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Quadriceps tendon autograft for anterior cruciate ligament reconstruction is associated with high revision rates: results from the Danish Knee Ligament Registry

Martin Lind[1] · Marc J. Strauss[2] · Torsten Nielsen[1] · Lars Engebretsen[2]

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Abstract

Purpose The quadriceps tendon (QT) has recently gained interest as an anterior cruciate ligament reconstruction (ACLR) autograft. There is a paucity of data from large cohort studies on failures and revision rates after ACLR using the QT graft. The purpose of the present study is to use the Danish Knee Ligament Reconstruction Registry (DKRR) to compare revision rates, objective knee stability and subjective clinical outcomes in patients who have undergone ACLR with QT, hamstring tendon (HT), and patellar tendon (PT) as a graft for ACLR. It was hypothesized that QT autografts would result in similar objective knee stability and revision rates as HT and PT autografts.

Methods Data on primary ACLRs in the DKRR from 2005 through 2017 were analyzed. Knee injury and Osteoarthritis Outcome Scores (KOOS), Tegner activity scale scores, sagittal knee laxity, pivot-shift tests at 1-year follow-up and revision rates at 2-year follow-up were compared for the three autograft cohorts.

Results A total of 531 QT, 14,213 HT and 1835 PT ACLR were registered in the DKLR between 2005 and 2017. QT autograft was associated with statistically significant increased laxity (1.8 mm) compared to HT autograft (1.5 mm) ($p < 0.001$) and more positive pivot shift. There was a significant higher revision rate for QT (4.7%), compared to PT (1.5%) and HT (2.3%) autografts at 2-year follow-up ($p < 0.002$).

Conclusion Quadriceps tendon autografts for ACLR was associated with higher revision rates than HT and PT grafts. QT graft was also associated with small increased objective knee laxity and more positive pivot shift than HT and PT grafts.

Level of evidence III

Keywords Quadriceps tendon · Hamstring tendon · Patellar tendon · ACL reconstruction · Clinical outcomes

Introduction

The ACL is most often reconstructed using one of two autografts: the patellar tendon (PT) or the hamstring tendon (HT). The choice between these two graft types typically depends on physician preference, with an overall predominance of HT autografts in Scandinavia [19, 20, 23]. The current paradigm is being challenged due to clinical outcomes data reporting a higher revision rate with HT autografts than with PT autographs [6, 28].

There is donor-site morbidity associated with both PT and HT autografts. The most common complication of PT autograft harvesting is anterior knee pain, which has been reported in up to 40% of patients [13, 21]. In addition, PT grafts cannot be used as an autograft in skeletally immature patients due to the risk of damage to open physes [8]. The most common complications of HT autograft harvesting are sensory deficits related to injury to the infrapatellar branches of the saphenous nerve [9], which also can cause anterior knee pain. Other complications of HT autograft harvesting include theoretically reduced medial knee stability in medial collateral ligament-deficient patients and weakness of knee flexion and internal rotation [9, 10]. Additionally, a meta-analysis reported that PT autografts lead to less residual anterior knee laxity than HT autografts [4].

✉ Martin Lind
martilin@rm.dk

1 Department of Orthopaedics, Aarhus University Hospital, Palle Juul-Jensens Boulevard 99, 8200 Aarhus N, Denmark

2 Orthopedic Clinic, Oslo Sports Trauma Research Center, Oslo University Hospital, Norwegian School of Sport Sciences, Oslo, Norway

There has been increased interest in the quadriceps tendon (QT) as an alternative autologous graft source for ACL reconstruction (ACLR), culminating in the creation of the International Quadriceps Tendon Interest group [30]. A randomized controlled trial demonstrated that ACLRs performed with QT autografts have reduced donor site morbidity and equivalent clinical outcomes scores compared to reconstructions with PT autografts after 2 years of follow-up [18]. Furthermore, a retrospective study by Geib et al. reported no difference in clinical outcomes between PT and QT autografts in the intermediate term [5].

The present literature on QT autografts for ACLR is limited by small study sizes, which has prevented reporting of failure rates and outcomes from a generalized surgical population. National clinical registries contain high-volume data that enable investigation of accurate low incidence failure rates (ACL revision) in procedures that are done relatively infrequently such as QT graft ACLR. National clinical registry data are not biased by a priori hypotheses and are generated from the full spectrum of surgeons in the country. In the Danish Knee Ligament Reconstruction Registry (DKRR), more than 600 QT ACLRs and more than 20,000 PT and HT ACLRs from 2005 through 2017 enable comparison of revision rates and objective clinical outcomes for these graft types [16].

The purpose of this study was to compare revision rates and objective knee stability of patients after ACLR with QT, HT, and PT autografts using the DKRR. It was hypothesized that QT autografts would result in similar revision rates and objective knee stability as HT and PT autografts.

Materials and methods

The study was based on the DKRR, which is a prospective, nationwide and web-based clinical database initiated in 2005. The registry contains data on primary and revision anterior and posterior cruciate ligament reconstructions as well as collateral ligament and multiligament reconstructions performed in Denmark. Both public and private hospitals supply data to this registry [15].

The operating surgeon records preoperative, operative and 1-year follow-up data, using a standardized form in a secure Internet portal. Furthermore, patients independently report on subjective knee function using self-assessed instruments, the Knee injury Osteoarthritis Outcome Score (KOOS) and Tegner Activity Scale scores [26, 32]. The surgeon or physician assistant records objective instrumented Lachman laxity at pivot shift test outcome at 1-year follow-up. The patients enter KOOS and Tegner activity scale data into a web-based form before the surgery and 1 year after the surgery.

No written consent is necessary in Denmark for studies based on data from national board of health approved national healthcare registries. However, the study was approved by the Regional Centre for Clinical Quality Development and the National Data Protection Agency approval number 1-16-02-65-17).

Patients

A total of 16,579 ACL reconstructions suiting the inclusion and exclusion criteria were registered in the DKLR between 2005 and 2017. Inclusion criteria were: primary ACL reconstruction with QT, HT or PT autograft. A total of 25,281 reconstructions were eligible for inclusion. Exclusion criteria were: Previous ligament procedure (312 excluded), Age below 16 years (1541 excluded), previous contralateral ACL injury (1801 excluded), other graft type (1126 excluded), multiligament injury (598 excluded) and any previous meniscus or cartilage surgery to the affected knee (3324 excluded). Three study populations were identified based on graft choice for ACL reconstruction: patients with QT autografts ($n=531$); patients with HT autografts ($n=14{,}213$); and patients with PT autograft ($n=1835$).

The completeness of surgical registration was determined by correlating the registry data with data in a national registry of patients in which all public and private hospital contacts and procedures are registered. The over-all completeness of ACL procedure registration in the ACL registry was 91% for study data.[24].

The completeness of 1-year follow-up objective knee stability assessment was 53%. The completeness of patient-reported outcome data was 34% pre-operatively and 25% at the 1-year follow-up. A validation study from the DKRR have demonstrated no difference in epidemiologic characteristics, clinical outcomes and revision rates between responders and non-responders [24]. Due to the low completeness the PROM data form KOOS and Tegner activity scores are not included in the present paper.

Patient characteristics

The average age of the patients was 28.2 years (range 16–70 years) and 63% of patients were male. Sports participation was the cause of injury in 84.9% of cases. There were differences between the three graft groups with QT graft patients having moderately lower age, more sports related injury mechanisms and presence of meniscus and cartilage injuries at the time of surgery (Table 1). Of the QT graft ACLR 288 (54%) used a patella bone block which was fixed in the femoral tunnel in 93% of cases.

Outcomes

The primary outcome was failure of the ACLR expressed as need for revision ACLR. Need for revision ACLR was

Table 1 Patient Characteristics of the three graft groups

Graft groups	QT	HT	PT	QT vs HT	PT vs QT	PT vs HT
N total	531	14.213	1.835			
Age (mean)	26.2	28.1	29.3	$p < 0.001$	$p < 0.001$	$p < 0.001$
Male (%)	70	62	70	$p < 0.001$	n.s	$p < 0.001$
Injury in sports (%)	86	85	83	n.s	n.s	$p = 0.04$
Meniscus injury (%)	51	45	45	$p = 0.01$	$p = 0.03$	n.s
Cartilage injury (%)	25	17	14	$p < 0.001$	$p < 0.001$	$p < 0.001$
Operation time (mean)	85	69	82	$p < 0.001$	$p = 0.04$	$p < 0.001$

PT patellar tendon, *HT* hamstring tendon, *QT* quadriceps tendon

decided by the individual surgeons based on continued instability or reinjury. Furthermore, subgroups analysis of 2-year revision rates was performed for the following cohorts. (1) Patients 16–20 years of age since young ACL injury patient have a known high risk of revision ACLR. (2) Patients with contact sports activity at the time of injury (defined as pre-injury Tegner activity score of 7–10) also because contact sport athletes have a known higher risk for ACL reinjury. (3) Graft cohorts with reduced learning curve procedures. The reduced learning curve cohorts were obtained by removing the first one-third performed procedures in each graft type cohort overall.

The secondary outcomes were objective knee stability in terms of instrumented sagittal knee stability testing and pivot-shift scores. The sagittal stability test measured the difference in sagittal stability between the operated knee and the healthy knee using the Knee Translation instrument 1000 (KT-1000) or the Rolimeter. The pivot-shift test is a dynamic but passive test of the knee that measures the rotational and anterior tibial translation stability of the ACL. The pivot-shift test is graded on a 4-point scale, where 0 = negative, 1 = glide, 2 = clunk, and 3 = gross [12]. The pivot-shift data were divided into negative pivot-shift tests and positive pivot-shift tests.

Statistical analyses

Descriptive data are presented as mean and standard deviations and compared with Student *T* test or ^{2} tests for proportional data. We used Cox regression analysis to compare the revision risk within the first 2 years after primary ACL surgery among patients operated in the three graft groups.

By applying the Kaplan–Meier method we estimated the revision probability for the three graft groups for the total follow-up period. Hazard ratios were computed the as a measure of relative risk (RR) both crudely and adjusted for potentially confounding factors. The included confounding factors were: gender, age (≤ 20 and > 20 years of age), cartilage damage > 1 cm^2 present (no/yes or missing data), surgical treatment of meniscal injury either resection or repair (yes/no or missing data). The confounding factor were chosen based on known factors influencing ACL reconstruction outcome.

p values < 0.05 were considered statistically significant. All statistical analyses were computed using Stata Version 15 (Stata Release 12, College Station, TX).

Results

Objective knee laxity

The knee laxity, as determined by the side-to-side difference with a knee arthrometer, was significantly decreased by the ACLR surgery in all three graft groups. At 1-year follow-up QT autograft use was associated with more objective knee laxity than HT autografts, producing 1.8 mm, 1.5 mm, and 1.6 mm of postoperative laxity, respectively (PT vs HT $p < 0.001$, QT vs PT $p = 0.01$) (Table 2).

A positive postoperative pivot-shift test was found in the QT autograft cohort (24%) the HT (18%) and PT (19%) cohorts, respectively, with QT grafts having significantly more positive pivot shift than HT and PT grafts ($p < 0.05$) whereas no difference were seen between PT and HT graft groups (Table 2).

Revision rates

QT autografts resulted in the highest revision rate. The revision rates after 2 years were 4.7%, 2.3%, and 1.5% for QT, HT, and PT ACL reconstructions, respectively (Table 3) (Comparison of revision rates between graft types using confounder unadjusted and adjusted hazard ratio's demonstrated significant higher revision rate for QT compared to HT with an unadjusted hazard ratio of 1.77 ($p < 0.002$) and an adjusted hazard ratio of 1.74 ($p < 0.003$). QT compared to PT had hazard ratios unadjusted of 2.23 ($p < 0.001$) and adjusted of 2.01 ($p < 0.001$) (Fig. 1).

Subgroups analysis of 2-year revision rates, for young patients, patients with contact sports activity and for graft cohorts with reduced learning curve surgeries demonstrated similar tendencies as the total cohort with QT grafts having

Table 2 Postoperative Objective Knee Laxity and negative Pivot Shift results after ACL reconstruction

	QT	HT	PT	QT vs HT *p* value	QT vs PT *p* value	PT vs HT *p* value
Pre-Op (mm)	5.1 ± 1.9	5.2 ± 2.2	5.4 ± 2.5	n.s	0.001	0.004
N	392	7419	1027			
Post-Op (mm)	1.8 ± 1.7*	1.5 ± 1.5*	1.6 ± 1.4*	< 0.001	0.01	0.01
Negative pivot shift pre-op (%)	2	11	11	< 0.001	< 0.001	n.s
Negative pivot shift post-op (%)	76	82	81	< 0.05	< 0.05	n.s
Glide pivot shift post-op (%)	23	16	17	–	–	–
Clunk pivot shift post-op (%)	1	2	2	–	–	–
Gross pivot shift post-op (%)	0	0	0	–	–	–

Knee laxity as measured by instrumented side-to-side difference laxity the KT-1000 device or the Rolimeter

QT quadriceps tendon, *HT* hamstring tendon, *PT* patellar tendon, *SD* standard deviation

*Significant reduced laxity from preoperative to postoperative

Table 3 Two-year revision rates and comparison of two-year revision rates for and between the following subgroups

Subgroups	QT	PT	HT	QT vs HT	QT vs PT	PT vs HT
N at risk at 2 years F-U	400	1761	13,436			
Total (16,579 pt)	4.7	1.5	2.3	0.002*	< 0.001*	n.s
16–20 years (3774 pt)	10.3	4.2	3.8	n.s	n.s	n.s
Tegner > 6 (3255 pt)	8.6	1.0	3.6	0.002*	< 0.001*	0.02*
Reduced learning curve (11,052 pt)	6.0	1.7	2.2	< 0.001*	0.005*	n.s

(1) Young patients between 16 and 20

(2) Contact sport athletes defined as patients with Tegner Score of 7–10 at the time of injury

(3) Reduced learning curve. Impact of learning curve was reduced for the cohorts was performed by exclusion of the first third of all operations in each graft group

*$p < 0.05$

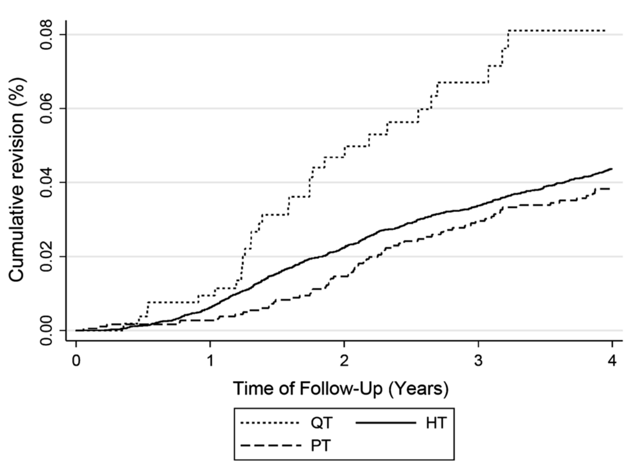

Fig. 1 Kaplan–Meier revision estimates. Revision rates of the three autograft cohorts, showing the highest revision rate after quadriceps tendon autograft (QT). *ACL* anterior cruciate ligament, *HT* hamstring tendon, *PT* patellar tendon

consistently higher revision rates than HT and PT grafts (Table 3). For both young patients and patients injured in pivoting sports, revision rates for QT grafts were higher than the overall revision rates for the graft types indicating very high risk of graft failure for contact young sport athletes treated with QT ACLR. The were no difference in revision rates for QT graft ACLR harvested with bone block compared to QT graft without bone block.

Discussion

The primary finding of the present study was that there was a significantly higher revision rate for ACLR with QT autograft compared to both HT and PT autografts. Two-year revision rates in the QT group were 4.7%, compared to 2.3% and 1.5% in the HT and PT groups, respectively. This is in contrast to the hypothesis that there would be no difference in stability and revision rates between the QT and HT and PT ACLR groups.

The findings of higher revision rates after QT graft ACLR compared to the HT and PT graft ACLR are contrary to what previous studies have reported [5, 7]. The subgroup analyses demonstrated that the high revision rate for QT graft was especially pronounced for young patients between 16 and 20 years and for patients injured in contact sports and therefore expected to return to contact sports. Lund et al. compared in a randomized controlled study of 30 ACLR reconstructions with bone plug QT grafts to 30 PT grafts. They had one graft rupture in the PT group resulting from a new trauma 15 months postoperative. No failures were found in the QT group 24 months postoperatively [18]. Geib et al. compared in 191 patients ACL reconstructions with QT grafts, both with and without bone plug, to PT grafts. They reported 11 failures in the QT group and only 1 in the PT group [5]. Runer et al. compared in 80 patient's QT grafts with a bone plug to HT grafts. They reported no differences in failures between patients after 24 months of follow-up [27]. Finally, Gorschewsky et al. compared in 194 patients with a minimum follow-up of 2 years with QT grafts with a bone plug compared to PT grafts and reported a failure rate of 2.2% after 24 months in the QT group compared to 4.9% in the PT group [7]. So the failure and revision rate reports have been quite inconsistent. However, the above-mentioned studies with limited patient number are subject to type 2 error for the rare incidence of revision surgery. The present study is the first study with a sufficient QT ACLR patient material to more accurately evaluate the rare failure parameter of revision reoperation, which for ACL reconstruction has an incidence typically below 5% at 2 years [16]. Furthermore, the present data from a national registry represents a more generalized surgical population than the above-mentioned single center studies. The finding of increase revision rates for QT graft could therefore be more valid than the other studies.

Several of the previously mentioned studies reported a learning curve when harvesting the quadriceps tendon graft and also with the use of the harvesting systems available on the market [3, 31]. There is a mix of techniques varying from a 5 mm thick (known as partial thickness) to 8 mm thickness (known as full thickness), and 10 mm to 12 mm width QT grafts. In the study by Geib et al. only full thickness grafts were used, and one surgeon performed the surgery [5].

The QT graft with its reported higher tissue strength and hamstring sparing surgical strategy has been suggested for patients with a wish to return to pivoting sports. This strategy would give strong graft and maintained hamstring function, which could give safer biomechanical function during and after return to sports. These patients are known to have a higher risk for traumatic re-ruptures [22]. In the present patient material, activity at the time of injury was sports in 86% in the QT group compared to 85% in the HT group and 83% in the PT group. We therefore did not have a dominance of sports patients in the QT group. Another known risk factor for graft failure is age with the adolescent patient group having a higher risk ACL graft failure than the older patients [2]. In the study material the age of QT patients was two year lower than the other graft groups. This could to some degree explain the higher revision rate for QT graft ACLR. In the present study there are multiple surgeons and choice of graft dimensions, which also may influence the difference in revision rates observed between the present registry study and the other single center studies.

The present study did observe a significantly higher postoperative laxity in the KT-1000 measurement of 0.3 and more positive pivot shift when using QT autograft compared to HT. A study by Lee et al. reported no difference in positive pivot-shift tests and KT-2000 stability [14]. Although statistically significant due to high patient number the 0.3 mm difference in laxity is not considered clinically relevant.

There are anatomical and biomechanical differences between the QT, HT, and PT grafts, which could explain the increased failure rate for the QT graft. The fibers of the PT and HT are parallel, while the QT is composed of several layers. Most studies describe the QT as a trilaminar structure with the rectus femoris (RF) tendon as the most superficial layer, the vastus medialis oblique (VMO) and vastus lateralis (VL) tendons constituting the middle layer, and the vastus intermedius (VI) tendon serving as the deep layer [1, 11, 17]. The RF and VI tendons have straight fibers directed towards the patella, whereas the VMO and VL tendons have oblique or crossing fibers. Therefore, the VMO and VL tendons may add tissue volume, but may not contribute to the strength of a harvested QT graft due to the sectioning of oblique and crossing fibers. However, in a biomechanical study, Shani et al. reported on the strength of the QT and PT grafts and fund a higher strength of the QT compared to the PT and that the QT had a cross sectional area two times that of the PT [29]. The clinical situation however might differ from the in vitro situation with fiber ruptures and graft elongation over time during rehabilitation due to the lack parallel fibers.

In the present study, it is possible to identify a specific cause for the higher revision rate found after QT ACLR. But as revision rate results are corrected for a number of surgical and comorbidity confounders, we believe that anatomical structure and in vivo biomechanical properties could be the main reason for the findings. It could also be speculated that a reason for the high revision rate following QT ACLR was that many surgeons were in their learning curve for many of the patient included in the study. But our subgroup analysis demonstrated that removing the first one-third of the operated patients did not reduce the higher revision rate for QT grafts and we therefore do not believe that a learning curve issue is causing the high revision rate for QT grafts. Differences in harvest technique and graft fixation did not appear to could contribute to high revision rate for QT graft as bone block usage or and screw fixation had similar revision rates as soft tissue QT graft fixed with various soft tissue fixation techniques. An unexpected finding was that removing the first one third of PT graft surgeries resulted in an increase in PT graft 2-year revision rate. A potential explanation for this, could be that PT graft have been decreasingly used during the existence of the ACL registry and that anatomical reconstruction techniques have been predominant in the most recent period of the registry. Since anatomical technique have been shown to be associated with higher revision rates [25], then a higher revision rate is to be expected when investigating revision rate for PT graft in a more recent period.

The concerning significantly higher failure rate indicates that QT grafts do not perform as well as HT and PT grafts. The hypothesis that QT could be an optimal graft type with similar knee stability, outcomes and a similar low revision rate as a patella tendon graft could not be supported be the results of the present study.

The most important strength of this study is the large sample size of all three graft groups investigated. Another strength is the inclusion of patients from several centers nationwide with a high completeness above 90%. Generally, registry data have high external validity due to prospective data collection, high volume from multiple centers and surgeons and the fact that no a priori data collection purpose exist which could bias data.

There are some limitations of this study. Selection bias is an important issue for registry data especially for new techniques such as QT graft usage as the motivation for using the new graft type is not recorded in the registry. However, our cohort characteristic analyses did only reveal a moderate younger age for QT graft cohort compared to the other graft cohorts. Evaluation of knee stability outcomes with instrumented knee laxity measurements and pivot shift test are in the majority of clinics investigated by the operating surgeons. Only a few clinics used independent evaluators. This can cause a bias towards better stability measurements, which should be taken into account when evaluating the objective outcomes. The fixation devices used was not take into consideration for the different grafts and it was not possible to include graft size in the three different groups. Revision surgery has been used as the endpoint of failure, but this parameter does not include the group of patients who have subjective or objective graft failure but did not undergo revision surgery.

Conclusion

Quadriceps tendon autografts for ACLR was associated with higher revision rates than HT and PT grafts. QT graft was also associated with small increased objective knee laxity and more positive pivot shift than HT and PT grafts.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval The study was approved by the Regional Centre for Clinical Quality Development and the National Data Protection Agency approval number 1-16-02-65-17).

Informed consent No written consent is necessary in Denmark for studies based on data from national board of health approved national healthcare registries.

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