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ORIGINAL ARTICLE

The gracilis and semitendinosus muscles: a morphometric study on 18 specimens with clinical implications

Chahine Assi[1,2] · Francois Bonnel[3,4] · Jad Mansour[1,2] · Jimmy Daher[1,2] · Bassam Gerges[5] · Alfred Khoury[1] · Kaissar Yammine[1,2]

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Abstract

Introduction The pes anserinus consists of the sartorius, semitendinosus, and gracilis muscles. They coalesce together with the leg fascia to form the anserine plate. The semitendinosus and gracilis both form the deep layer of this plate and are clinically relevant for ligament reconstruction. The aim of the study is to report a detailed morphometric evaluation of the semitendinosus and gracilis muscles and assess their clinical implications.

Methods Using a rigorous dissection process on 18 cadaveric hips, measurements of both the semitendinosus and gracilis muscles with bone parameters were conducted. We measured the following: (a) total femur, femoral shaft, and neck lengths, (b) total muscle lengths, and (c) intra-muscular and extra-muscular (free) tendon lengths. Correlation values between bone variables, muscle variables, and in-between muscle variables were computed.

Results The total muscle and the distal intra-muscular tendon length of the St and Gr are correlated with the total femur length. When compared to gracilis, the total muscle and distal intra-muscular tendon lengths of the ST are much better correlated with the total femur length. The free distal tendon length for both muscles did not show a significant correlation with any of the femoral bone lengths.

Conclusion The variability of tendon length of the ST/Gr poses a significant challenge to surgeons. This study reports a detailed morphometric evaluation of the ST/Gr hamstring muscle and tendons. It revealed a positive correlation between the femoral length and the ST/Gr graft lengths. This could help orthopedic surgeons in predicting the graft lengths pre-operatively and develop better planning for reconstructive surgeries.

Keywords Hamstring · Semitendinosus · Gracilis · Anterior cruciate ligament reconstruction

Introduction

Pes anserinus (PA) is an anatomical terminology used to describe the three conjoined tendons that insert onto the anteromedial aspect of the proximal tibia. It is formed by the free distal tendons of the sartorius, semitendinosus (ST) and the gracilis (Gr) muscles. The tendons coalesce with the fascia of the leg to form the anserinus plate shortly distal to their insertion. The sartorius forms the superficial layer of the anserinus plate while both the ST and Gr form the deep layer [3, 9]. Physiologically, these muscles are known to contribute to the rotational stability of the knee [24, 39].

Clinical relevance

This anatomical landmark is of major clinical importance since tendon autografts from the ST and Gr are commonly

✉ Kaissar Yammine
cesaryam@gmail.com

1 Department of Orthopedic Surgery, Lebanese American University Medical Center-Rizk Hospital, Lebanese American University School of Medicine, Achrafieh, Lebanon

2 Center for Evidence-Based Anatomy, Sport and Orthopedics Research, Beirut, Lebanon

3 Anatomy Laboratory, School of Medicine, BD. Henri IV, 34000 Montpellier, France

4 Department of Orthopedic Surgery, Clinique Beau Soleil, 119 Avenue de Lodeve, 34070 Montpellier, France

5 Department of Anesthesia, Lebanese American University Medical Center-Rizk Hospital, Lebanese American University School of Medicine, Achrafieh, Lebanon

used mostly for anterior cruciate ligament (ACL) reconstruction. Less frequently, those tendons were reported to serve as grafts for acromioclavicular reconstruction, patellar tendon ruptures, calcaneal tendon repair and reinforcement of medial knee stabilizing structures [17, 38].

Several graft choices exist for ACL reconstruction where the ST/Gr graft along with the patellar tendon, bone-tendon-bone (BTB), graft is most commonly chosen [33]. Many surgeons prefer the ST/Gr graft over the BTB since it provides powerful material strength without affecting the extensor mechanism of the knee [4]. Unlike BTB graft, the ST/gracilis graft is harvested via a small incision, has less graft donor site morbidity, less postoperative anterior knee pain and minimal discomfort during knee joint motion [11].

Gross anatomy

The gracilis muscle is a thin, long muscle of the medial compartment of the thigh that originates from the ischio-pubic ramus and courses inferiorly toward the knee where it inserts posterior to the Sartorius muscle (lateral compartment) and anterior to the semitendinosus tendon (posterior compartment), its main vascularity originates from the adductor artery [14, 46, 51]. It allows flexion and adduction of the hip and also is a knee extensor playing a key role in the rotational stabilization of the knee, combating excessive lateral rotation by elastic recall in medial rotation [24, 29, 39].

The semitendinosus is a fusiform pennate muscle that originates from the ischial tuberosity along with long head of the biceps femoris muscle and courses as a fleshy spindle shaped muscle until it reaches the posterior mid-thigh where it becomes a long round tendon. The tendinous part then courses inferiorly and passes through the medial aspect of the popliteal fossa before bending over the medial tibial plateau to insert onto the anteromedial part of the proximal tibia posterior to the gracilis tendon [51]. It allows for knee flexion and hip extension and similar to the gracilis muscle, it plays an essential role in the rotational elastic stabilization of the knee combating excessive lateral rotation of the tibia [24, 39].

The research questions

The variability in the length of the ST/Gr graft could be a significant challenge for surgeons. Having a close approximation value of the graft pre-operatively would help surgeons in the process of graft selection/indication. The harvested graft is usually folded in either a double-, triple- or quadruple-strand, knowing that the higher the number of strands, the higher is the resistance for rupture [5, 38]. Nevertheless, the possible number of strands is related to the length of the ST/Gr graft. Different methods have been used preoperatively to assess hamstring autograft size, such as anthropometric studies and imaging modalities (MRI, Ultrasound and CT scans). However, the reported results were highly variable and not applicable to clinical settings [19]. Based on a standardized method of dissection and measurement, this paper attempts to answer two questions: (a) what are the exact lengths of the different parts of ST and gracilis muscles? and (b) which parts have their lengths correlated with the femur bone length?

Therefore, the aim of our study is to report a detailed morphometric evaluation of the semitendinosus and gracilis muscles and to look for clinical correlations between free tendons (extra-muscular), intra-muscular with femur lengths.

Materials and methods

Specimen preparation

Eighteen formalized hips were dissected from nine cadavers (five females and four males) with nine hips for each side. All cadavers were of senior age and were embalmed using formalin fixation. The samples included the lumbar spine, pelvis and both lower limbs. Ethical approval for this study was granted by the Anatomy Laboratory of the University in accordance with the Guidelines for Cadaver Dissection in Education and Research of Clinical Medicine. The semitendinosus and gracilis muscles were extracted totally after recording their course in the thigh before conduction of measurements. Femoral bone measurements were carried out following removal of all the hip and thigh muscles.

Definition of the studied structures

The extra-muscular tendons (proximal and distal) were termed free tendons (Fig. 1). The aponeurosis (the fibro-tendinous tissue) within the muscle belly was termed the intra-muscular tendon (Fig. 2).

Bone measurements

The total femoral length is defined as the distance between the superior edges of the femoral head to the center of the distal articular line tangent to both condyles. The length of the femoral diaphysis was measured from the superior edge of the greater trochanter to the center of the articular line tangent to both condyles.

Muscle measurements

Total and belly muscle lengths

Using a measuring tape, the lengths of the medial and lateral border of the muscle were conducted. The total length

Fig. 1 The gracilis muscle

(muscle + tendon) was defined as the average of the total lengths of the lateral and medial borders.

Fig. 2 The semi-tendinous muscle

Tendon measurements

We defined the limit between the free tendon and the intra-muscular tendon as the area of insertion of the muscle belly fascicles. The length of the free tendon was measured from the edge of the extra-muscular tendon to its intersection with the belly fibers. The length of the intra-muscular tendon was measured from the intersection to the termination of the tendon fibers within the belly part.

Statistical analysis Mean values were calculated with their standard deviation (SD). Univariate regression analysis was conducted to test correlations between tendon and bone values. A p value less than 0.05 was considered as significant. All analyses were performed using the StatsDirect software.

Table 1 Bone measurement results

	Total femur length	Femoral shaft length	Femoral neck length
Minimum	37.5	36.5	4.5
Maximum	56.6	48.5	7.3
Median	43.4	42	5.9
Mean	44.3	42.3	5.9
Standard deviation	4.9	3.5	0.8

Results

Morphological and size results

Femoral bone measurements

The descriptive statistics of the different measurements of the femoral bone are shown in Table 1.

The gracilis muscle

The muscle is inserted proximally on the pubic bone and symphysis via a short tendon (average = 2.2 cm) in 89% of cases or less frequently through its fleshy fibers (11% of cases). The muscular body descends vertically along the medial edge of the adductor muscles to join the tendons of the sartorius muscle and the ST muscle to form the pes anserinus. Large and flattened at its origin, the length of its fascicles showed a mean of 43.4 cm. The distal-free tendon–intra–muscular tendon complex represents on average 51% of the total muscle length, with a mean intra-muscular tendon length of 9.6 cm and a mean free distal tendon length of 12.8 cm. Size values are shown in Table 2.

The semitendinosus muscle

This muscle is inserted proximally onto the ischial tuberosity through a very short tendon in all cases (mean = 1.2 cm). The proximal tendon always joins that of the long head of the femoral biceps.

Its belly mean length of 13.1 cm represents only 29% of the total length while the tendon and aponeurotic structures represent on average 85% of its length. On the lateral face of the muscular body and at mid-height of all specimens, an oblique intermediate intra-muscular tendon was present, extending from dorsal to ventral and halving the average length of the muscle fascicles.

The intra-muscular tendon and free distal tendon of the ST present mean lengths of 15.5 and 11.2 cm, respectively. In all specimens, the free distal tendon sends fibers from its posterior edge which is lost in the crural fascia of the leg. Size values are shown in Table 3.

Correlation analysis

For both muscles, the total muscle length and the distal intra-muscular tendon length are correlated with the total femur length whereas only the ST showed correlation between the same both lengths with the femoral diaphysis length. The total muscle and distal intra-muscular tendon lengths of the ST are much better correlated with the total femur length

Table 2 Size values of gracilis muscle

Gracilis	Total length (cm)	Proximal tendon (cm)	Distal tendon (cm)	Distal intramuscular tendon (cm)	Distal-free tendon (cm)	Belly length (cm)
Minimum	35.5	0	2	0	6	13.7
Mean	43.4	2.2	12.8	3.4	9.6	22.6
Maximum	51.5	4	18.5	14	15	27.3
SD	5	1.1	3.7	3.1	2.6	3.6
Median	43.9	2.2	13	3	9	22.2

Table 3 Size values of Semi-Tendinous muscle

Semi-tendinous	Total length (cm)	Proximal Tendon (cm)	Distal Tendon (cm)	Distal Intramuscular Tendon (cm)	Distal-Free Tendon (cm)	Belly length (cm)
Minimum	36	0	8	0	6	5.33
Mean	44.9	1.2	15.5	10.4	11.2	13.07
Maximum	54.7	5	20	16.5	17	25
SD	5.3	1.3	3.1	3.78	3.01	5.2
Median	44.2	1	16	11	11	12.1

when compared to gracilis. The free distal tendon length for both muscles did not show significant correlation with any of the femoral bone lengths. All correlation values are shown in Table 4.

Discussion

Major findings and clinical implications

This study demonstrates that for both muscles, the free tendon length is correlated to the femoral bone length. Total muscle and distal intramuscular tendon lengths were highly correlated with the total femoral length and that for both muscles. Only the ST was found to show correlation between belly and distal intramuscular tendon lengths *and* femoral diaphysis length. However, this correlation was lesser than that with the total femoral length. From an anatomical perspective, knowing the total femoral length could serve as a good estimation of the distal intramuscular tendon length, while the distal-free tendon length showed limited size variation. From a surgical perspective, estimating the distal intramuscular tendon length from the measurement of the total femoral length could help in assisting surgeons to plan ACL reconstruction when using the ST-Gr grafting technique.

Tendon size and graft performance in ACL reconstruction

The hamstring tendon is considered as one of the most popular autograft used among orthopedic surgeons [23]. This graft widely used for ACL reconstruction particularly in skeletally immature patients. [20]. Hamstring graft choice and thickness is important and may play a role in the patient's functional outcome [12]. Usually, ACL reconstruction requires a triple- or 4-stranded ST and GT grafts to reconstruct both the anteromedial and posterolateral bundles [45]. The number of possible strands depends on the length of the graft; the higher is the number and the higher is the thickness. While it has been reported that a double-bundle or multi-stranded semitendinosus graft provide an initial load to failure greater than that of the native ACL [20], a graft with smaller thickness have been shown to be weaker [44]. Noyes et al. [36] showed how the ultimate tensile strength of the graft differs by the number of strands; a single-stranded ST graft had a tensile strength of only 70% compared to the native ACL, whereas a double-bundle ST graft could increase the tensile strength by 60–70% [21]

The quadruple ST graft was found to have an excellent tensile strength (4400 N), however, a minimal graft length should be harvested to loop the graft into 4 strands [42]. The minimum length a harvested graft should be is 4 times the length of the native intraarticular ACL part combined with the bony embedded length of the ACL. Miller et al. [34], conducted a cadaveric study to measure the length of the intraarticular portion of the ACL and found the length to be 3 cm on average. In another study, Shrock et al. [47] showed that the tibial and femoral tunnel distance was also 3 cm; the authors suggested to use the following equation to calculate the minimum required length for the graft $[4 \times (3+3)]$ yielding a minimum length of 24 cm for ST grafts.

In our study, the average total ST and Gr tendon lengths were found to be 26.7 and 22.4 cm, respectively. These values are closely related to the results of other studies showing a mean total length of 27.1 cm for ST and 24.8 cm for Gr tendons. Our results show that when applying Shrock et al.'s [47] equation, a triple-stand Gr graft and a quadrupled-strand ST graft could be easily obtained. Those results are important since it is known that the number of strands is related to the length of the graft, and the higher the number of strands, the higher is the resistance for rupture [5, 38]. Calvo et al. [8] and Magnussen et al. [32] stated that a hamstring graft, should have a diameter of at least 8 mm. If less than that, the graft will be more vulnerable to failure; the risks of failure were 1.7 and 13.6% for grafts wider than 8 mm versus grafts less than 7 mm wide, respectively.

Can we predict the size of the hamstring graft?

Multiple studies demonstrated a relationship between lower limb length, gender and weight with the length and diameter of the hamstring graft. Treme et al. [49] and Tuman et al. [50] found that older female with short stature tends to have smaller hamstring graft diameter and shorter graft length. However, other studies showed mild to moderate positive

Table 4 Correlation between total length of the muscles and distal tendon parts with femoral lengths

Muscle	Total femur length			Femoral diaphysis length		
	Total muscle length	Distal-free tendon length	Distal intramuscular tendon length	Total muscle length	Distal-free tendon length	Distal intramuscular tendon length
Gracilis	$\mathbf{R=0.6\ (p=0.01)}$	$R=0.42$ ($p=0.09$)	$\mathbf{R=0.5\ (p=0.04)}$	$R=0.5$ ($p=0.3$)	$R=0.1$ ($p=0.7$)	$R=0.3$ ($p=0.3$)
Semi-tendinous	$\mathbf{R=0.86\ (p<0.00001)}$	0.25 ($p=0.3$)	$\mathbf{R=0.85\ (p<0.00001)}$	$\mathbf{R=0.61\ (p=0.009)}$	$R=0.09$ ($p=0.7$)	$\mathbf{R=0.59\ (p=0.01)}$

Values in bold are found to be significant correlations between height and the total diameter of the quadruple graft, and between lower limb length and graft length [4, 38]. In a study performed by Kupniratsaikul et al. [26], patients with height less than 160 cm and an average leg length of 80.5 cm had a mean ST graft tendon length of 23.1 cm while patients who are taller than 160 cm had a longer ST graft length with an average of 26.2 cm. Our results showed a moderate to highly positive correlations between total femur length and distal intra-muscular tendon length of the ST and Gr with a Pearson's correlation of $r = 0.5$ and $r = 0.85$; respectively. However, no correlation was found between both femoral lengths and the free tendon lengths. In addition, we were able to find a correlation between the femoral diaphyseal length and distal intra-muscular tendon length of the ST only ($r = 0.59$). Comparing our results with other studies [2, 41, 48], we believe that we are able to predict the hamstring autograft length prior to surgery by measuring the total femur length of the patient pre-operatively.

Relevance of hamstring graft size in other reconstructive tendon procedures

In addition to ACL reconstruction, hamstring grafts have been used in multiple procedure, such as MPFL reconstruction, acromioclavicular joint reconstruction, patellar tendon and Achilles tendon rupture reconstruction [38]. MPFL reconstruction has doubled over the last decade [27, 52] using semitendinosus and gracilis autografts [6, 13] due to their low donor site morbidity and availability [7, 35]. Ladenhauf et al. [28] stated that a double-bundle gracilis graft should be at least 9 cm in length therefore a minimum of 18 cm of gracilis autograft should be harvested to ensure proper MPFL reconstruction. Our results indicated the possibility to obtain an average length of 13 and 11 cm for a double-bundle ST and Gr grafts respectively, which exceeds the needed length for a suitable MPFL reconstruction.

For chronic patellar tendon ruptures, semitendinosus and gracilis are also used for reconstruction [1, 30] described the docking technique which is a combination of a figure-of-eight ST graft and a U-shaped pattern Gr graft during reconstruction, but did not state an issue with graft length. Ovigue et al. [37] described a more anatomic reconstruction using a 6-strand graft (4-strand semitendinosus + 2 strand gracilis). Unlike Leo et al. [29], graft length was of a concern since the patellar socket (20 mm), the patellar tendon length (60–80 mm) and the tibial tunnel (20 mm) are taken into account, requiring a minimum graft length of 10–12 cm. Compared to our results, our mean total tendon lengths of ST and Gr were 26.7 and 22.3 cm, respectively. This makes it not possible to perform a 6-strand graft therefore, the technique described by Ovigue et al. [37] for repair of chronic patellar tendon ruptures cannot be supported.

Acute and chronic Achilles tendon ruptures might also require reconstruction using tendon grafting [10, 25, 30]. As an alternative to the commonly used FHL tendon graft [15, 16], some authors favor hamstring grafts and reported favorable outcomes, but without stating a particular size or length needed for the tendon graft used [18, 40].

Conclusion

The most commonly used autograft in orthopedic procedures remains the hamstring tendons. However, the variability of tendon length of the ST/Gr poses a significant challenge to surgeons. Our study reports a detailed morphometric evaluation of the ST/Gr hamstring muscle and tendons. It revealed a positive correlation between the femoral length and the ST/Gr graft lengths. We believe that our results would help orthopedic surgeons in predicting the graft lengths pre-operatively and develop a better planning for reconstructive surgeries.

Author contributions CA and FB conceived the study. CA performed dissection and measurements. CA and KY conducted data analysis. KY, AK, JM, JD and BAG edited the draft. All authors revised and approved the final draft.

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Declarations

Conflict of interest None.

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