly consisted of the muscular part.

In all specimens, the posterior compartment of the tendon of the long head of the biceps femoris was widely connected to the sacrotuberous ligament as a strong tendinous part via the ischial tuberosity. For three specimens it was observed that most of the fibers of the sacrotuberous ligament were directly connected to the tendon of the long head of the biceps femoris (Fig. 2a). However, the tendon of the semitendinosus muscle was not found to be a direct extension of the sacrotuberous ligament. To examine the fibers of the sacrotuberous ligament and the tendon of the long head, we conducted histological observation of the fibers covering the ischial tuberosity. Separation of the ligament and the tendon was not confirmed by the histological findings (Fig. 2b). The fibers of both structures were at least partly connected to each other, and it was found that fibers of the two structures were not clearly independent of each other. The sacrotuberous ligament was also attached to the posterior margin of the ischial tuberosity, and some fibers of the ligament extended to the medial surface of the tuberosity as a falciform process (Fig. 2c).The semimembranosus muscle originated from the lateral surface of the ischial tuberosity as a broad area posterior to the origin of the quadratus femoris muscle (Fig. 3). The origin of the muscle was clearly independent of those of the long head and the semitendinosus. The origin of the semimembranosus had two directions of orientation:

1. the major part was directed vertically towards the tendon of the muscle (indicated by a black arrow); and
2. the minor part was directed posteriorly towards the tendon (indicated by a red curved arrow).

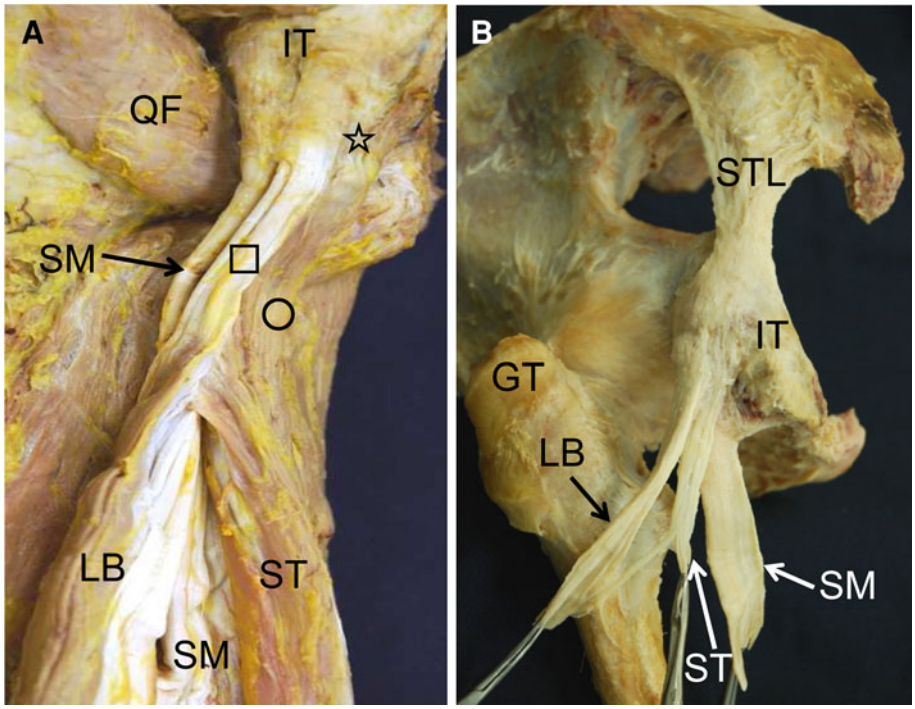

Fig. 1 The origin of the long head of the biceps femoris and the semitendinosus (posterior, *left-sided view* of the left thigh). **a** The long head of the biceps femoris originated from the postero-medial surface of the ischial tuberosity as a thick tendinous part (*square*), and the semitendinosus tightly adjoined the medial surface of the tendon of the long head of the biceps femoris as a muscular part (*circle*), and partly originated from the ischial tuberosity as a short and thin tendinous part medial to the tendon of the long head (*star*). **b** After removal of the muscular parts, the tendons of the hamstring muscles were observed. The semitendinosus muscle had a short and thin tendon which originated directly from the ischial tuberosity. *GT* greater trochanter, *IT* ischial tuberosity, *LB* long head of the biceps femoris, *QF* quadratus femoris, *SM* semimembranosus, *ST* semitendinosus, *STL* sacrotuberous ligament

Both parts were combined to a thick tendon at the distal part of the ischial tuberosity (indicated by a black asterisk).

Discussion

Many reports imply the long head of the biceps femoris muscle and the semitendinosus muscle have a common origin. Sallay et al. [10] stated that tendons of the long head of the biceps femoris and the semitendinosus form a conjoint tendon, and, further, the tendon of the semimembranosus also joins to form a common tendon which originates from the ischial tuberosity. Miller et al. [11] reported that the semitendinosus and the long head of the biceps femoris have a common origin from the ischial tuberosity, although the semimembranosus originates just laterally. Woodley and Mercer [12] reported that the conjoint tendon occupies a medial quarter of the medial portion of the ischial tuberosity, and the semitendinosus muscle fiber arises from the lateral three-quarters of the ischial tuberosity. In our study, the origins of the hamstring muscles were observed on the basis of characteristics of the tendinous portions of each muscle, especially patterns of origins and lengths. The long head of the biceps femoris muscle originated from the ischial tuberosity as a thick and long tendinous part. The semitendinosus muscle mainly originated from the medial surface of the tendon of the long head of the biceps femoris, and also originated from the ischial tuberosity with a thin tendon and a muscular part. The semimembranosus muscle originated from the lateral surface of the ischial tuberosity as a tendon with a broad area of origin.

It is widely known that the biceps femoris is consistently the most commonly injured muscle of the hamstrings. Garret et al. [13] reported that injuries and ruptures of muscles commonly occurred at the musculotendinosus junction. The long head of the biceps femoris originates from the ischial tuberosity as a strong tendinous part, whereas the origin of the semitendinosus is mainly a muscular part and also a small tendinous part on the ischial tuberosity. The high incidence of injuries to the long head of the biceps femoris could be explained by the anatomical configuration, that is, the long head of the biceps femoris originates from the ischial tuberosity as a strong part and it is vulnerable to traction force in injuries. Because the semimembranosus originates vertically in two orientations, it could tolerate the force causing the injury, and because the semitendinosus has mainly muscular part and only a

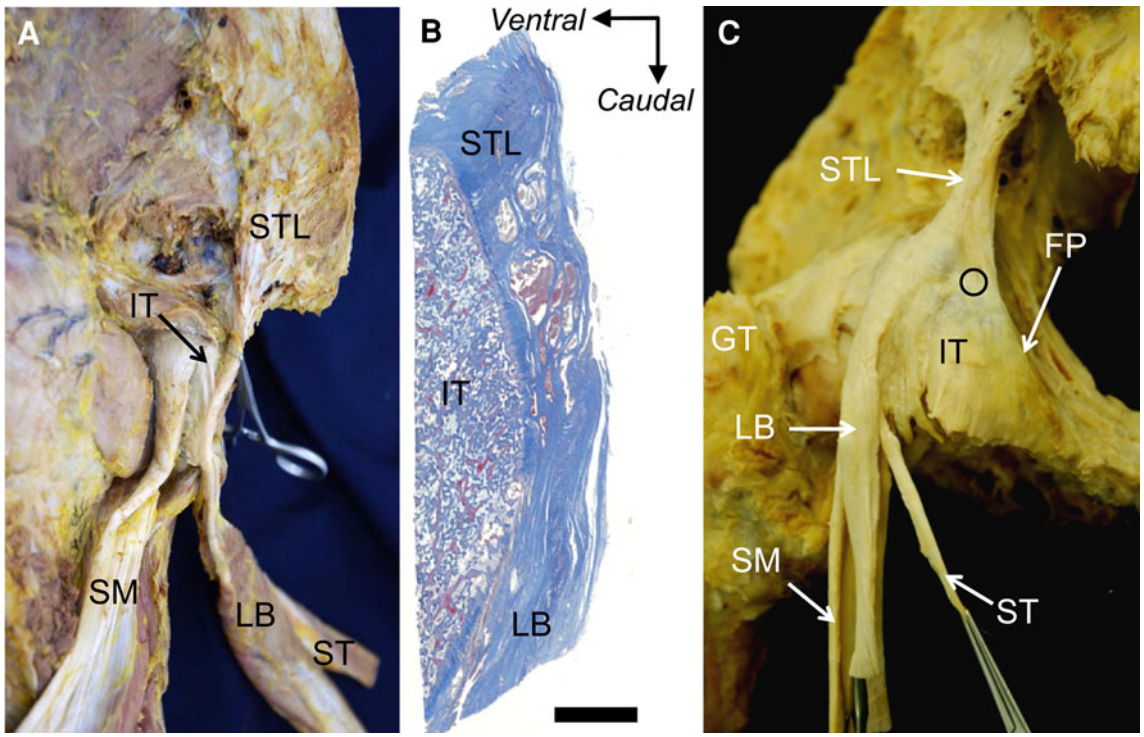

Fig. 2 The connection between the long head of the biceps femoris and the sacrotuberous ligament. **a** Posterior view of the left thigh. A wide posterior compartment of the tendon of the long head of the biceps femoris connected to the sacrotuberous ligament as a strong tendinous part via the ischial tuberosity. **b** The sagittal section of the ischial tuberosity stained with Masson trichrome. The fibers of the sacrotuberous ligament and long head of the biceps were at least partly connected to each other. *Scale bar* 5 mm. **c** Posterior, *left-sided view* of the left thigh. The sacrotuberous ligament was also attached to the posterior margin of the ischial tuberosity (*circle*) and some fibers of the ligament extended to the medial surface of the tuberosity as a falciform process. *FP* falciform process, *GT* greater trochanter, *IT* ischial tuberosity, *LB* long head of the biceps femoris, *SM* semimembranosus, *ST* semitendinosus, *STL* sacrotuberous ligament

small tendinous part on the ischial tuberosity, it could disperse the force causing the injury.

Some authors [14–17] regard the sacrotuberous ligament as the debris of the caudal portion of the long head of the biceps femoris. In contrast, Appleton [18] reported that, in some primates, formation of the sacrotuberous ligament is associated with extension of the origin of the gluteus maximus muscle to the ischial tuberosity. Uhlman et al. [19] do not believe the sacrotuberous ligament of humans is the transformed caudal head of the hamstring muscles, as suggested in many reports. Rather, they propose it is derived from the posterior part of the aponeurosis of the superficial gluteal muscle, and originated by translocation of the caudal head of this muscle from the tail to the ischial tuberosity in a pongid-like stage of our evolution. Moreover, they described degeneration of the gluteus maximus muscle, shortening of the tail length, and transformation of the caudal part of the gluteus maximus muscle into the sacrotuberous ligament. In our study we showed that part of the tendon of the long head of the biceps femoris is strongly connected to the sacrotuberous ligament.

In some specimens, the sacrotuberous ligament and the tendon of the long head of the biceps were directly connected to each other. It would be very difficult to discuss the origins of the ligament, however it might be suggested that there is a close relationship between the ligament and the tendon. Because of the connection between the thick and long tendon of the long head of the biceps femoris and the sacrotuberous ligament, longitudinal rupture of the long head of the biceps femoris might have an effect on the function of the gluteus maximus muscle.

Some implications of this study with clinical relevance can be proposed. In clinical cases of avulsion of the ischial tuberosity, soft tissue around the fracture sites is cleared for preparation of precise fixations of the bony segment [20, 21]. The anatomical information described in this study could avoid excessive cleaning of the soft tissue where the healthy origins are not injured. In addition, for diagnosis of hamstring muscles injuries in the proximal regions, the findings in relation to the connection between the tendon and the ligament should be taken into consideration. In avulsion fractures of the ischial tuberosity, if the connection between the tendon of the biceps and the sacrotuberous ligament did not rupture, this might be because the fracture site was, to some extent, displaced.

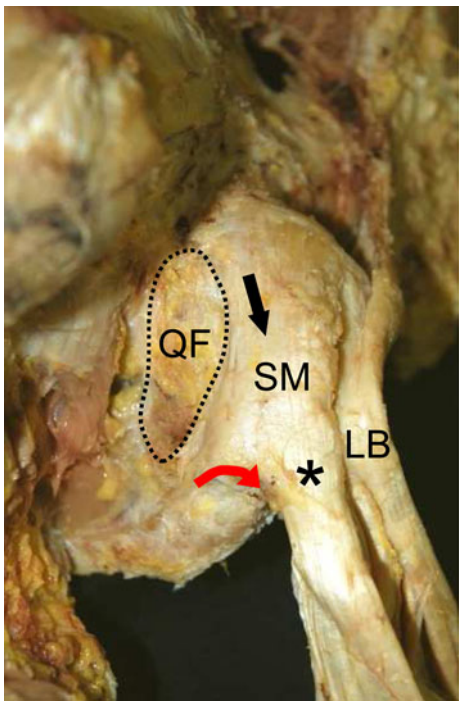

Fig. 3 The origin of the semimembranosus (posterior, *left-sided view* of the left thigh). The semimembranosus muscle originated from the lateral surface of the ischial tuberosity with a broad area of origin posterior to the origin of the quadratus femoris muscle (*black-dotted area*). The major part of the origin of the semimembranosus was directed vertically to the tendon of the muscle (*black arrow*) and the minor part was directed posteriorly to the tendon (*red curved arrow*). Both parts were combined as a thick tendon at the distal part of the ischial tuberosity (*black asterisk*). *LB* long head of the biceps femoris, *QF* quadratus femoris, *SM* semimembranosus

This study has revealed that the origins of the long head of the biceps femoris and the semitendinosus are adjoined. In the proximal regions of these muscles, the long head consisted of the tendinous part; the semitendinosus, however, mainly consisted of the muscular part. Some of the fibers of the long head extended to fuse with the sacrotuberous ligament. Additionally, the semimembranosus had a broad area of origin on the lateral surface of the ischial tuberosity that was clearly independent of those of the long head of the biceps femoris and the semitendinosus. We believe these anatomical findings on the origins of the hamstrings muscles are quite useful as a precise basis for exact diagnosis and appropriate treatment of hamstring muscle injuries.

Conflict of interest All authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article. The authors declare that they have no conflict of interest.

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