MRI evaluation to predict tendon size for knee ligament reconstruction

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Summary

Background: **The aim of this study is to evaluate a possible correlation between specific anthropometric parameters and sizes of knee tendons commonly used for ACL reconstruction. We hypothesized that specific clinical and radiological knee measurements could be better tendon sizes predictors than age, gender, height and weight.**
Materials and methods: **100 consecutive patients were enrolled and 77 patients met the inclusion criteria of the study. All patients underwent a MRI of the knee with a 1.5 T super conducting MR System. For each patient, anthropometric data such as gender, height, weight, body mass index (BMI) and knee circumference were recorded. Specific MRI knee measurements were performed on each study: patellar tendon (PT) thickness and length, quadriceps tendon (QT) thickness, semitendinosus tendon (ST) diameter, gracilis tendon (GR) diameter, the largest patella and intercondylar width.**
Results: **The mean ST diameter, QT thickness and PT thickness were higher in males than in females. No significant differences were noted between males and females concerning GT diameter and the knee circumference. In addition, male knees had greater patellar and intercondylar width than female knees. Significant, but only weak correlations were found between patient anthropometric data and hamstrings diameter, PT length, and QT and PT thickness. Intercondylar and patellar width present a moderate correlation between PT thickness, PT length and ST diameter.**
Conclusion: **The intercondylar and patellar width presented a moderate correlation with PT thickness, PT length and ST diameter. Further, weak correlations were found between patient anthropometric data (gender, weight, height, BMI) and GR and ST diameter, PT length, and QT and PT thickness. This results may help surgeons during preoperative planning, specifically regarding graft choice and size.**
Level of evidence: III.

KEY WORDS: quadriceps tendon autograft, patellar tendon autograft, acl reconstruction, mri, graft size measurement, preoperative measures, hamstring.

Introduction

Over the last years, an increased interest on graft options for knee ligament reconstructions has been observed. Specifically, this depends on previous studies that assessed the risk of ligament reconstruction failure in case of unsatisfactory graft diameter[1,2]. Further, high risk of cruciate ligament reconstruction failures in cases of concomitant untreated peripheral ligament tears has been described, underlining the need of repair or reconstruct other ligaments in setting with anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL)[3]. In these circumstances, the graft choice represents an argument often understated. In addition, in the case of unavailable allograft or during ligament revision, other options than conventional hamstring tendons have to be considered. Further, having accurate preoperative information on the graft dimensions could help the orthopedic surgeon to make a proper graft selection prior to surgery[4-6].
Historically, hamstrings and the central-third of patellar tendon (PT) have been considered to be the gold standard for ACL reconstruction over the last decades. Even if quadriceps tendon (QT) autograft has not gained widespread use like other autograft options, recently it has gained popularity[7-10]. In fact, several Authors supported its use because of a good biomechanical behavior of the QT graft[9,11-13]. Howev-

er, poor data concerning proper indications for the use of QT in place of bone-patellar tendon-bone or hamstring autograft are present in literature[9]. Because of an individual variability in tendon diameter, great attention was focused to predict graft size using different anthropometric parameters, such as height, gender and weight. In addition, magnetic resonance imaging (MRI) is routinely performed to assess the ACL injury and to evaluate other concomitant ligament injuries. For this reason, MRI is readily available for use in preoperative planning with satisfactory accuracy and reliability when the autologous PT or hamstrings are considered as the graft source for ACL reconstruction[14-16]. Similarly, MRI assessment of QT dimensions would provide valuable information on the preoperative planning of an ACL reconstruction, without additional costs.

The aim of this study is to evaluate a possible correlation between specific anthropometric parameters and sizes of knee tendons commonly used for ACL reconstruction. We hypothesized that specific clinical and radiological knee measurements could be better tendon sizes predictors than age, gender, height and weight.

Materials and methods

For this study, 100 consecutive patients were enrolled. All research was conducted ethically according to international standards[17]. Inclusion criteria of the study were patients considered to be skeletally mature. Exclusion criteria were: previous knee surgery, knee deformity or history of fractures around the knee, knee osteoarthritis, abnormalities in the extensor mechanism (such as sequelae of Osgood-Schlatter's disease) and history of patellar dislocation or subluxation. All patients underwent a MRI of the knee with a 1.5 T super conducting MR System (Achieva, Philips Healthcare, the Netherlands) using a knee-specific circular coil and all MRI exams were carried out using a picture archiving and communication system (PACS) (Impax; Agfa, Antwerp, Belgium). An 18-cm field of view with a 512 x 512 matrix size was used. Slices thickness was 3 mm with no interslice gap for all studies. We used the standard knee protocol for each patient. Specifically, the MRI protocol included:

1) sagittal proton density-weighted;
2) sagittal proton density-weighted fat-saturated;
3) coronal short time inversion recovery (STIR);
4) coronal proton density-weighted;
5) axial T2-weighted turbo spin-echo.

For each patient, anthropometric data such as gender, height, weight, and body mass index (BMI) was recorded. Further, the knee circumference was measured on each patient using a conventional plastic tape measure placed at the upper pole of the patella. Specific MRI knee measurements were performed on each study. PT and QT length and thickness were measured on the sagittal proton density-weighted images. Specifically, patellar tendon length was measured from the posterior insertion of the tendon to the tibia to the posterior insertion of the tendon to the patella. PT thickness was measured three times, respectively 1 cm below the lower border of the patella (P_1), at the middle of the patellar tendon (P_2) and 1 cm above the upper border of the tibial tubercle portion (P_3), respectively, as described by Chang et al.[14]. QT was measured at three levels, at distances of 10 (Q_1), 20 (Q_2) and 30 mm (Q_3) from the superior pole of the patella[18] (Fig. 1). For analysis, the mean thick-

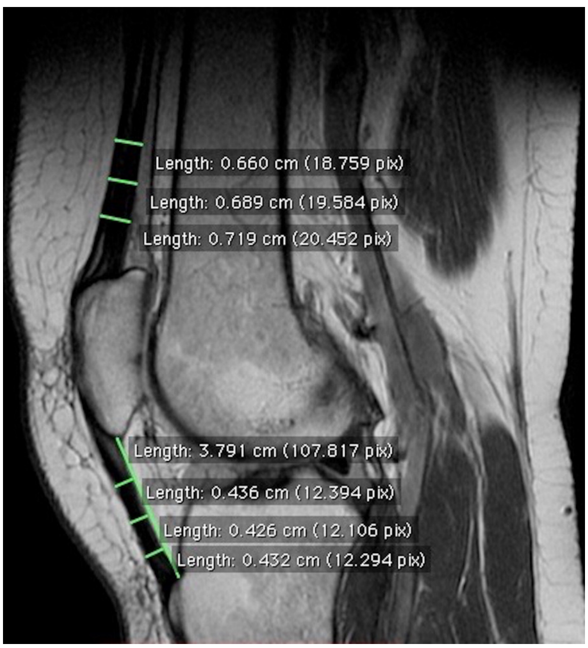

Figure 1. Sagittal MRI measurements. Patellar tendon thickness was measured three times. Similarly, the quadriceps tendon thickness was measured at three levels. Patellar tendon lenght was measured from the posterior insertion of the tendon to the patella to the posterior insertion of the tendon to the tibia.

ness at the three measured distances was used. Concerning hamstrings, the largest diameter of the semitendinosus tendon (ST) and the gracilis tendon (GR) were measured on axial T2-weighted turbo spin-echo images (Fig. 2). In the same images, the largest patella width and intercondylar width were measured (Figs. 3, 4). Data were obtained measuring the largest diameter of the patella and the largest intercondylar line. All measurements were taken by the same radiologist in order to prevent possible inter-observer variables in the measurement technique. Further, the radiologist was blinded to the subject and purpose of the study.

Statistical analysis

Statistical analyses were performed with commercially available software (SPSS 12.0, Chicago, Illinois, US). Descriptive statistics were generated for patient demographics, anthropometric data and MRI measurements. All data were summarized as the mean and standard deviation (SD). The measured dimensions were compared between male and female patients using independent-sample *t* tests. Pearson's correlation coefficients were calculated to determine the relationship between MRI tendons measurements and height, weight, BMI, knee circumference, intercondyle and patellar widths. A value of $P<0.01$ was considered significant.

Results

For this study, 77 patients met the inclusion criteria. There were 33 females (42.9%) and 44 males (57.1%). The mean age was 44 ± 7 years, ranging from 17 to 77 years. The mean patient weight, height, and body mass index (BMI) were 70.6 kg ± 13 (range, 40-111), 170.1 cm ± 8.0 (range, 150-191), and 24.3 kg/m^2 ± 3.8 (range, 16.6-37.3), respectively.

The mean *QT thickness* was 7.3 mm ± 1.1 (range 5.2-1.1) and it was higher in males (7.7 ± 1.1) than in females (7 ± 0.9) ($p=0.0085$). Similarly, the mean *PT thickness* was 4.5 mm ± 0.6 (range 3.5-6.1) and it was lower in females (4.2 ±0.6) than males (4.8 ± 0.5) than ($p<0.00001$). Concerning hamstrings, the mean *ST diameter* was 4.2 mm ± 0.4 (range 3.1-5.2) and it was larger in males (4.3 ± 0.4) than in females (4 ± 0.4) ($p<0.007$). No significant differences were noted between males and females concerning *GT diameter* (3.4 mm ± 0.4 *vs* 3.2 mm ± 0.4, $p= 0.018$) and the knee circumference (40.3 cm ± 3.1 *vs* 39.6 cm ± 3.9, $p=0.378$). Additional comparisons, demonstrated that male knees had greater *patellar and intercondylar width* than female knees (46.6 mm ± 2.7 *vs* 40.3 mm ± 2.2 and 85.7 mm ± 3.9 *vs* 74.8 mm ± 3.1, respectively) (Tab. I). Correlations between anthropometric data of included subjects (weight, height, BMI, knee circumference, intercondyle diameter, patellar width) and QT thickness, PT thickness, PT length, ST and GR diameters are displayed in Table II.

Discussion

The main result of the present study was that significant, but only weak correlations were found between patient anthropometric data and hamstrings diameter, PT length, and QT and PT thickness. The second im-

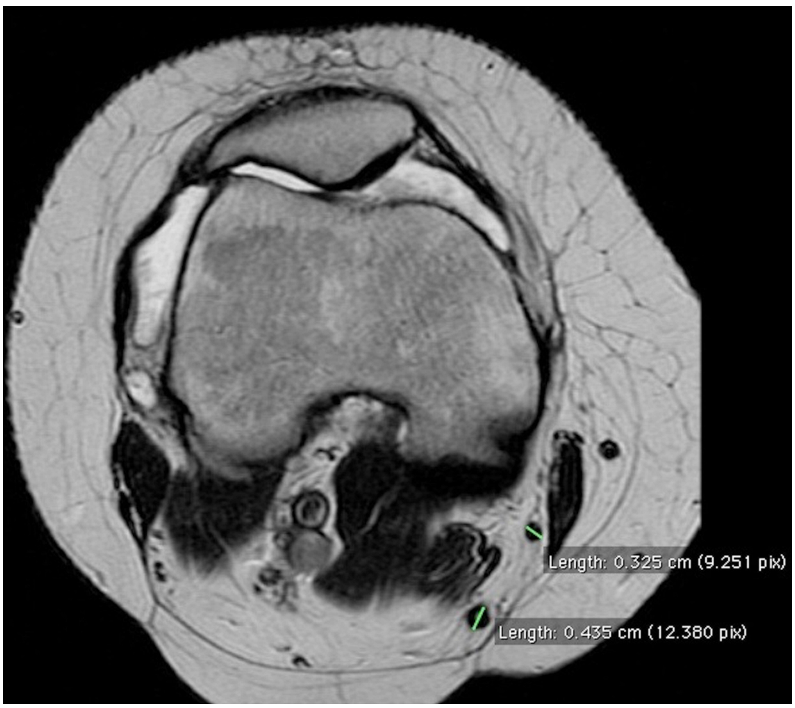

Figure 2. MRI measurement of the largest diameter of the gracilis and semitendinosus.

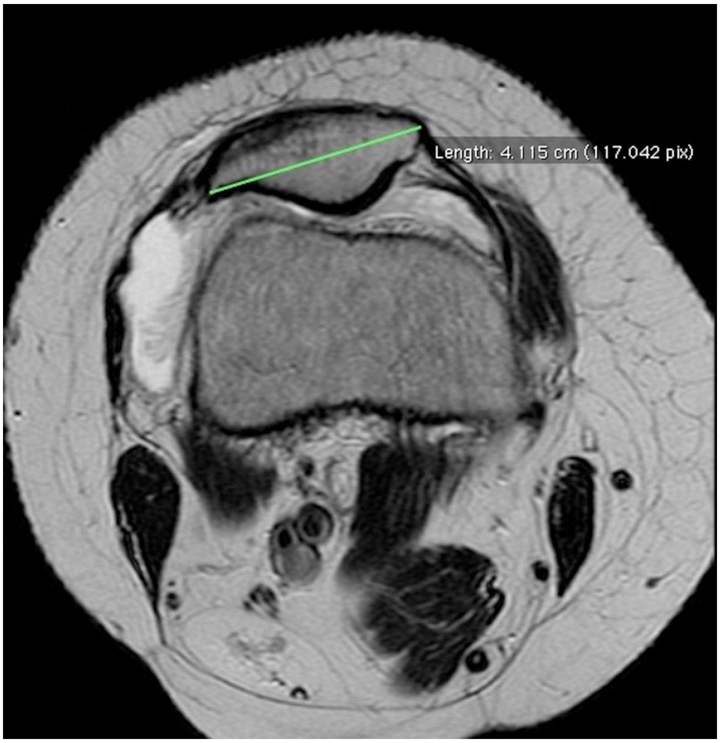

Figure 3. MRI measurement of the largest diameter of the patella.

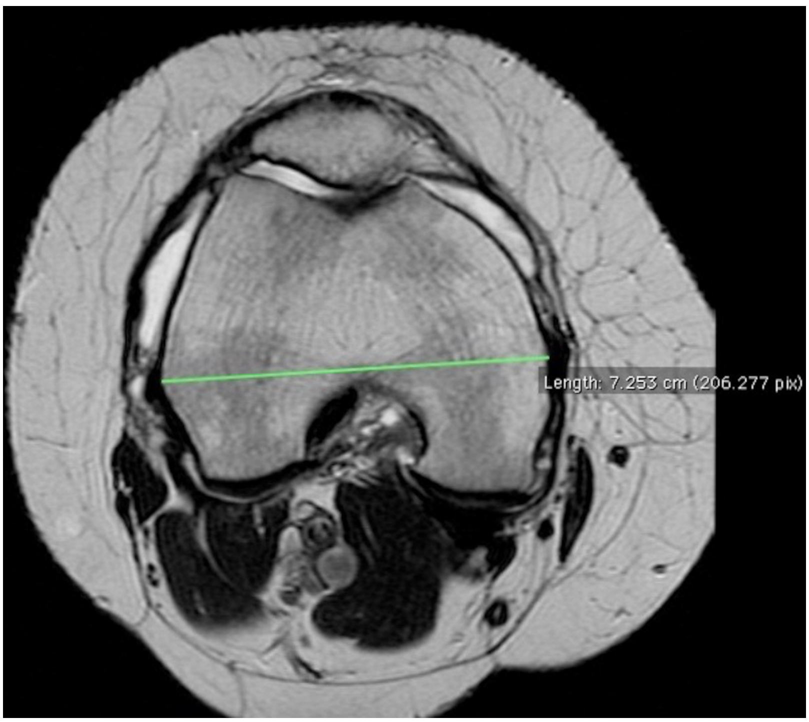

Figure 4. MRI measurement of the largest intercondylar line.

portant finding was that intercondylar and patellar width present a moderate correlation between PT thickness, PT length and ST diameter.

Following a recent study that noted a greater incidence of ACL reconstruction failure in patients with grafts smaller than 8 mm, great attention was made to evaluate parameters that could be helpful to predict acceptable graft size[1,4]. Pre-operative knowledge of graft size will allow surgeons greater confidence in evaluating and counseling patients regarding graft choice. Consequently, alternative options of choosing another graft source can then be considered prior to

Table I. Value expressed in mm.

		Female	Male
	Mean (mm)	Mean (mm)	Mean (mm)
Quadriceps tendon thickness	7.3 (1.1 SD) min 52 - max 106	7 (0.9 SD) * min 52 - max 97	7.7 (1.1 SD) * min 56 - max 106
Patellar tendon thickness	4.5 (0.6 SD) min 3.5 - max 6.1	4.2 (0.4 SD) *** min 3,5 - max 5,2	4.8 (0.5 SD) *** min 3.8 - max 6.1
Gracilis diameter	3.3 (0.4 SD) min 2.3 - max 4.3	3.2 (0.4 SD) * min 2,3 - max 4,2	3.4 (0,4 SD) * min 2.4 - max 4.3
Semitendinousus diameter	4.2 (0.4 SD) min 3.1 - max 5.2	4 (0.4 SD) ** min 3.1 - max 4.9	4.3 (0,4 SD) ** min 3.5 - max 5.2
Patellar width	43.9 (3.9 SD) min 36 - max 52	40.3 (2.2 SD) *** min 36 - max 46	46.6 (2,7 SD) *** min 40 - max 52
Circumference of the knee	400 (35 SD) min 340 - max 500	396 (39 SD) * min 350- max 500	403 (31 SD) * min 340 - max 460
Intercondylar width	81 (6,5 SD) min 69 - max 96	74.8 (3.1 SD) *** min 69 - max 81	85.7 (3,9 SD) *** min 75 - max 96

* no significant differences between male and female (p>0.01).
** significant differences between male and female (p>0.01).
*** significant differences between male and female (p>0.0001).

Table II. Correlation coefficient between tendon size and anthropometric data. Level of significance when anatomical structures were compared to anthropometric data: a p<0.05, b p<0.01, cp<0.001, dp<0.0001.

Amatomical Structures	Weight	Height	BMI	Circumference of Knee	Intercondylar Width	Patellar Width
Quadriceps Tendon Thickness (ΔQ)	r = 0.34 b	r = 0,21 a	r = 0,22 a	r = 0.34 b	r = 0.33 b	r = 0.35 b
Patellar thickness (ΔR)	r = 0.29 a	r = 0,47 d	NS	r = 0.29 b	r = 0.52 d	r = 0.43 d
Patellar Length	r = 0.29 a	r = 0.52 d	NS	NS	r = 0.54 d	r = 0.37 c
Semitendinousus diameter	r = 0.42 c	r = 0.29 a	r = 0.24 a	r = 0.45 c	r = 0.45 d	r = 0.40 d
Gracilis diameter	r = 0.31 b	NS	NS	r = 0.27 a	r = 0.28 a	r = 0.29 b

NS=no significant differences.

surgery and made available during the operation.
Although hamstrings and patellar ligaments remain the first choice for ACL reconstruction, several Authors reported the use of QT with good clinical outcomes[19,20]. The reported benefits of using the QT are that it eliminates the morbidities related to other graft options, with less reported anterior knee pain and numbness compared with PT-bone graft, as well as none of the residual cramping that can occur with hamstring tendon harvest. Other advances include a larger uniform graft diameter compared with hamstrings or PT autograft. However, there is little known regarding the graft size that could be harvest assuring integrity of the quadriceps function. In fact, even if no reports of quadriceps rupture have been reported so far following ACL reconstruction, the risk of quadriceps weakness is obvious. For these reasons, preoperative planning provides surgeons with a clearer understanding of expected graft sizes, reducing the risk of unsatisfactory grafts, the operative time and the complication rate.
In the recent years, several anatomical cadaveric and MRI studies were then performed to better define length and size of the graft. Further, it was observed

that MRI is repeatable and enables the planning of graft choice and size. In fact, previous studies have demonstrated correlations between graft diameter with height, gender, thigh circumference measurements and BMI[21-25]. Specifically, most of these studies have reported correlation between hamstring graft and anthropometric data, not including other clinical and radiological parameters that were considered in the present study such as knee circumference, intercondylar and patellar width. Contrary, with regard to existing literature, there are poor data concerning MRI measurements of the QT. For this reason, correlation between anthropometric data, specific knee measurement and QT are unclear. In a recent study on 62 patients that underwent ACL surgery, Zakko et al. observed that preoperative MRI measurements of QT, PT and hamstring graft size are highly reliable with moderate-to-good accuracy. Further, a significant correlation between patient anthropometric data and the thicknesses of both QT and PT was observed[18]. Our results are consistent with previous MRI studies demonstrating weakly positive correlations between QT thickness and anthropometric data. Further, weakly positive correlations were also observed between QT thickness and specific knee measurements (circumference measurements, intercondylar and patellar width). In addition, moderately positive correlations were noted between specific knee measurements and other tendon parameters, specifically between intercondylar width and PT length/thickness ($r=0.54$, $p<0.001$ and $r=0.53$, $p<0.001$). Regarding patellar width, a moderately positive correlation with PT thickness ($r=0.43$, $p<0.001$) and ST diameter ($r=0.40$, $p<0.001$) was found. Last, a moderately positive correlation was found between knee circumference and ST diameter ($r=0.45$, $p<0.001$) (Tab. II). These results are surprisingly interesting, specifically considering that measurements of patella width, intercondylar width and knee circumference could be obtained effortlessly through clinical and MRI exams. In fact, specific knee measurements used in this study have no cost and does not require specific skills as those required for cross-sectional area measurements[26]. On the basis of the results observed in the present study, it is reasonable to assume that other anthropometric parameters such as patella width, intercondylar width and knee circumference could be used to obtain information on the magnitude of the knee and consequently on the size of tendons used as graft.

The present study has some limitations. At first, no intraoperative tendon size was performed. Indeed, the mean tendon sizes obtained by MRI assessment could differ from intraoperative real measurement observed during graft harvesting. However, negligible discrepancy was observed between graft measurement with MRI and intraoperative assessments[13]. Second, the length of quadriceps tendons was not assessed. This was due to a unique MRI protocol used for all knee pathologies. Third, intraobserver or interobserver variability was not tested and a single radiologist made all measurements.

In conclusion, this study found weak correlations between patient anthropometric data (gender, weight, height, BMI) and hamstrings diameter, PT length, and QT and PT thickness. Conversely, the intercondylar and patellar width presented a moderate correlation with PT thickness, PT length and ST diameter.

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