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Rectus femoris tendon morphometry and practical landmarks for harvesting: A cadaveric study

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Abstract

Purpose: To perform a qualitative and quantitative cadaveric analysis of the rectus femoris (RF) tendon to determine its suitability as a standalone autograft for knee ligament reconstruction and to identify consistent anatomical landmarks for safe and reproducible harvest.

Methods: Ten fresh-frozen cadaveric specimens (nine female, one male) without lower limb pathology were dissected to isolate the RF tendon. Distances from the patella to key anatomical fusions, tendon length, width and thickness were measured. A 1-cm-wide graft was harvested using a 7-mm tendon harvester along an oblique path through two stab incisions, then folded into double-, triple- and quadruple-strand configurations. Diameters and usable lengths were recorded. All measurements were analysed descriptively.

Results: The RF tendon formed a reproducible superficial layer of the quadriceps tendon (QT) with two consistent fusion zones: a distal confluence at 22.4 ± 3.5 mm and a proximal confluence at 58.5 ± 13.2 mm above the patella, defining a 36.1 ± 13.0 mm segment free of deep attachments. Mean tendon length was 300.8 ± 29.6 mm. The tendon was widest proximally (47.0 ± 13.5 mm at 20 cm) and thickest distally (2.07 ± 0.6 mm at 5 cm). Graft diameters measured 8.75 ± 0.75 mm (double), 9.9 ± 1 mm (triple) and 11.4 ± 0.8 mm (quadruple), with corresponding lengths of 151.2 ± 16.3, 98.5 ± 13.3 and 74.0 ± 7.7 mm, respectively.

Conclusions: This cadaveric study mapped the RF tendon as the superficial layer of the QT and identified two consistent confluence zones that define a harvest corridor. Its dimensions support its use in both primary and revision procedures, including combined intra- and extra-articular reconstructions.

Level of Evidence: Level V, basic science study.

KEYWORDS

ACL reconstruction, autograft, cadaver study, quadriceps tendon, rectus femoris

Abbreviations: ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; ALL, anterolateral ligament; BPTB, bone–patellar tendon–bone; dQT, deep layers of the quadriceps tendon; LEAP, lateral extra-articular procedure; PCL, posterior cruciate ligament; PCLR, posterior cruciate ligament reconstruction; QT, quadriceps tendon; RF, rectus femoris; RFT, rectus femoris tendon; SD, standard deviation; VI, vastus intermedius; VL, vastus lateralis; VM, vastus medialis.

INTRODUCTION

Among the several graft choices that are currently available for knee ligament reconstruction, the rectus femoris (RF) tendon, that is the superficial lamina of the quadriceps tendon (QT), has emerged as a viable autograft option [2, 9, 13, 17, 18]. These studies report minimal morbidity at the donor site, and the ample length of the graft enables combined anterior cruciate ligament reconstruction (ACLR) and lateral extra-articular procedures (LEAPs) to be performed using a single graft [17]. Consequently, it can be useful for ACL revision surgeries, posterior cruciate ligament (PCL) reconstruction and it represents a valuable option in multiligamentous knee injuries. Early clinical evidence in revision ACL reconstruction suggests that an isolated RF autograft can achieve four-strand diameters around 9 mm with improved postoperative stability and low reported harvest-site morbidity [6]. Also, at short-term, PROMs were found to be comparable to hamstring autografts, with similar failure rates [7].

Despite these promising data, few anatomical studies have mapped the landmarks that would enable surgeons to confidently and reproducibly harvest the RF. The precise definition of the tendon's width and thickness, its fusion points, and its spatial relationship to neurovascular structures is essential before the RF can be used routinely in clinical practice.

The aim of the current study was to perform a qualitative and quantitative cadaveric analysis of the RF tendon, investigating its dimensions, insertions and relationship to adjacent structures, and to define consistent surface landmarks that can guide the safe harvest of the tendon for knee ligament reconstruction. The hypothesis was that easily identifiable anatomical landmarks can be described, confirming the RF tendon as a reliable standalone autograft for primary or revision knee ligament procedures.

METHODS

Specimen preparation

Ten fresh-frozen whole-body cadavers (nine female, one male) without evidence and history of surgery or trauma to the lower limbs, macroscopic degenerative or scarred tendon lesions, were included.

Each specimen was thawed at room temperature, and the chosen limb was left unfixed to mimic the range of motion experienced during surgery. Unilateral dissection of one lower limb was done following a standardised sequence.

A longitudinal midline skin incision was carried from the anterior superior iliac spine to the tibial tubercle, followed by dissection of the subcutaneous tissue and opening of the quadriceps fascia. The RF muscle was then exposed from its origin at the anterior-inferior iliac spine to its insertion within the QT. The muscle was then detached from the anterior iliac spine, and a proximal-to-distal dissection was performed to document the anatomic relationships and to obtain measurements with a flexible tape.

The following were recorded in succession (1) the distance from the upper pole of the patella to the distal fusion of the RF's superficial layer with the deeper quadriceps layers; (2) the distance from the upper pole of the patella to the proximal fusion of the superficial layer with deeper layers of the QT; (3) the distance from the upper pole of patella to the most distal RF muscle fibres; (4) the distance between the aforementioned proximal and the distal fusion points; (5) the overall tendon length (Figure 1).

With the muscle belly carefully removed, tendon width and thickness were measured at 5, 10 and 20 cm proximal to the patella using a tape and a digital caliper, respectively (Figure 2).

Two parallel incisions, each 3–4 cm in length and 2–3 mm in depth, were made on the superficial lamina of the RF within the harvest window, centred mediolaterally and 1 cm apart, to isolate the superficial layer. After detaching the tendon from its insertion, a 7-mm closed tendon harvester (Arthrex Inc) was advanced proximally between the incisions, aiming for the anterior inferior iliac spine, to strip a segment along the entire length, to reproduce the surgical harvest technique. The resulting graft was folded into double-, triple- and quadruple-strand constructs. Then, diameters were measured with a standard stepped graft sizer (0.5-mm increments) after folding, and usable lengths were recorded with a measuring tape.

Following dissection, the limbs were closed with skin sutures, in compliance with French ethical regulations governing body donation for scientific research, and in accordance with the Code of Public Health and institutional ethical standards. Cadaveric specimens were obtained through our institutional body donation program; all materials were de-identified. Under applicable regulations and institutional policy, cadaveric anatomical studies do not require IRB approval.

Statistical analysis

Analyses were performed using SPSS (version 28.0.0.1, IBM Corp.). Continuous variables (as distances, tendon width, thickness, graft diameter and length) were summarised as the mean ± standard deviation (SD) and range (minimum–maximum).

Single measurements (as total tendon length, distances to proximal and distal fusions, and graft diameters in double-, triple- and quadruple-strand configurations) were reported descriptively.

FIGURE 1 Superior view of a right knee after dissection and removal of the rectus femoris muscle belly. Left, distal. QT, quadriceps tendon; RFT, rectus femoris tendon; VL, vastus lateralis; VM, vastus medialis.

RESULTS

The RF tendon displayed a reproducible layered organisation. Proximally, the tendinous fibres of the RF originated from the iliac bone and extended along the anterior aspect of the muscle belly. Distally, the tendinous fibres consistently occupied the deeper region of the muscle before integrating into the stratified structure of the QT. The distal tendinous fibres were oriented obliquely in a lateral direction from distal to proximal relative to the femoral shaft.

Two constant junctions marked this course. The first junction, proximal fusion,

was observed between the superficial layer of the QT and the deeper aponeurotic fibres, distal to the termination of the RF muscle fibres. This confluence appeared to represent the insertion point of the initial tendinous fibres of the vastus medialis and vastus lateralis. On average, it was 58.5 ± 13.2 mm (range 39–90 mm) above the upper pole of the patella (Table 1).

The second junction, or distal fusion, united the superficial and deep quadriceps layers just proximal to the patellar insertion (Figure 3). On average, it was 22.4 ± 3.5 mm (range 16–26 mm) from the patella (Table 1).

Between these two fusions, a 36.1 ± 13.0 mm segment of the superficial QT layer remained free of underlying attachment. So, the superficial layer of the QT was easily individualised from the other layers between the proximal and distal confluences previously described, and this made the RF tendon distinguishable and harvestable.

It also consistently represented a direct continuation of the RF tendon (Figure 4).

The entire RF tendon measured 300.8 ± 29.6 mm (260–340 mm) in length. The tendon width was 20.1 ± 3.8 mm at 5 cm above the patella, then broadened to 26.4 ± 8.2 mm at 10 cm and 47.0 ± 13.5 mm at 20 cm leading to a triangular shape of the tendon. The thickness followed the opposite pattern, being greatest near the patella (2.1 ± 0.6 mm at 5 cm), decreasing proximally to 1.5 ± 0.5 mm at 10 cm, and with further narrowing to 0.6 ± 0.2 mm at 20 cm.

Simulated harvest of a 1-cm-wide strip produced grafts suitable for multiple configurations. When folded in half length-wise, the construct measured 8.85 ± 0.8 mm in diameter and 151.2 ± 16.3 mm in length. Triple folding led to dimensions of 9.9 ± 1 mm by 98.5 ± 13.3 mm, and quadruple folding produced dimensions of 11.4 ± 0.8 mm by 74.0 ± 7.7 mm (Table 1).

DISCUSSION

The most important finding of this cadaveric study was that the RF forms a reproducible, superficial lamina of the QT that can be safely and predictably harvested, with satisfying length and diameters in multiple configurations for ligament reconstruction of the knee. Two constant fusion zones define this lamina: a distal confluence located at a mean of 22 mm above the upper pole of the patella and a proximal confluence located at a mean of 58 mm above the patella. A 36-mm segment lies between them, and this segment is entirely free of deep attachments. This allows for recognition, isolation and passage of a 7-mm harvester. It is critical to recognise and dissect the proximal fusion before advancing the harvester to avoid premature detachment.

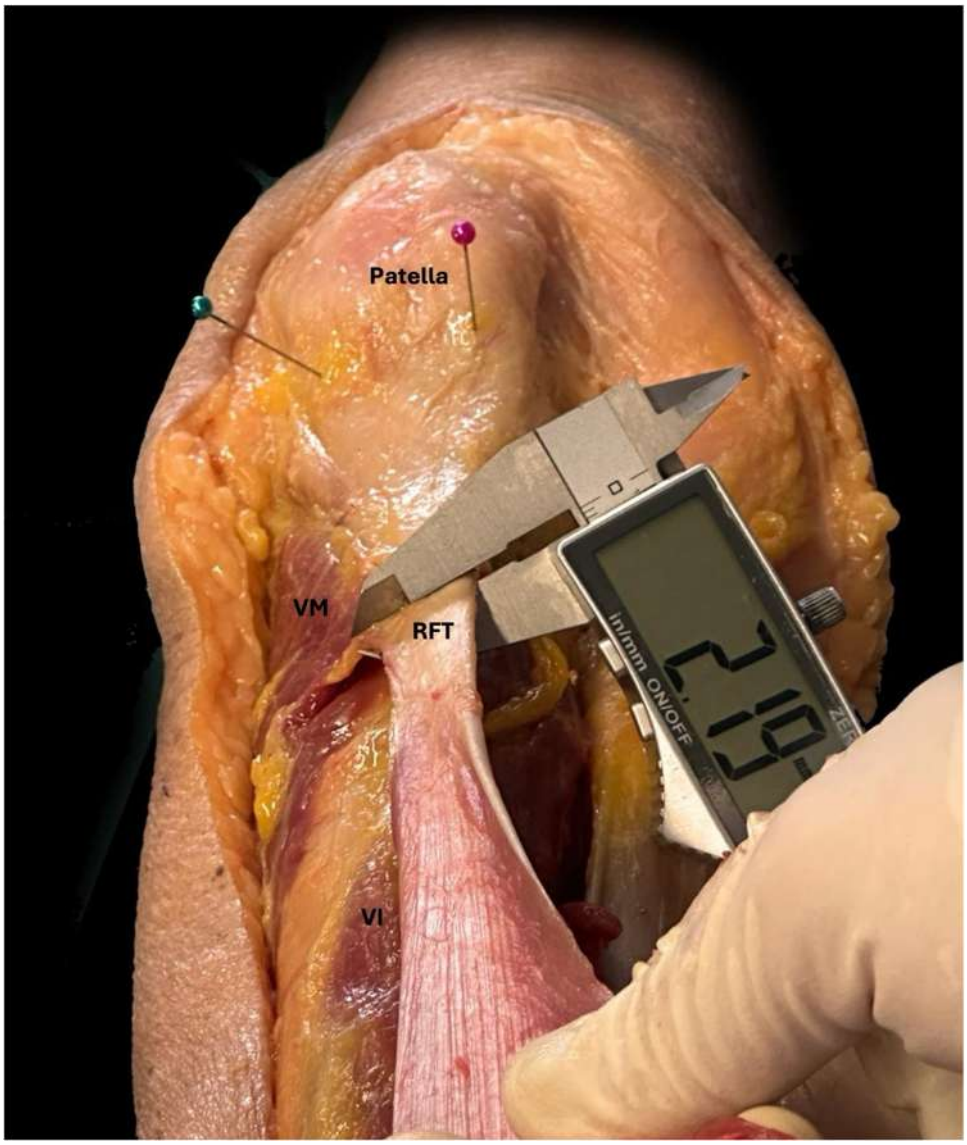

FIGURE 2 Tendon width measurement. Proximal view of a right knee after dissection and exposure of the RFT. The measurements are carried out with a digital caliper. RFT, rectus femoris tendon; VI, vastus intermedius; VM, vastus medialis.

In clinical practice, a simple operative marker confirms the correct dissection path. At the proximal level, if the surgeon cannot easily create a plane of detachment between the superficial and deep layers using a finger, then it's not the correct plane (Figure 5).

This quick, minimally invasive tactile check allows to redirect the dissection before introducing the harvester. This reduces the risk of lacerations or premature harvestings.

An important factor to consider during harvesting is the orientation. The distal fibres run obliquely, from medial-distal to lateral-proximal relative to the femoral shaft, aiming for the anterior inferior iliac spine. Advancing the harvester along this trajectory gave intact grafts in every specimen. Another practical implication of our findings relates to the location of the skin incision. The incision should be made precisely between the two deep adhesions, which are 22 and 58 mm proximal to the upper pole of the patella. In this 'window', the superficial tendon flap is free of connections to the deep layers. This allows for direct access to the RF, reduces dissection of the surrounding tissues, and facilitates the safe passage of the harvester along the tendon's oblique course.

Respecting these landmarks and the oblique path allows to harvest a 1-cm-wide strip averaging 301 mm in length, and even in its narrowest part, the tendon is 20 mm wide and 2 mm thick. The quantitative profile of the RF tendon supports its clinical use. When doubled, it provides an 8.8 mm graft diameter per approximately 15 cm length. If a thicker graft is required, for instance, in posterior cruciate ligament reconstruction (PCLR), it can be tripled, yielding an average diameter of 9.9 mm

TABLE 1 Quantitative morphometric measurements of the rectus femoris tendon and dimensions of the harvested 1-cm-wide graft in double-, triple-, and quadruple-strand configurations (*n* 10 cadaveric specimens).

Mesure (mm)	Mean	Min	Max	Standard deviation
Distance: Upper pole of patella to division of quadriceps tendon layers	22.4	16.0	26.0	3.5
Distance: Upper pole patella to proximal tendon fusion	58.5	39.0	90.0	13.2
Distance: Upper pole of patella to distal muscular fibres of rectus femoris	69.0	50.0	100.0	12.9
Distance: Division of quadriceps tendon layers to proximal tendon fusion	36.1	23.0	66.0	13.0
Tendon length	300.8	260.0	340.0	29.6
Tendon width at 5 cm	20.1	15.0	29.0	3.8
Tendon width at 10 cm	26.4	14.0	38.0	8.2
Tendon width at 20 cm	47.0	28.0	76.0	13.5
Tendon thickness at 5 cm	2.1	1.2	3.1	0.6
Tendon thickness at 10 cm	1.5	0.7	2.4	0.5
Tendon thickness at 20 cm	0.6	0.3	0.8	0.2
Diameter of 1 cm wide graft folded double	8.8	8.0	10.0	0.8
Diameter of 1 cm wide graft folded triple	9.9	9.0	11.0	1.0
Diameter of 1 cm wide graft folded quadruple	11.4	10.5	12.5	0.8
Length of graft folded double	151.2	130.0	175.0	16.3
Length of graft folded triple	98.5	80.0	120.0	13.3
Length of graft folded quadruple	74.0	65.0	86.0	7.7

Note: Values are presented as mean, median, minimum, maximum and standard deviation.

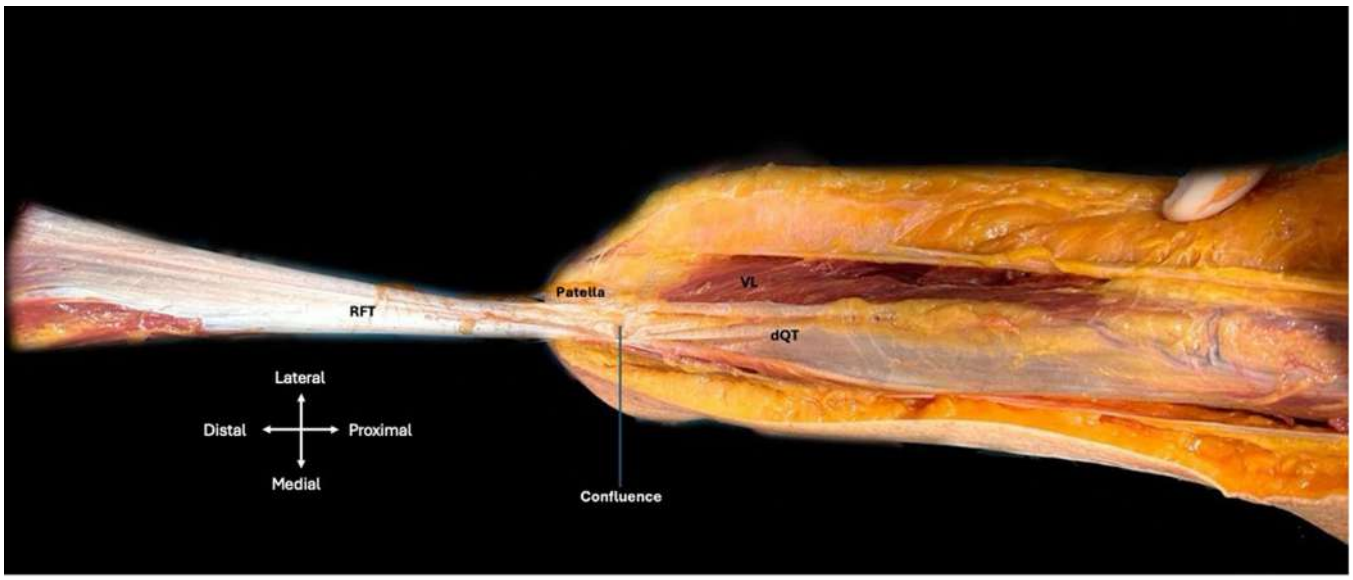

FIGURE 3 Confluence between the superficial layer of the quadriceps tendon and the deeper aponeurotic fibres. Superior view of a right knee after dissection and exposure of the rectus femoris. The distal confluence is identified. Left, distal. dQT, deep layers of quadriceps tendon; RFT, rectus femoris tendon; VL, vastus lateralis.

for a length of 98.5 mm. The overall RF graft dimensions allows for multiple ligament reconstructions using the same tendon, such as ACL + LEAP, or ACL + posterolateral corner reconstruction [1, 8, 10]. Moreover, given the significant graft length obtained, harvesting the most distal part of the tendon, where the layers are fused, may not be necessary, thereby simplifying the procedure.

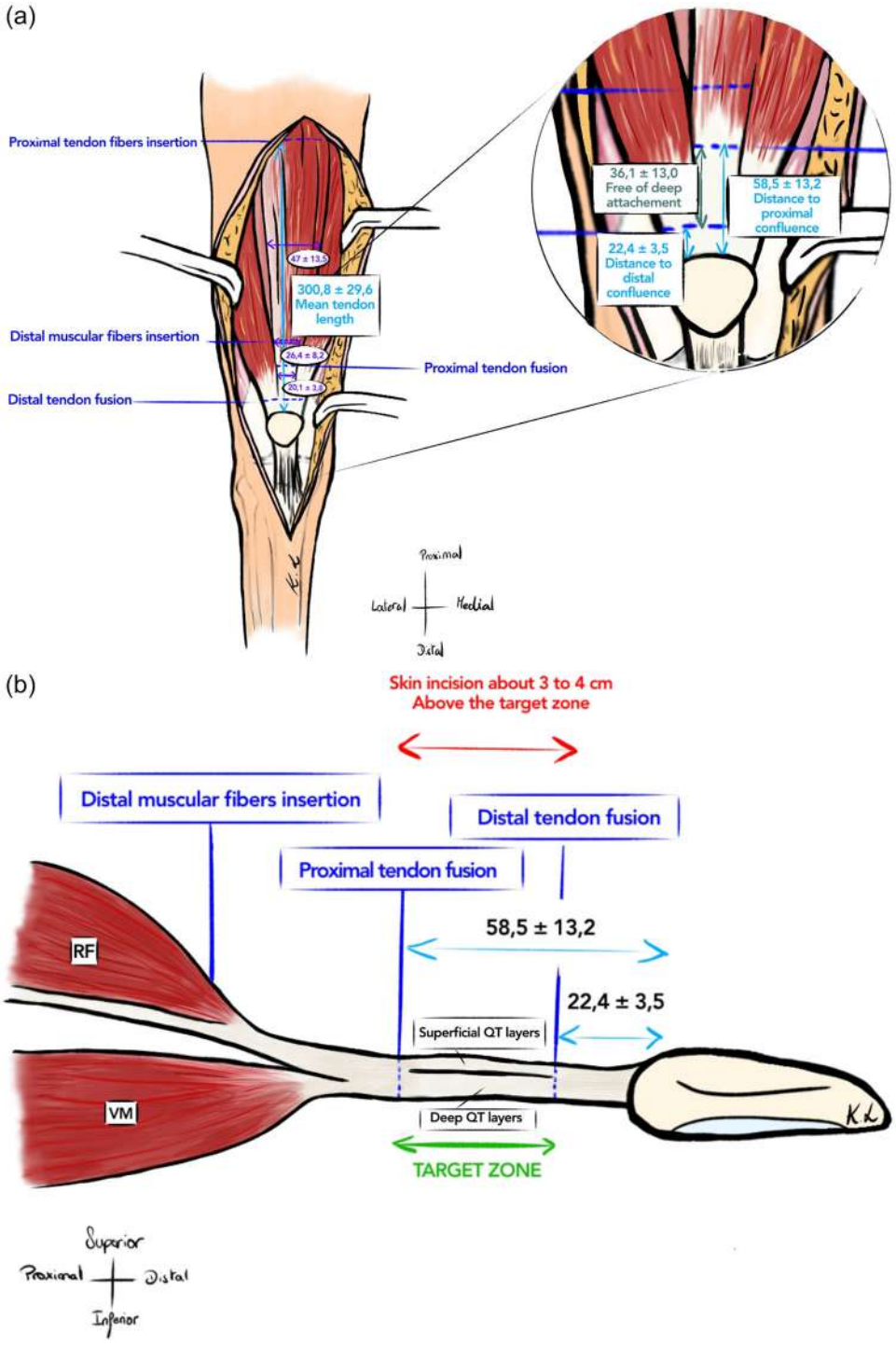

FIGURE 4 Schematic representation of rectus femoris (RF) harvest landmarks. (a) An anterior view of a right thigh shows the RF tendon (blue) forming the superficial lamina of the QT. Two constant fusion points are highlighted: the distal fusion with the deeper quadriceps layers, 22.4 ± 3.5 mm above the patellar upper pole, and the proximal fusion, 58.5 ± 13.2 mm above the patella. The intervening 36.1 ± 13.0 mm 'free segment' (green box) lacks deep attachments and can be safely isolated. Mean entire-tendon length (300.8 ± 29.6 mm) is indicated along the shaft. (b) Lateral view. The recommended 3–4 cm skin incision (red double arrow) is centred over the 'free segment'. Blue double arrows denote the measured distances to the proximal and distal fusion zones; the green double arrow marks the ideal harvest window. QT, quadriceps tendon; VM, vastus medialis.

Importantly, harvesting only the superficial layer preserves the deeper quadriceps fibres. Traditional QT harvesting has been associated with a risk of anterior knee pain, extensor mechanism weakness and long-term patellofemoral osteoarthritis, and maybe harvesting only the RF component may reduce these adverse effects [3, 4, 12, 15]. Also, this approach may be linked to less anterior knee pain, faster extensor recovery and

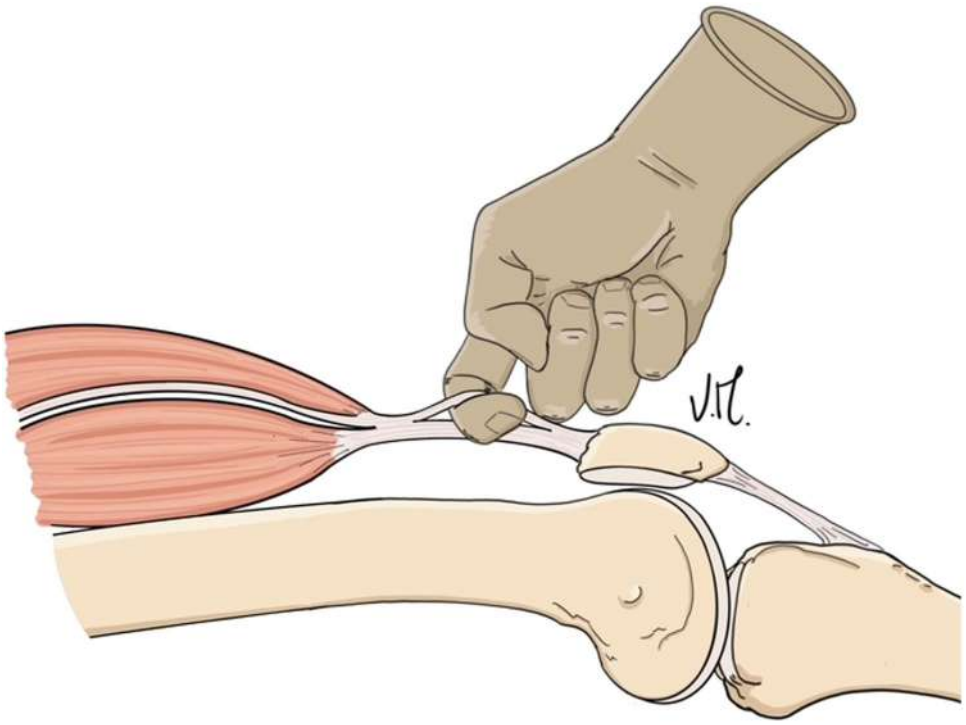

FIGURE 5 Intraoperative verification of the harvest plan. The surgeon inserts its finger between the superficial lamina of the rectus femoris and the deeper layers of the quadriceps at the proximal fusion zone (approximately 58 mm above the upper pole of the patella). Digital separation confirms that the dissection is in the correct plane before advancing the harvester; an inability to create this cleavage indicates an incorrect plane, necessitating reorientation to avoid premature tendon detachment.

lower donor site morbidity in respect to B-PT-B grafts [11, 14, 15]. Another advantage of using a RF graft is that it spares both hamstring tendons, preserving dynamic valgus restraint, which can be advantageous in cases of combined ACL-medial collateral ligament injuries [19]. Additionally, it avoids the anteromedial tibial incision that can result in saphenous nerve hypaesthesia [5]. However, these considerations remain theoretical at present. There is insufficient evidence specifically evaluating the RF graft in terms of donor-site morbidity, its impact on the biomechanics of the extensor mechanism, and potential graft-specific complications.

The RF is the only bi-articular head of the quadriceps. Therefore, removing part of it could theoretically compromise knee extension and hip flexion torque, leading to postoperative deficits. However, clinical experience suggests that the functional impact is modest. In a series of professional footballers who underwent surgical excision of the proximal RF musculotendinous junction, all athletes resumed full match play within 15 ± 1 weeks and remained symptom-free at follow-up, despite moderate strength deficits in two players [16]. The authors attributed this favourable outcome to two compensatory mechanisms: hypertrophy of the remaining vastus muscles and lateral force transmission through intact intramuscular connective tissue. Similar reasoning can be applied to RF harvest for ligament reconstruction. With the vasti intact and the distal RF fibres preserved, the impact on knee extension and hip flexion is expected to be minimal. Nevertheless, isokinetic and gait analyses after RF harvest are necessary to quantify short-term strength changes and verify that compensatory adaptations reliably offset the loss of RF tissue.

A new finding of the current paper is the identification of two separate confluence zones within the QT complex: one proximal (approximately 58 mm above the patella) and one distal (approximately 22 mm above). Earlier anatomical descriptions cited only a single fusion point. Demonstrating a second, consistently reproducible junction clarifies the true length of the tendon, free of deep attachments (approximately 36 mm), and explains how the RF can be mobilised with minimal disruption to the underlying vastus fibres and deep QT layers.

Our measurements are comparable to the study by Iriuchishima et al., who conducted a cadaveric analysis on sixteen knees (mean age: 78.8 years) to assess the anatomical structure of the QT for ACL graft use [9]. Similar to this study, the authors reported that the tendon exhibited a trilaminar organisation, with the RF forming a mostly independent superficial layer. The narrowest point of the RF was 15.3 mm and located 4.8 mm proximal to the patella; its average length was 27.3 cm. Ethnic anthropometry and tissue shrinkage

from formalin fixation likely explain the discrepancy in size; however, the qualitative architecture they described matches ours, which reinforces the validity of our landmarks.

Future biomechanical testing of fresh-frozen grafts is essential to confirm tensile strength, especially in the thinner proximal zone, and to determine if single-strand use is appropriate for ligament reconstructions. Until such data are available, the present work should be interpreted as anatomical feasibility. However, the successful use of this graft in the clinical setting have been reported [6, 7]. To this end, based on this anatomical study, it is important to isolate the superficial layer of the QT in the area located between 22 and 58 mm proximal to the patella; insert the scalpel blade slightly more than 2 mm deep along two parallel lines spaced 1 cm apart and oriented obliquely from medial-distal to lateral-proximal aiming for the anterior inferior iliac spine, relative to the femoral shaft; detach the superficial layer of the QT 22 mm from the proximal pole of the patella without needing to disturb the distal-most fibres; sufficiently separate the proximal fusion point from the underlying dQT layers before applying the tendon harvester, and then advancing the harvester in an oblique orientation relative to the femoral shaft.

Limitations

The present study has certain limitations. The number of cadavers was limited, and no subgroup analyses by sex or age were performed. Notably, 9 out of 10 specimens were female, which limits the generalisability of the findings to male patients, and precluded subgroup analyses by sex or age; however, previous anatomic studies suggest minimal intergender differences in the structural composition and dimensions of RF tendons after accounting for height-weight differences. Donor-level anthropometrics (e.g., age and height/body size) were unavailable, preventing the correlation of measurements with body size or age strata. Dissections were performed on a single limb per donor (unpaired) and bilateral analyses were not undertaken. As this is an anatomic cadaveric study, the proposed advantages remain theoretical and require confirmation with dedicated biomechanical testing before any clinical claims can be made. One of the strengths of this study is that dissections were performed on whole cadavers rather than isolated anatomical parts. All measurements were made without detaching the RF, ensuring accuracy and minimising bias.

CONCLUSION

This cadaveric study mapped the RF tendon as the superficial layer of the QT and identified two consistent confluence zones that define a harvest corridor. Its dimensions support its use in both primary and revision procedures, including combined intra- and extra-articular reconstructions.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions to the study. Vincent Marot, Alessandro Carrozzo and Etienne Cavaignac conceived and designed the study. Vincent Marot, Alessandro Carrozzo, Nicolas Bouguennec and Kenza Limam performed dissections and data collection. Alessandro Carrozzo, Vincent Martinel, Jorge Chahla and Nicolas Bouguennec analysed the data. All authors participated in drafting and critically revising the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

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CONFLICT OF INTEREST STATEMENT

Jorge Chahla reports relationships with the American Orthopaedic Society for Sports Medicine, Arthroscopy Association of North America, and the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (board membership); Arthrex Inc., CONMED Corp, and Ossur Americas (consulting/advisory roles); and Smith & Nephew Inc. (consulting, advisory, and speaking fees). Etienne Cavaignac is a consultant for Arthrex Inc., Smith & Nephew Inc., and Amplitude. Alessandro Carrozzo has received travel reimbursements from Arthrex Inc. and Smith & Nephew Inc. Nicolas Bouguennec is a consultant for Stryker Inc. The remaining authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data sets generated and analysed during the current study are available from the corresponding author on reasonable request.

ETHICS STATEMENT

The use of human cadaveric specimens was in accordance with French public health regulations; ethical approval was not required for this anatomical study.

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