Graft Diameter and Graft Type as Predictors of Anterior Cruciate Ligament Revision

A Cohort Study Including 18,425 Patients from the Swedish and Norwegian National Knee Ligament Registries

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Background: It is important to investigate and compare graft diameters as well as graft types to identify risk factors for revision after an anterior cruciate ligament (ACL) reconstruction. We performed the current study in order to analyze the early ACL revision rate among patients treated with hamstring tendon (HT) autografts or patellar tendon (PT) autografts of different diameters. Our hypothesis was that an increase in both HT and PT autograft diameters would reduce the risk of early ACL revision.

Methods: This retrospective study was based on prospectively collected data from the national knee ligament registries of Norway and Sweden and included patients who underwent primary ACL reconstruction during the period of 2004 through 2014. The primary end point was the 2-year incidence of ACL revision. The impact of graft type and diameter on the incidence of revision surgery was reported as relative risks (RRs) with 95% confidence intervals (CIs), estimated by using generalized linear models with a binomial distribution and log-link function.

Results: Of 58,692 patients identified, a total of 18,425 patients were included in this study. The 2-year rate of ACL revision was 2.10% (PT autografts, 2.63%; HT autografts, 2.08%; RR = 0.93 [95% CI = 0.60 to 1.45]). There was an increased risk of ACL revision among patients treated with HT autografts with a diameter of <8 mm compared with larger HT autografts (RR = 1.25 [95% CI = 1.01 to 1.57]). Patients treated with HT autografts with a diameter of ≥9.0 mm or ≥10.0 mm had a reduced risk of early ACL revision compared with patients treated with PT autografts.

Conclusions: Patients treated with larger-diameter HT autografts had a lower risk of early ACL revision compared with those treated with HT autografts of <8 mm. Patients treated with HT autografts of ≥9 or ≥10 mm had a reduced risk of early ACL revision compared with patients treated with PT autografts.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

The surgical technique of anterior cruciate ligament (ACL) reconstruction is constantly evolving[1,2]. In the early days of surgical reconstruction of the ACL, the use of patellar tendon (PT) autografts was the gold standard[3]. In Sweden, the use of hamstring tendon (HT) autograft has become the treatment of choice when performing an ACL reconstruction. In Norway, use of HT autograft was the treatment of choice for primary ACL reconstruction during the period of study; however, since 2015, >50% of primary ACL reconstructions have been performed using PT autografts[4]. The literature is not unanimous when it comes to autograft choice in terms of success rate, limiting the occurrence of adverse events, and restoring stability[3,5-13]. In previous comparative analyses of patient-reported outcomes following ACL reconstruction among patients treated with HT or PT autografts, the grafts were analyzed as 2 directly comparable tissues. This can be questioned because PT autografts are known to be more homogeneous in shape and size, while HT autografts have a more variable anatomy[14,15]. The structure of the tendon in a PT autograft is rectangular in shape (Fig. 1), with a height of

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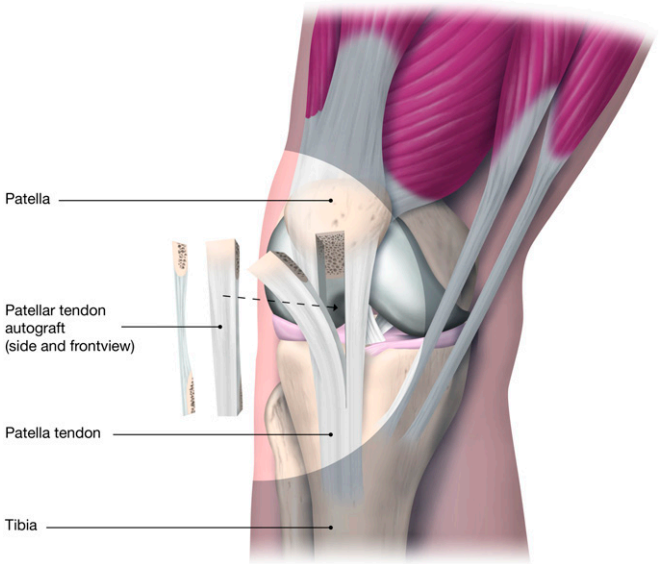

Fig. 1
Patellar tendon autograft.

around 2 to 3 mm, and the tendon width is usually harvested with a 10-mm block[16]. The fixation of a PT autograft includes bone blocks at both ends, providing a platform for bone-to-bone healing, and screw fixation as the standard fixation method. The shape of HT autografts is more elliptical, and the tendon diameter varies substantially[17]. The semitendinosus tendon alone, or in combination with the gracilis tendon, is folded in many ways (Fig. 2), creating a variance in the HT autograft diameter and, accordingly, in its strength and stiffness[18]. The greater variability in HT autograft construction compared with PT autograft is therefore a consequence of the size and number of harvested tendons, the suture technique for the autograft, and the folding of the tendons[19]. Moreover, there are a greater variety of commonly used fixation methods for HT autografts[20].

The risk of early ACL revision has been reported to decrease with increased graft diameter when using HT autografts[21,22]. These findings underline the importance of considering graft diameter as a factor when analyzing the revision rate after ACL reconstruction and, in particular, when comparing the 2 graft options. With the current study, our goal was to compare early ACL revision risk for both PT and HT autografts in relation to different graft diameters using data from 2 national databases[23,24]. Our hypothesis was that an increase in both HT and PT autograft diameters would reduce the risk of early ACL revision.

Materials and Methods

Patients

Patient data were extracted from the Norwegian Knee Ligament Registry (NKLR) and the Swedish National Knee Ligament Registry (SNKLR). Eligible for inclusion were patients aged 13 to 59 years who underwent primary ACL reconstruction with use of either an HT or a PT autograft during the period of June 7, 2004 (Norway), or January 1, 2005 (Sweden), to December 31, 2014. Excluded were patients who underwent contralateral ACL reconstruction within the study period or who had sustained concomitant bone, vascular, or other ligament damage. Also excluded were patients for whom data on autograft diameter were not recorded.

The diameters of PT and HT autografts were measured and decided on intraoperatively, depending on the harvesting of the tendons. Femoral fixation was classified as cortical fixation or use of cross-pins, a metal interference screw, or a bioabsorbable interference screw. Tibial fixation was classified as cortical fixation, post fixation, or use of cross-pins, a metal interference screw, or a bioabsorbable interference screw.

Norwegian and Swedish National Knee Ligament Registries

The NKLR and the SNKLR were established in 2004 and 2005, respectively[25]. These registries were initiated to improve treatment outcomes through feedback to hospitals and surgeons and through the collection of data that can assist in the detection of procedures and devices that result in premature failure and the identification of prognostic factors associated with good and poor postoperative outcomes[26].

The SNKLR and NKLR serve as nationwide clinical databases[25]. The estimated coverage of registration for primary ACL reconstruction is approximately 90% in Sweden[27] and 86% in Norway[28]. Surgical data are reported by treating surgeons, while patient-reported outcome data are registered by patients. Both databases collect data prospectively, including

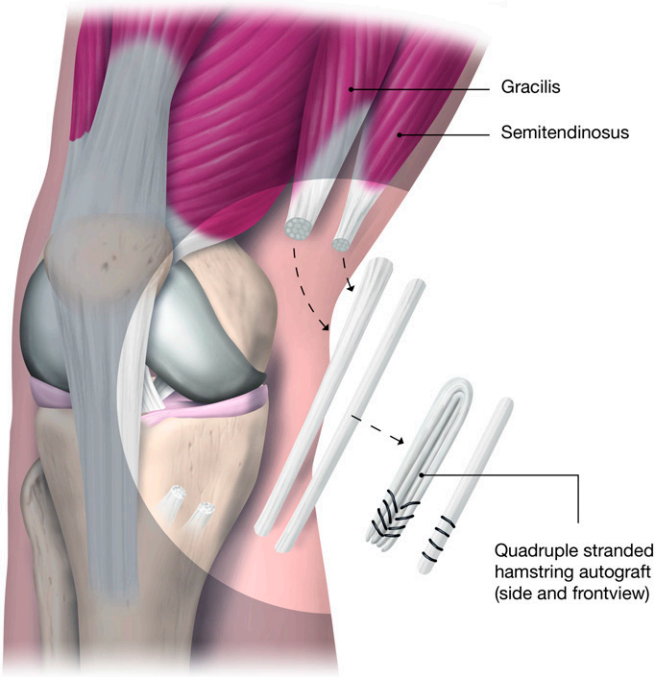

Fig. 2
Hamstring tendon autograft.

TABLE I Baseline Demographics*

	Total (N = 18,425)	PT Autograft (N = 1,329)	HT Autograft (N = 17,096)
Sex *(no. [%])*			
Male	10,532 (57.2%)	769 (57.9%)	9,763 (57.1%)
Female	7,893 (42.8%)	560 (42.1%)	7,333 (42.9%)
Age at index ACL injury *(yr)*			
Mean (SD)	24.9 (9.3)	25.0 (8.8)	24.9 (9.3)
Median (range)	22.1 (6.3-58.9)	22.7 (13.7-50.8)	22.1 (6.3-58.9)
Q1; Q3	17.8; 29.8	17.9; 29.4	17.8; 29.8
No. with data available	13,471	273	13,198
Age at index ACLR *(yr)*			
Mean (SD)	26.8 (9.7)	25.8 (8.8)	26.4 (9.3)
Median (range)	23.9 (13.0-59.9)	22.6 (13.5-59.3)	24.1 (13.0-59.9)
Q1; Q3	19.0; 33.0	18.5; 30.7	19.0; 33.2
No. with data available	18,425	1,329	17,096
Adolescents *(no. [%])*	5,663 (30.7%)	474 (35.7%)	5,189 (30.4%)
Duration of surgery *(min)*			
Mean (SD)	74.4 (24.0)	82.3 (27.5)	74.2 (23.9)
Median (range)	70.0 (25.0-304.0)	75.0 (40.0-184.0)	70.0 (25.0-304.0)
Q1; Q3	57.0; 90.0	62.5; 95.5	56.0; 90.0
No. with data available	14,378	304	14,074
Time to surgery *(mo)*			
Mean (SD)	16.4 (29.8)	14.3 (25.8)	16.6 (30.1)
Median (range)	8.0 (0.0; 468.0)	7.0 (0.0; 367.0)	8.0 (0.0; 468.0)
Q1; Q3	5.0; 15.0	4.0; 13.0	5.0; 15.0
No. with data available	16,774	1,242	15,532
Meniscal injury *(no. [%])*	8,656 (47.0%)	695 (52.3%)	7,961 (46.6%)
Cartilage injury *(no. [%])*	4,532 (24.6%)	230 (17.3%)	4,302 (25.2%)
Activity (n = 18,388) *(no. [%])*			
Football (soccer)	8,376 (45.6%)	618 (46.8%)	7,758 (45.5%)
Floorball	1,388 (7.5%)	31 (2.3%)	1,357 (8.0%)
Handball	1,326 (7.2%)	183 (13.9%)	1,143 (6.7%)
Alpine	1,682 (9.1%)	53 (4.0%)	1,629 (9.5%)
Other	5,616 (30.5%)	436 (33.0%)	5,180 (30.4%)
Revision within 2 yr† *(no. [%])*			
Total	391	35 (9.0%)	356 (91.0%)
Male	206	20 (9.7%)	186 (90.3%)
Female	185	15 (8.1%)	170 (91.9%)

*ACLR = anterior cruciate ligament reconstruction, and SD = standard deviation. †Revision percentages are based on the total number for the given row.

data on cruciate ligament reconstructions and revisions, and have been described in previous reports[25,27].

Surgeon participation in these registries is voluntary in both countries. In Sweden, no written consent is necessary for the collection of data in national registry databases[25]. The regional ethical board in Stockholm, Sweden, approved the research (approval number: 2011/337-31/3). In Norway, all patients are asked to sign an informed consent form before ACL reconstruction. When processing data from the database, access was bound to de-identified data. Data from the NKLR were treated according to Norwegian legislation[29].

Outcome Measurements

The primary end point in this study was the 2-year cumulative incidence of ACL revision, defined as the occurrence of new ACL reconstruction within 2 years of the primary ACL reconstruction. Follow-up started the same day on which the primary ACL reconstruction occurred. The end point of

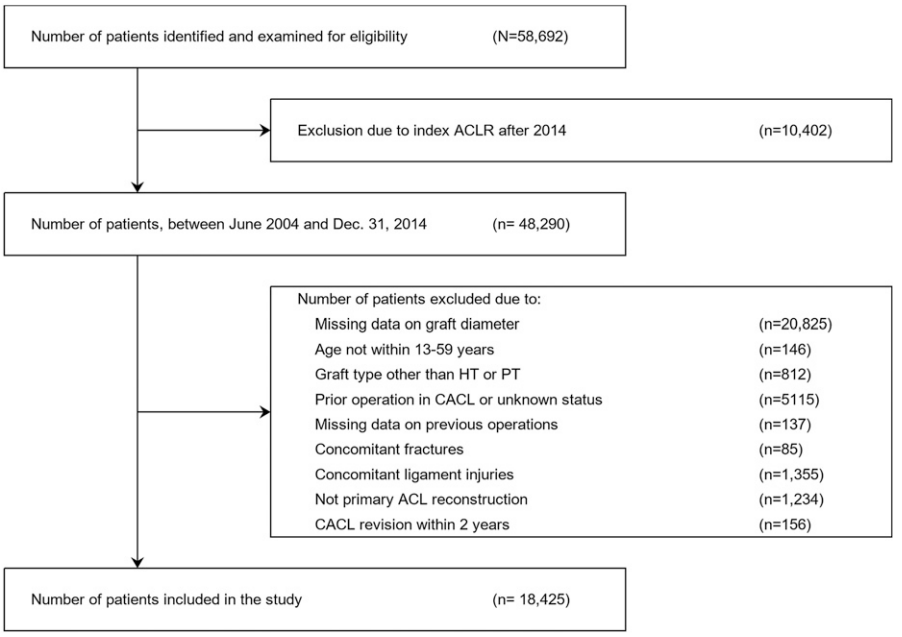

Fig. 3

Flowchart of inclusion and exclusion criteria. ACLR = anterior cruciate ligament reconstruction, HT = hamstring tendon, PT = patellar tendon, and CACL = contralateral anterior cruciate ligament.

follow-up was revision surgery or 2-year follow-up, whichever occurred first.

Statistical Methods

A combined data file from the registries was created, and statistical analyses were performed using SAS for Windows (version 9; SAS Institute). Descriptive statistics for patient demographics are reported as the number and percentage for categorical variables; continuous variables are reported as the mean and standard deviation, and the median and range.

The impact of graft type and diameter on the incidence of revision ACL reconstruction was described as relative risk (RR) with the 95% confidence interval (CI), estimated by using generalized linear models with a binomial distribution and log-link function. Adjustments for known confounders were made using multivariable analysis. All of the tests were 2-sided and conducted at the 5% significance level. Significance was defined as a 95% CI for risk estimates not including 1.00 and $p < 0.05$.

Results

A total of 58,692 individuals were registered for primary ACL reconstruction in the NKLR and SNKLR and were assessed for eligibility. Of the identified patients, 18,425 patients (10,532 male and 7,893 female) were ultimately included in the study. Baseline demographics are presented in Table I. As shown in Figure 3, >10,000 patients were excluded because they did not have 2 years of follow-up. Another subgroup of patients (20,825) did not have data regarding graft diameter. With respect to femoral fixation, cortical fixation was

TABLE II Two-Year ACL Revision Incidence and Revision Risk by Graft Type and Diameter*

Comparison	ACL Revision Incidence *(%)*	Unadjusted			Adjusted†		
		RR	95% CI	P Value	RR	95% CI	P Value
PT vs. HT	2.63 vs. 2.08	1.26	0.90-1.78	0.18	0.93	0.60-1.45	0.76
HT <7 mm vs. HT ≥7 mm	2.65 vs. 2.07	1.28	0.61-2.68	0.51	0.93	0.44-1.95	0.84
HT <8 mm vs. HT ≥8 mm	2.71 vs. 1.87	1.45	1.16-2.68	0.0009	1.25	1.01-1.57	0.047
HT <9 mm vs. HT ≥9 mm	2.26 vs. 1.56	1.45	1.11-1.88	0.0052	1.29	0.99-1.68	0.061
HT <10 mm vs. HT ≥10 mm	2.12 vs. 1.07	1.99	0.94-4.18	0.064	1.81	0.86-3.82	0.12
PT <10 mm vs. PT ≥10 mm	1.57 vs. 3.17	0.49	0.22-1.12	0.084	0.50	0.21-1.19	0.12

*ACL = anterior cruciate ligament, RR = relative risk, CI = confidence interval, PT = patellar tendon, and HT = hamstring tendon. †Adjusted for age, diameter (PT vs. HT comparison only), meniscal injury, and femoral and tibial fixation (not PT graft diameter comparison).

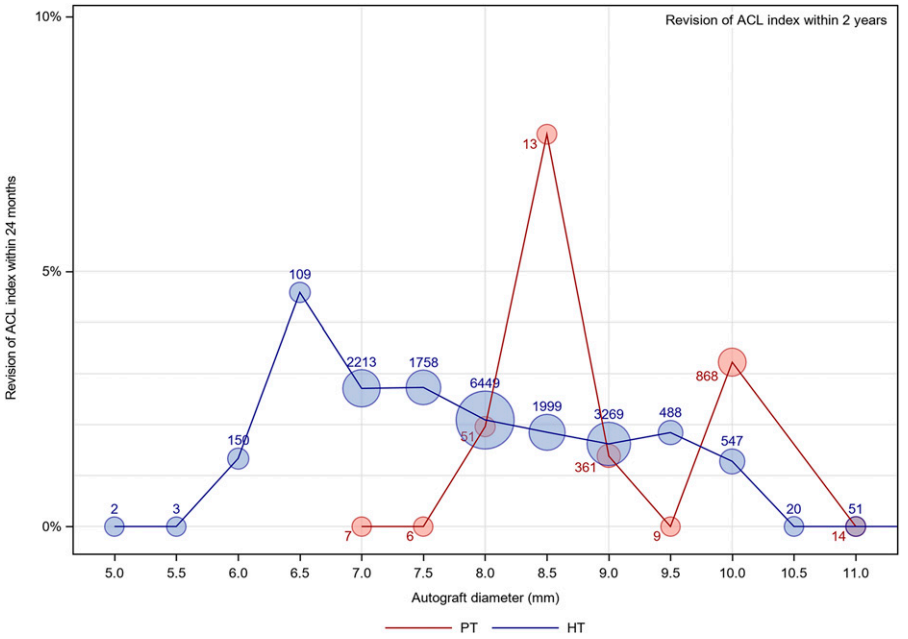

Fig. 4

Incidence of revision surgery within 2 years following ACL reconstruction, by graft type (patellar tendon [PT] or hamstring tendon [HT]) and graft diameter. The number presented by each dot is the total number of patients who received autografts of the indicated type and diameter. A total of 38 patients were treated with an HT autograft of ≥12 mm (not shown).

used in 66.6% of the patients; a metal interference screw, in 15.8% of the patients; and cross-pins, in 15.6%. For tibial fixation, a metal interference screw was used in 43.4% of the patients, while a bioabsorbable screw was used in 41.8%; post fixation (6.8%) and cortical fixation (5.2%) were more seldomly used.

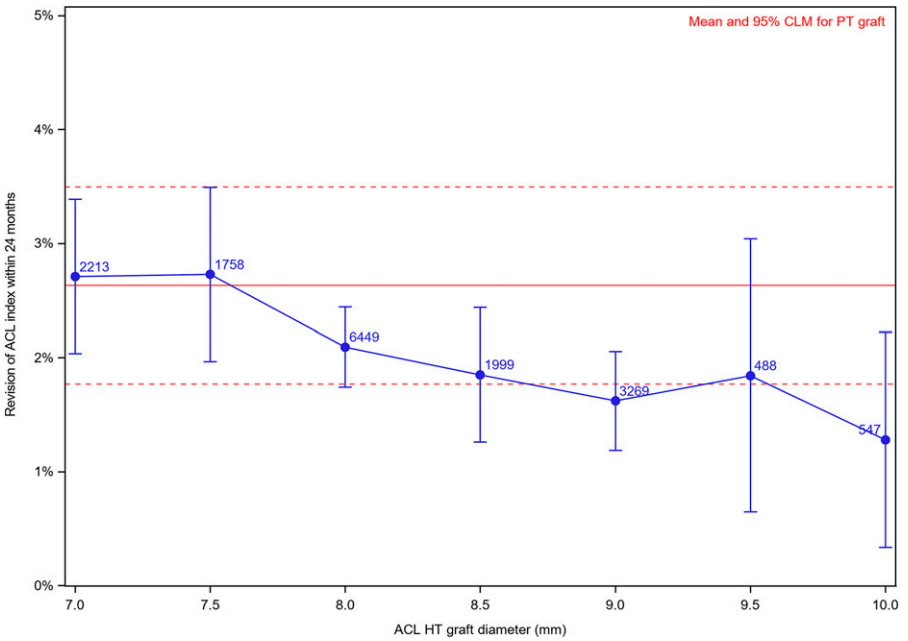

Fig. 5

Incidence of revision surgery within 2 years following ACL reconstruction, comparing all patellar tendon (PT) autografts with hamstring (HT) autografts of ascending graft diameter. The number presented by each dot is the total number of patients who received HT autografts of the indicated diameter. CLM = confidence limits for the mean, indicated by the red dashed lines for PT graft and by the blue error bars for HT graft.

TABLE III Two-Year ACL Revision Incidence and Revision Risk by Graft Type and Diameter: HT of Increasing Diameter Versus PT*

		Unadjusted			Adjusted†		
Comparison	Incidence *(%)*	RR	95% CI	P Value	RR	95% CI	P Value
HT ≥7.0 mm vs. PT	2.07 vs. 2.63	0.79	0.56-1.11	0.17	0.83	0.59-1.17	0.28
HT ≥7.5 mm vs. PT	1.98 vs. 2.63	0.75	0.53-1.06	0.1	0.81	0.57-1.14	0.22
HT ≥8.0 mm vs. PT	1.87 vs. 2.63	0.71	0.51-1.01	0.056	0.77	0.54-1.09	0.14
HT ≥8.5 mm vs. PT	1.65 vs. 2.63	0.63	0.43-0.92	0.015	0.71	0.48-1.03	0.072
HT ≥9.0 mm vs. PT	1.56 vs. 2.63	0.59	0.40-0.89	0.01	0.66	0.44-1.03	0.048
HT ≥9.5 mm vs. PT	1.40 vs. 2.63	0.53	0.30-0.96	0.032	0.56	0.31-1.01	0.053
HT ≥10.0 mm vs. PT	1.07 vs. 2.63	0.41	0.18-0.91	0.023	0.41	0.18-0.93	0.032

*RR = relative risk, CI = confidence interval, HT = hamstring tendon, and PT = patellar tendon. †Adjusted for age and concomitant meniscal injury.

Risk of Revision Depending on Graft Type

A total of 17,096 (92.8%) of the patients underwent ACL reconstruction with use of HT autograft, while 1,329 (7.2%) of the patients underwent reconstruction with use of PT autograft. A total of 391 patients underwent ACL revision within 2 years of primary ACL reconstruction (Table I). The 2-year incidence of ACL revision for patients who had received HT autografts was 2.08%, and for patients who had received PT autografts, it was 2.63% (Table II). The overall risk of 2-year ACL revision did not differ between patients treated with PT autograft and those treated with HT autograft (RR = 0.93 [95% CI = 0.60 to 1.45]; p = 0.76).

Risk of Revision Depending on Graft Diameter

Figure 4 shows the 2-year revision incidence by graft type and diameter, and the number of patients treated with a PT or an HT graft, by graft diameter. The most common diameter of the PT graft was 10 mm, and the most common diameter of the HT graft was 8 mm.

There was an increased risk of ACL revision within 2 years when comparing the use of HT autografts with a diameter of <8 mm with larger HT autografts (RR = 1.25 [95% CI = 1.01 to 1.57]; p = 0.047) (Table II). The likelihood of a patient requiring ACL revision within 2 years following the index ACL reconstruction with an HT autograft was 0.84 times lower for each 1-mm increase in graft diameter (95% CI = 0.74 to 0.96; p = 0.01). There was no significant difference in the risk of 2-year revision for patients treated with PT autografts when comparing the use of grafts with a diameter of <10 versus ≥10 mm (RR = 0.50 [95% CI = 0.21 to 1.19]; p = 0.12).

Risk of Revision Depending on Graft Diameter and Graft Type

The risk of revision within 2 years of primary ACL reconstruction, adjusted for age and meniscal injury, for patients treated with HT autografts by increasing diameter was compared with that for patients treated with PT autografts of any size (Fig. 5, Table III). There was a decreased risk of revision when comparing the use of HT autografts of ≥9.0 mm with all PT autografts (RR = 0.66 [95% CI = 0.44 to 1.03; p = 0.048). Similar results were found for patients treated with HT autografts of ≥10.0 mm compared with all PT autografts (RR = 0.41 [95% CI = 0.18 to 0.93]; p = 0.032).

Discussion

The most important finding of this study was that patients treated with HT autografts ≥9.0 or ≥10.0 mm in diameter had a lower risk of 2-year ACL revision compared with patients treated with PT autografts of any size. Other findings included a significant difference in the risk of revision among patients treated with HT autografts of <8 mm compared with ≥8 mm, where patients treated with grafts with smaller diameters had an increased risk of ACL revision. No difference in the early revision rate was found between PT and HT when adjusting for graft diameter. The crude revision rate decreased with every 0.5-mm increase in HT diameter, starting at 6.5 mm. The overall ACL revision rate was 2.10%, which is similar to that in other registry studies with comparable patient epidemiology[30,31].

Autograft Type

In this study, no difference in the overall rate of 2-year ACL revision was found between patients treated with HT or PT autografts. Previous studies did not demonstrate any differences in early graft failure between the 2 graft alternatives[32,33]. The results of this study suggest that surgeons may choose between an HT and a PT autograft and expect no difference in the overall risk of early ACL revision. Graft choice can also depend on regional variability and traditions[34]. However, HT autografts should not be regarded as a homogeneous choice, as previous analysis of solely HT autografts may have been confounded by graft diameter, where the risk of ACL revision decreased by 30% for every 0.5-mm increase in HT graft diameter[21,22]. Previous studies have not accounted for the effect of the HT autograft diameter, which may have biased their results. In the current study, we adjusted for age, autograft diameter (HT versus PT comparison), meniscal injury, and femoral and tibial fixation (not for the PT graft diameter comparison).

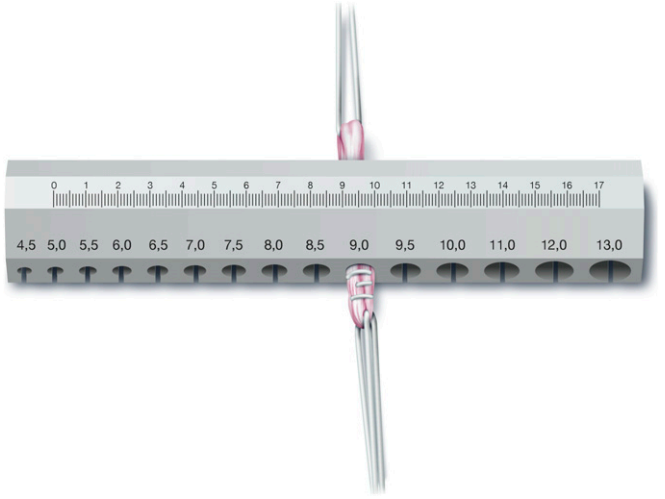

Fig. 6
Illustration demonstrating the intraoperative measurement of the diameter of a hamstring autograft.

It is important to bear in mind that we have focused on revision rate, but have not included any other comorbidity or outcome. As an example, if rehabilitation after ACL reconstruction for patients treated with a PT autograft is in any way more painful[35] compared with those treated with HT autograft, these patients could be less likely to undergo accelerated rehabilitation, therefore lowering their activity level and reducing the risk of revision surgery. In addition, there are also no data on return to sport in the registries, which may make a substantial contribution to the risk of requiring revision. A recent meta-analysis suggests that patients treated with PT autografts have greater knee stability after the reconstruction; however, patients treated with HT autografts have fewer postoperative complications[33].

Comparative analyses of early graft survival in a large population-based cohort could have a considerable clinical impact in terms of selecting the optimal graft for each individual and subsequently the need for ACL revision surgery.

Autograft Diameter

Patients treated with HT autografts had an increased risk of undergoing revision when HT autografts with a diameter of <8 mm were compared with larger HT autografts. Another main finding was a decreased likelihood of early ACL revision with an increase in HT autograft diameter. We found no significant difference in the 2-year ACL revision rate among patients with PT autografts of <10 compared with ≥10 mm.

Our findings indicated both a reduction in the survival of HT autografts of <8 mm compared with larger-diameter HT autografts and an ACL revision rate in line with a recent study from our research group[22] as well as other studies[21,36,37]. There is 1 study with conflicting results in terms of the favorable effect of increased HT autograft diameter[36]. The difference in results between the studies can be attributed to the fact that different measures were used as end points or to different definitions of graft failure or graft laxity[13].

The measurements of graft diameter were made intraoperatively (Fig. 6). The standard technique is to use a testing block with sample diameters varying by 0.5-mm increments[38]. The smallest diameter of the block through which the graft is able to be passed is reported as the graft size.

The PT autograft has been less studied with regard to diameter and the effect on revision rate. This is most likely because the standard PT graft chosen is 10 mm in diameter.

Autograft Type and Diameter

Patients treated with HT autografts with a diameter of ≥9.0 mm or ≥10.0 mm had a reduced risk of early ACL revision compared with patients undergoing ACL reconstruction with PT autografts of any size. This finding is important because of the variability in the diameter of HT autografts compared with the relatively predictable size of PT autografts.

There are concerns about the possible negative effect of using overly large grafts for patients undergoing ACL reconstruction[39] due to the risk of graft impingement. Despite this risk, the results in this study suggest decreased risk of revision with increased HT graft diameter through 10 mm. A larger autograft will contain a larger amount of collagen, thereby increasing its tensile strength, which may provide at least a theoretical explanation of this association. As an example, an autograft with a diameter of 8 mm has an area of 50.3 mm^2, while a graft with a 10-mm diameter has an area of 78.5 mm^2.

Limitations

It is important to bear in mind that the cohort size for PT autografts was considerably smaller, and no attempt could be made to adjust for rehabilitation or return to sport because of the limited collection of variables in registries, as seen in other studies[40,41]. There was a risk of selection bias, as younger patients with greater intensity of sport participation may have been chosen to have ACL reconstruction with PT autograft, bearing in mind that ACL reconstruction performed with HT autograft was chosen in the great majority of cases. Unfortunately, no information is available in the registries regarding rehabilitation, activity level, or return to sport. The proportion of PT autografts is, however, typical of current practice in Scandinavia, where >90% of all primary ACL reconstructions prior to 2014 were performed using HT autografts. Another limitation could be that, when reconstruction using HT autograft is the treatment of choice for primary ACL reconstruction, the routine for performing ACL reconstruction with PT autografts could be less standardized, bearing a worse outcome in terms of risk of revision.

One major limitation to this study was that the end point was a new ACL reconstruction, thereby missing the patients who experienced a graft rupture but who decided not to undergo a revision surgery. The total number of patients undergoing primary ACL reconstruction in the study period was 58,692, while we only had complete data for 18,425.

Verification of the correctness of data is not possible, and causality cannot be identified, with subsequent risk of residual confounding. Autograft diameter was not reported during the early years of the registries, which entailed a loss of data. The vast majority of PT autografts had a diameter of 9 or 10 mm. The results for PT autografts with diameters of other sizes may be underpowered.

Conclusions

There was no significant difference in terms of the overall rate of 2-year revision ACL reconstruction among patients treated with HT compared with PT autografts. Using a thicker HT autograft yielded a lower risk of ACL revision than did using smaller HT autografts. Patients treated with HT autografts with a diameter of ≥9.0 or ≥10.0 mm had a reduced risk of early ACL revision compared with patients who underwent ACL reconstruction with PT autografts of any size. ■

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