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Hamstring and Quadriceps Autografts Revascularization after Anterior Cruciate Ligament Reconstruction: Evaluation with Magnetic Resonance Imaging

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Abstract

Purpose: Evaluation of the clinical outcome and the revascularization of five-strand single-bundle hamstring (SBH) and bone-quadriceps (BQ) tendon autografts used for ACL reconstruction.

Material and Methods: 46 patients included in the study, 26 underwent reconstruction with five-strand SBH (group A), while 20 with BQ tendon autograft (group B). All patients underwent MRI three days, six and twelve months postoperatively. The evaluations included the Lachman test, Tegner activity score, Biodex isokinetic test, Lysholm score and KT-1000 arthrometer displacement. The enhancement index (EI) was calculated in three specific sites of each graft and comparisons for every time interval were performed.

Results: Lachman test, Lysholm scores, Tegner activity scores and side-to-side difference values showed a significant improvement after surgery in both groups (P<.001). Regarding the knee extensor strength, no significant difference was found between the two groups, while flexor strength was significantly better in group B. QT showed better revascularization compared to HT grafts (P<.001) at six months, while no significant difference was observed

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twelve months after the surgery. The intra-articular site showed a higher EI (P<.001) compared to intraosseous tibial tunnel and intraosseous juxta screw sites at six months, while a non-significant increase was found twelve months after the surgery.
Conclusions: There was no difference between the two graft types regarding the stability and the functional outcome, except flexor muscle recovery where QT graft is better. Revascularization was better in QT graft in the sixth month, but there was no significant difference in the final follow-up after twelve months' time interval.

KEY WORDS
Anterior cruciate ligament; magnetic resonance imaging; hamstring tendon; revascularization

Introduction

Anterior cruciate ligament (ACL) tear is considered as one of the most common knee injuries that occur during sports that involve sudden stops or changes in direction, jumping and landing [1]. ACL injury may result in functional instability of knee joint, and surgery is advocated in these patients. Hamstring tendon (HT) and bone quadriceps tendon (BQT) grafts are two graft types to reconstruct the ruptured ACL without, however, clear evidence which is a better option [2]. QT grafts have been used for revision cases in the past, but recently there has been an increased interest for primary ACL reconstruction [3] probably due to the development of a graft harvesting technique related to less invasive procedures using smaller incisions [4]. Some studies outlined that there is less donor site morbidity after ACL reconstruction using QT than BQT grafts [5]. Furthermore, donor site morbidity for the free quadriceps graft without a patellar bone block was lower than that with the HT graft [6]. Additionally, the graft maturity has been shown to be better six months after ACL reconstruction with QT compared to the reconstruction with the HT autograft [7]. To our knowledge, there is a few data comparing clinical outcomes in patients who underwent ACL reconstruction using a free QT or HT autografts [8].

Magnetic resonance imaging (MRI) is a valuable non-invasive tool that is used to evaluate the revascularization of the grafts over time. MRI provides information about the status of the graft through the changes observed in the signal intensity after the enhancement of tissues obtained with contrast medium administration. Several previous studies reported signal intensity changes at different sites of various types of grafts [9, 10].

The purpose of this prospective cohort study was to compare the clinical outcomes after ACL reconstruction using BQT or five-strand single-bundle hamstring (SBH) autografts with a follow-up up to twelve months and to evaluate the graft revascularization rate by measuring the signal intensity (SI) changes over time in three distinct sections of the grafts, utilizing contrast-enhanced MRI with intravenous administration of paramagnetic substance.

Material and Methods

Patients

From May 2015 to November 2019, 46 male patients underwent single-bundle ACL reconstruction, using either HT (Group A) or BQT (Group B) grafts. Patients' data are presented in Table 1. The collection of these data was approved by the local Ethics Committee.

Clinical examinations and assessment of stability were performed preoperatively and three days, six and twelve months postoperatively. All clinical examinations were performed by two experienced physicians. Muscle force was tested on an isokinetic dynamometer (Biodex Medical Systems). The functional outcome was evaluated with the Tegner and Lysholm scores preoperatively and twelve months postoperatively. An assessment of postoperative graft integrity was also performed utilizing MRI scans. The MRI protocols used for imaging are included in Table 2.

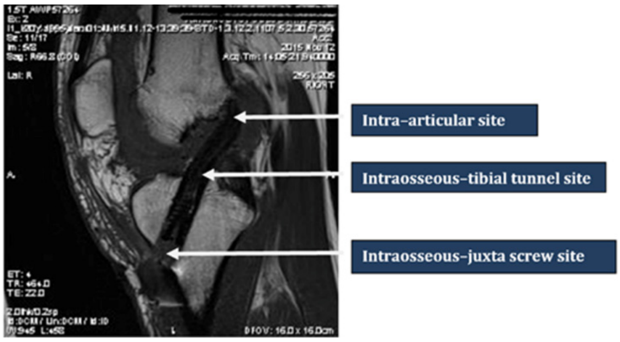

Figure 1: *The three sites used for the measurement of SI; from top right to bottom left: intra-articular, intraosseous-tibial tunnel and intraosseous-juxta screw sites.*

Figure 2: *The point in background (highlighted with the yellow arrow) selected for the noise measurement is 1 cm distance perpendicular to the tuberosity of the tibia.*

Surgical technique

All patients had general anesthesia and they were placed supine on the operating table with the operated knee in 90° of flexion. A tourniquet was applied in all cases. For quadriceps graft harvesting, a 4 cm transverse skin incision was done placed over the superior border of the patella. The prepatellar bursa was incised, and the QT was then carefully exposed from the proximal pole of the patella extending proximally to provide adequate exposure. A central strip of the QT was harvested measuring 8 to 10 mm in width and 70 to 90 mm in length, along with a 20-mm bone block from the proximal patella. An oscillating saw was used to create the patella bone block. The cut surface of the tendon was then closed with interrupted sutures of No. 2 Vicryl. The bone block defect in the proximal patella was filled with bone debris generated during bone tunnel drilling. Two holes were drilled in the bone end of the graft to pass a No. 5 Ethibond suture. The tendon of the graft was whipstitched using 2-0 Ethibond sutures. For hamstring graft harvesting, a vertical skin incision was made over the anteromedial aspect of the proximal tibia over the pes anserinus. Both the gracilis and semitendinosus were harvested using a closed tendon stripper and the distal attachments of the tendons were detached. The tendons were then folded to form a 5-strand hamstring graft (the semitendonosis was folded three times).

The intra-articular surgical technique was identical: The single femoral tunnel was defined using the outside-in method closer to the anteromedial footprint. It was drilled with a cannulated reamer in a diameter corresponding to the width of the harvested graft. The tibial tunnel was created with a tibial jig set at 50° and then drilled with a cannulated reamer. Tibial remnants of the ACL stump were preserved as much as possible during tunnel preparation, which was drilled at the footprint of the native ACL. The mean diameter of the QT graft was 9.5 mm, and the mean diameter of the HT graft was 9 mm.

In both methods, the graft was then passed through the tibial tunnel, across the joint, and into the femoral tunnel. For the quadriceps graft the femoral (bone block) part of the graft was fixed first using an interference screw (MILAGRO; DePuy Synthes). The tibial part (tendinous) of the graft was then fixed using an interference screw (MILAGRO) with the knee in 30° of flexion and posterior drawer application. For the hamstrings graft an adjustable button was used, while the tibial part was fixed with The Aperfix (Cayenne Ltd). All the grafts were wrapped around withpresoaked vancomycin gauzes.

MRI system and data analysis

All the scans were performed by experienced MRI technologists at the Radiology Department of the University Hospital of Patras utilizing a 1.5T MRI system Magnetom

Table 1. Patients' data.

	Group A (HT)	Group B (BQT)
Age[a] (years)	24.6 (18-32)	27.2 (19-36)
Cases	26	20
Operation side (Right Left)	18:8	12:8
Height[b] (cm)	170.1±5.8	172.3±5.7
Weight[b] (kg)	70±3.5	75.1±2.8
BMI[b] (kg/m²)	24.2±2.9	25.3±2.8

[a]Values are reported as mean (range). [b]Values are reported as mean±SD. BMI, body mass index

Avanto (Siemens Healthcare, Germany). To avoid any motion artifacts, the leg of each patient was fixed with soft pads. A central venous catheter was placed to inject the contrast medium without any patient movement.

Oblique images were used to evaluate the obtained data. These images display the implanted graft making the discrimination of three separate sites possible: (a) the intra-articular, (b) the intraosseous-tibial tunnel, and c) the intraosseous-juxta screw (Fig. 1). The amount of the MRI contrast medium injected was in accordance with the patient's body weight; 0.1 mmol per kilogram of body mass [11]. The signal intensity (SI) was calculated in the three different sites utilizing the ImageJ software (Wayne Rasband, National Institute of Health, USA, v.1.52a). The region of interest (ROI) used for the measurements was a square with dimensions 8 x 8 mm.

The enhancement index (EI) was calculated in these sites according to the following formula [9, 10]:

$$\textit{Enhancement Index (EI)} = \frac{SNR_{after\ Gd\ administration}}{SNR_{before\ Gd\ administration}}$$

The signal-to-noise ratio (SNR) was calculated by dividing the SI and noise obtained from images before and after intravenous gadolinium (Gd) administration. The noise was measured as the standard deviation of the SI of the background using a ROI equal to 250 mm², placed over a homogeneous region, with a distance of 1 cm from the tuberosity of the tibia (Fig. 2). Comparisons of the EIs in the three graft sites and for every postoperative time interval were performed.

The benefit of EI calculation is the immediate availability of information regarding the vascularization of the three graft sites investigated (Fig. 1). The unit is considered to be the numerical threshold value necessary to assess the graft vascularization. EI values greater than unity correspond to sufficient vascularization, while EI values equal or less than unity indicate an insufficient one.

Statistical analysis

Descriptive statistics of the patients' and technical data were utilized. The Kolmogorov-Smirnov test was used to check the normality of the data. The statistical comparisons were carried out using the Mann-Whitney test for two groups or Kruskal-Wallis test for three groups of non-normal data. The Wilcoxon signed rank test or student's t test was used for comparison of paired groups. Tukey's post hoc test was used for comparisons between different variables. Power sample analysis was also performed. The kappa (κ) correlation coefficient with 95% confidence interval (CI) was used to measure the intra-and inter-observer variability regarding the ROI placement. The agreement was characterized as poor when $\kappa<0.4$, moderate when $0.4\leq\kappa<8$ and excellent when $\kappa\geq0.8$. Statistical analysis was performed with SPSS statistical package. A *P*-value of less than .05 was considered statistically significant.

Results

Orthopedic physical evaluation

The comparison between the two groups of patients showed no statistically significant differences regarding the Lachman test, KT-1000 arthrometer displacement, modified Lysholm and Tegner activity score (Table 3). The muscle strength recovery between the two groups was evaluated in terms of angular velocity 60°/s and 180°/s for knee extension and flexion. Regarding the knee extensor muscle recovery as measured after a 12-month follow-up interval, there was no statistically significant difference between the two groups. However, the knee flexor muscle recovery was significantly better in group B (Table 4).

Contrast enhanced MRI evaluation

The greater the presence of the contrast agent in the

Table 2. MRI protocols utilized for postoperative assessment of grafts' integrity

Protocols	Plane	TR (ms)	TE (ms)	FA (degrees)	NSA	Thickness/ Gap (mm)	FOV/RFOV (mm)
STIR	Coronal	2700	93	90	2	4.0/0.8	170/90
T1W/TSE	Coronal	480	11	90	2	3.3/0.5	160/90
T2W/TSE	Coronal	3200	122	90	2	4.0/0.8	160/90
PDW/TSE/ Fat-Sat	Sagittal	3080	44	90	2	3.1/0.5	180/90
T1W/TSE	Sagittal	534	22	90	2	2.0/0.2	160/60
T1 Vibe (GRE)	Sagittal	15.4	6.0	25	2	1.0/1.0	170/80
T1 Vibe (GRE) (Gd Dynamic)	Sagittal	15.4	6.0	25	2	1.0/1.0	170/80
T1W/TSE (Gd)	Sagittal	534	22	90	2	2.0/0.2	160/60

STIR: short tau inversion recovery; T1W: T1 weighted; TSE: turbo spin echo; T2W:T2 weighted; PDW: proton density weighted; Fat-Sat: fat saturation; GRE: gradient echo; TR: repetition time; TE: echo time; FA: flip angle; NSA: number of sample averages; FOV: field of view; RFOV: rectangular field of view; Gd: gadolinium.

graft is, the better the vascularization [12]. The EI values calculated at three different sites of both graft types at three follow-up intervals are presented in Table 5. The three sites demonstrated insufficient vascularization only three days postoperatively (EI<1) for both grafts. QT grafts showed higher EI values compared to HT grafts (*P*<.001) six months after the surgery, while no significant difference was observed twelve months after the surgery. A significantly higher EI (*P*<.001) was observed for the intra-articular site compared with the two other sites for both grafts six months after the surgery, while a non-significant increase was found twelve months after the surgery, although the mean EI values were relatively lower for the other two sites.

Power analysis revealed that effect sizes for all comparisons were >0.8. Thus, it was considered that the sample is sufficient for detecting correctly the lack or presence of differences between graft sites at every time interval. The intra-observer and inter-observer agreement was excellent in every case (k=0.91: CI, 0.9-0.93 and k=0.9: CI, 0.89-0.91, respectively).

Discussion

There were no statistically significant differences between the two graft types regarding the side-to-side stability measurements and the clinical outcome, as they have been assessed with KT-1000 arthrometer, Lachman test, modified Lysholm and Tegner activity scores (Table 3). The patients in the two groups had almost the same demographics, were operated by using the same surgical technique and underwent the comparison of these groups in terms of graft type used. There were no graft ruptures in both groups. Cavaignac et al. [13] reported a Lachman component that was higher in the QT group than in the HT group (90% vs 46%), while Lee et al. [14] reported a Lachman component almost similar for the QT and HT groups (71% vs 67%), as in this study. In a previous study, Sofu et al. [15] also reported that there were no significant differences in Tegner and Lysholm scores when comparing QT and HT grafts three years after the surgery. The residual laxity (using the KT-1000 arthrometer) was less in the HT than in the QT patients. More than 3-mm side-to-side difference in laxity was found in 52.1% of QT patients and 9.6% of HT patients. However, these results differ from the results of our study where a side-to-side difference of 1.6 mm and 2.5 mm was found for the QT and HT patients 12 months after the surgery. Generally, a significant variation in

Table 3. Orthopedic physical evaluation results[a] between the two groups

	Group A (HT)	Group B (BQT)	P
Lachman test (grade 0:1:2:3) Prior to operation 12-month follow-up	5:12:7:2[e] 18:7:1:0 <.001[c]	4:9:6:1[e] 13:6:1:0 <.001[c]	.711[b] .589[b]
KT-1000 arthrometer displacement[d] Prior to operation 12-month follow-up	3.8±2.0 1.6±1.5 <.001[c]	3.7±1.0 2.5±2.0 <.001[c]	.888[b] .691[b]
Modified Lysholm score Prior to operation 12-month follow-up	60.2±19.0 79.6±12.5 <.001[c]	70.1±7.4 85.0±9.0 <.001[c]	.703[b] .318[b]
Tegner activity score Prior to operation 12-month follow-up	4.6±1.3 4.4±2.0 <.001[c]	4.2±1.5 4.6±1.4 <.001[c]	.926[b] .893[b]

[a]Data are reported as number or mean±SD. [b]Mann-Whitney test. [c]Wilcoxon signed-rank test. [d]Side-to-side difference measured in mm. [e]Number of patients in each grade.

side-to-side displacement between various published studies has been observed, when ACL reconstruction is performed with the HT method; there is less variability when the QT method is used [13]. Results similar to those reported in this study have been reported by Lee et al. [13], who compared single bundle ACL reconstruction using the QT and double-bundle ACL reconstruction using the HT for a two-year follow-up interval. Cavaignac et al. [12] compared ACL reconstruction using the QT and ACL reconstruction using HT for a 3.6-year follow-up interval. A difference was observed concerning the side-to-side displacement, while the pre-operative and postoperative Tegner scores are lower compared to Cavaignac et al. [13].

There were no statistically significant differences in knee extensor muscle strength recovery between the two types of grafts. However, a statistically significant difference in knee flexor muscle strength recovery was found (Table 4), with the BQT grafts being superior compared to the HT grafts, when the angular velocity was set 180°/s instead of 60°/s. This is in agreement with the results of Lee et al. study for a two-year follow-up [13]. Additionally, the QT technique appears to result in better outcomes in terms of extensor mechanism strength compared to bone-patellar tendon-bone (BPTB) technique, mainly due to the significantly lower incidence of anterior knee pain after QT [13].

BPTB and HT grafts are currently considered the most commonly used autografts in ACL reconstruction, while the QT is the least used graft [8]. However, in this study as well as in several previous studies, similar or better clinical results compared to HT graft have been reported with the use of the QT graft. Lee et al. [14] reported no significant differences in stability and functional outcomes among the BQT graft and single-bundle HT graft and double-bundle HT grafts, respectively. A recent systematic review of clinical results [8] has confirmed that the QT is a suitable and safe graft for ACL reconstruction. Postoperative anterior knee pain is an issue when using HT graft. In the current study, a slightly better recovery of knee extensor strength in the HT versus the QT group was reported; however, the differences were not statistically significant.

The vascularization occurred at the three different sites along the graft during the different follow-up intervals was evaluated by introducing the concept of EI. This index required the calculation of the SNR before and after the contrast medium administration. The EI provides immediate information about the vascularization of a tissue in a non-invasive manner [9, 10]. The main finding of this study was the quickest revascularization of the BQT compared to HT graft (Table 5), as indicated by the relatively higher EI values at each specific site of the graft. This finding is in agreement with the results of previous studies [9, 10, 12].

Several MRI studies have been performed to describe the appearance of the graft postoperatively. Many of these studies were performed without the administration of contrast medium, and the imaging changes observed on the graft were characterized subjectively by using visual scoring, reflecting indirectly its overall vascularization process. However, without the objective measurements of contrast medium uptake, the changes of SI could only be attributed to vascular supply. The use of a contrast medium, such as Gd, can improve the diagnostic sensitivity and specificity by direct visualization of tissue vascularity. The enhancement of a tissue after contrast medium administration results in an increase of SI. Therefore, contrast-enhanced MRI can monitor the SI changes during the revascularization

Table 4. Muscle strength recovery assessment around the knee joint between the two groups[a]

	Group A (HT)	Group B (BQT)	P
Knee extensor strength[b]			
60°/s extension 12-month follow-up	72.8±25.6	72.6±24.1	.779
180°/s extension 12-month follow-up	76.3±26.6	73.4±25.3	.439
Knee flexor strength[b]			
60°/s flexion 12-month follow-up	79.6±26.0	91.5±22.1	.104
180°/s flexion 12-month follow-up	82.6±23.8	95.3±19.7	.012

[a]Data are reported as number or mean±SD. All P values are based on Student's-t test.

[b]Percent (%) values in relation to the opposite (contralateral) lower limb.

Table 5. Enhancement index (EI) values calculated along the three different sites of both grafts, for every follow-up time interval

Enhancement index (EI)						
	Group A (HT)			Group B (BQT)		
Follow–up	3 days	6 months	12 months	3 days	6 months	12 months
Intra-articular site	0.94	1.56	1.58	0.95	1.66	1.70
Intraosseous tibial tunnel	0.93	1.38	1.46	0.94	1.47	1.51
Juxta screw Site	0.91	1.31	1.39	0.92	1.41	1.44

process of the ACL graft [9, 10]. Muramatsu et al. [15] compared the revascularization progress in autografts and allografts by means of contrast-enhanced MRI.

The absence of functioning vasculature three days after the surgery, due to necrosis after graft harvesting resulted in absence of contrast medium uptake and EI<1 in all sites; however, there were no statistically significant differences between the two groups. Six months after the surgery, a satisfactory enhancement was observed in all sites of both grafts; however, significantly higher EI values were observed for QT group than HT group. Twelve months after the surgery, a satisfactory enhancement was observed in all sites of both grafts; however, higher EI values were also observed for QT group than HT group but were not significantly different.

The intra-articular site was found to be the first graft site that reached maximum EI values at six months without any significant alteration noticed at twelve months, indicating the completion of the revascularization process for this site by this time period. The intraosseous tibial tunnel site of the graft exhibited a slower revascularization process and six months after the surgery had significantly lower EI values than those of the intra-articular site (P<.001). Between six and twelve months after the surgery, a non-statistically significant increase in EI values was observed; however, the mean EI was lower compared to this of the intra-articular site. Non-significant differences were also found when the mean EI values of the intraosseous tibial tunnel and intraosseous juxta screw sites between six- and twelve-months follow-up interval were compared (P=.09 and .11, respectively). These differences in the EI values represent the differences in the revascularization process at the different graft sites, supporting the hypothesis that the microenvironment conditions existing around the graft would affect its revascularization process [9, 10].

There are some limitations in this study. The sample is relatively small to extract significant differences regarding the clinical outcome and the graft rupture rate. The postoperative follow-up interval is relatively short because most of the graft ruptures occur after this interval. Additionally, a bias is also possible, as the procedures were performed by two different physicians that were not blinded to the procedure. However, the results presented are similar to those in previously published studies, where the sample size and the postoperative follow-up interval are comparable to this study.

Conclusion

Contrast-enhanced MRI is useful to detect the revascularization rate of the graft after ACL reconstruction. In this study, the QT graft showed a quicker maturation rate than the HT graft. There was no difference in the side-to-side stability measurements and clinical outcome parameters, except flexor muscle recovery where QT is better than HT graft. The clinical significance of this study is the quicker return to athletic activities after ACL reconstruction with QT graft. **R**

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Conflicts of Interest

There is no conflict of interest.

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