Graft Size and Patient Age Are Predictors of Early Revision After Anterior Cruciate Ligament Reconstruction With Hamstring Autograft

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Purpose: To evaluate whether decreased hamstring autograft size and decreased patient age are predictors of early graft revision. **Methods:** Of 338 consecutive patients undergoing primary anterior cruciate ligament (ACL) reconstruction with hamstring autograft, 256 (75.7%) were evaluated. Graft size and patient age, gender, and body mass index at the time of ACL reconstruction were recorded, along with whether subsequent ACL revision was performed. **Results:** The 256 patients comprised 136 male and 120 female patients and ranged in age from 11 to 52 years (mean, 25.0 years). The mean follow-up was 14 months (range, 6 to 47 months). Revision ACL reconstruction was performed in 18 of 256 patients (7.0%) at a mean of 12 months after surgery (range, 3 to 31 months). Revision was performed in 1 of 58 patients (1.7%) with grafts greater than 8 mm in diameter, 9 of 139 patients (6.5%) with 7.5- or 8-mm-diameter grafts, and 8 of 59 patients (13.6%) with grafts 7 mm or less in diameter (P = .027). There was 1 revision performed in the 137 patients aged 20 years or older (0.7%), but 17 revisions were performed in the 119 patients aged under 20 years (14.3%) (P < .0001). Most revisions (16 of 18) were noted to occur in patients aged under 20 years with grafts 8 mm in diameter or less, and the revision rate in this population was 16.4% (16 of 97 patients). Age less than 20 years at reconstruction (odds ratio [OR], 18.97; 95% confidence interval [CI], 2.43 to 147.06; P = .005), decreased graft size (OR, 2.20; 95% CI, 1.00 to 4.85; P = .05), and increased follow-up time (OR, 1.07; 95% CI, 1.02 to 1.12) were associated with increased risk of revision. **Conclusions:** Decreased hamstring autograft size and decreased patient age are predictors of early graft revision. Use of hamstring autografts 8 mm in diameter or less in patients aged under 20 years is associated with higher revision rates. **Level of Evidence:** Level III, retrospective comparative study.

The anterior cruciate ligament (ACL) is commonly injured and is the most frequently reconstructed ligament of the knee. Reconstructive techniques have evolved over time with variable results.[1] Modern intra-articular reconstructive techniques allow clinically stable ligament reconstruction in the majority of cases; however, failed reconstruction continues to be a problem.

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Hamstring autografts are frequently used for ACL reconstruction,[2-4] with multiple authors showing successful outcomes.[5-10] The most frequently used hamstring graft configuration is a 4-strand graft consisting of doubled semitendinosus and gracilis tendons. Biomechanical studies have shown that these grafts have equivalent or superior strength when compared with patellar tendon grafts.[11,12] Several authors report the mean graft diameter of 4-strand hamstring grafts to be between 7.7 and 8.5 mm.[11-14] However, both clinical experience and magnetic resonance imaging (MRI) evidence show significant variability in hamstring size across the population.[14,15] Biomechanical studies show a correlation between graft size and ultimate failure load.[11]

Revision rates for ACL reconstruction have been reported to be between 5% and 20%.[1,16-19] However, these studies are difficult to assess because the definition of failure varies and thus is not consistently reported. Persistent or recurrent instability is the most frequent reason for early revision ACL reconstruction. As shown by Shelbourne et al.,[20] younger patients may be at increased risk for graft failure and less tolerant of recurrent instability, possibly leading to higher revision rates in younger patient populations. The purpose of this study was to evaluate hamstring autograph size and patient age as predictors of early graft revision. We hypothesised that decreased hamstring autograft size and decreased patient age are would be predictors of early graft revision after ACL reconstruction.

METHODS

Identification of Patients

From a prospectively collected procedure log, we identified 469 consecutive isolated ACL reconstructions performed in 451 patients. These procedures were performed by 3 experienced, sports medicine fellowship–trained surgeons at our institution between January 1, 2006, and December 31, 2009. Revision ACL reconstructions (75 reconstructions in 64 patients) and ACL reconstructions performed with grafts other than hamstring tendon autograft (56 reconstructions in 52 patients) were excluded. Of the 338 patients eligible for inclusion in this retrospective study, 256 (75.7%) had a minimum of 6 months' follow-up and form the study group.

Surgical Technique

Harvest of the semitendinosus and gracilis tendons was performed by standard techniques through a 3-cm longitudinal incision centered between the tibial tubercle and the posteromedial border of the tibia. The sartorius fascia was divided parallel to the superior border of the semitendinosus tendon and reflected inferomedially. The semitendinosus and gracilis tendons were identified on deep surface and harvested with a tendon stripper. All grafts were stripped of muscle and doubled to form a 4-strand graft.

ACL reconstruction was performed with either an all-endoscopic or arthroscopic-assisted technique. Femoral tunnels were drilled with either an antegrade, transtibial, or medial portal technique depending on surgeon preference. The femoral tunnel was consistently drilled to be the same diameter as the prepared graft. Femoral fixation was achieved with a cortical button in all cases. Tibial fixation consisted of an interference screw backed up with either a staple or a screw and washer.

Standard accelerated ACL postoperative rehabilitation was used in all patients, with a goal of returning to sports at 6 months, assuming that all of the rehabilitation goals had been met.[21]

Revision ACL reconstruction was performed in patients with subjective symptoms of recurrent instability in association with physical examination findings consistent with graft rupture (soft endpoint on Lachman examination or grade II or III pivot shift). All revisions were performed for recurrent instability.

Data Collection

Data collected retrospectively from the electronic medical record included graft size, patient gender, patient age at surgery, and patient height and weight at surgery. Body mass index (BMI) was calculated from height and weight. Finally, it was noted whether the patient underwent revision ACL reconstruction during the follow-up period. Revision reconstruction was performed in patients with subjective symptoms of knee instability or pain associated with increased anterior tibial translation (Lachman examination) or abnormal pivot shift on physical examination. Revision served as the primary outcome variable in this review.

Statistics

The ratio of graft revisions to reconstructions performed was compared in patients with grafts greater than 8 mm in diameter, 7.5 to 8 mm in diameter, and

Table 1. *Distribution of ACL Graft Size by Gender*

Graft Size	Male Patients	Female Patients	Total
>9 mm	6	0	6
9 mm	30	9	39
8.5 mm	10	3	13
8 mm	47	60	107
7.5 mm	19	13	32
7 mm	21	32	53
<7 mm	3	3	6
Mean graft size (mm)	8.1	7.7	7.9

less than or equal to 7 mm in diameter by use of the Cochran-Armitage test for trend. The test was used to compare revision rates among patients aged 20 years or older with revision rates in patients aged under 20 years and to compare failure rates based on patient gender. The Mann-Whitney *U* test was used to compare graft size based on gender. A multiple logistical regression model was used to evaluate the correlation of patient age, gender, and graft size with the need for revision. The length of follow-up each patient received was included as a variable in the regression to account for variability in exposure time. Interaction terms, consisting of products of the respective variables, were added to the model to assess interaction between the terms. A second regression was performed on the subset of patients with height and weight available to evaluate the influence of these terms on risk of revision. Simple logistical regression models were used to evaluate for correlation between graft revision rate and the ratio of graft size to patient weight, graft size to patient height, or graft size to BMI. $P < .05$ was defined as statistically significant.

RESULTS

The study population of 256 patients was 53.1% male (136 male and 120 female patients) and ranged in age from 11 to 52 years (mean, 25.0 years; SD, 10.5 years). The mean follow-up was 14 months (range, 6 to 47 months; SD, 8 months). Revision ACL reconstruction was required in 18 patients, for an overall revision rate of 7.0%. Graft failures occurred at a mean of 12 months after surgery (range, 3 to 31 months), with 10 of 18 revisions occurring before 1 year postoperatively. Revision reconstruction was required in 7 of 136 male patients (5.1%) and 11 of 120 female patients (9.2%) ($P = .23$). These patients included 11 competitive athletes and 7 recreational athletes. Of these 18 patients, 13 had returned to their prior activity level at a mean of 201 days after ACL reconstruction. Of the 18, 14 reported a traumatic reinjury leading to the revision surgery.

The mean graft diameter was 7.9 mm; it was 8.1 mm in male patients and 7.7 mm in female patients ($P < .001$) (Table 1). Revision was required in 1 of 58 patients (1.7%) with grafts greater than 8 mm in diameter, 9 of 139 patients (6.5%) with 7.5- or 8-mm-diameter grafts, and 8 of 59 patients (13.6%) with grafts 7 mm or less in diameter ($P = .027$). The distribution of graft revisions by graft size is noted in Table 2 and increases with smaller graft diameter.

With respect to age, 1 revision was required in the 137 patients aged 20 years or older (0.7%), but 17 revisions were required in the 119 patients aged under 20 years (14.3%) ($P < .0001$). No difference in graft size was noted between older and younger patients. Among patients aged under 20 years, revision was required in 1 of 22 patients (4.5%) with grafts greater than 8 mm in diameter, 9 of 68 patients (13.2%) with 7.5- or 8-mm-diameter grafts, and 7 of 29 patients (24.1%) with grafts less than or equal to 7 mm in diameter ($P = .046$). The distribution of graft failures by graft size in the population aged under 20 years is noted in Table 3. Revisions were noted to occur at a high rate in patients aged under 20 years with grafts 8 mm in diameter or less (Table 4).

Table 2. *Revision Rates by Graft Size in All Patients*

Graft Size	Patient Age (Mean ± SD) (yr)	No. of Patients	Revisions	% Revised
>9 mm	24.5 ± 10.1	6	0	0
9 mm	26.9 ± 10.5	39	1	2.6
8.5 mm	30.7 ± 10.7	13	0	0
8 mm	24.7 ± 11.2	107	7	6.5
7.5 mm	25.0 ± 10.2	32	2	6.2
7 mm	23.8 ± 9.4	53	6	11.3
<7 mm	20.1 ± 7.2	6	2	33
All	25.0 ± 10.5	256	18	7.0

Table 3. *Revision Rates by Graft Size in Patients Aged Under 20 Years*

Graft Size	Patient Age (Mean ± SD) (yr)	No. of Patients	Revisions	% Revised
>9 mm	16.0 ± 1.4	3	0	0
9 mm	16.4 ± 1.6	15	1	6.7
8.5 mm	17.7 ± 0.6	4	0	0
8 mm	16.1 ± 1.6	53	7	13.2
7.5 mm	16.8 ± 1.8	15	2	13.2
7 mm	16.5 ± 1.7	26	5	19.2
<7 mm	14.0 ± 2.6	3	2	67
Total	16.3 ± 1.7	119	17	14.3

No differences in revision rates were noted based on whether the femoral tunnel was drilled through a transtibial (11%), medial portal (7.1%), or independent (6.6%) technique ($P = .77$). Similarly, no differences in revision rates were noted among the 3 surgeons involved in the study (6.4%, 7.1%, and 7.2%, respectively) ($P = .98$) or based on whether a screw (7.1%) or staple (7.0%) was used for backup tibial fixation ($P = .97$).

Multiple logistical regression showed age less than 20 years at reconstruction (odds ratio [OR], 18.97; 95% confidence interval [CI], 2.43 to 147.06; $P = .005$), decreased graft size (OR, 2.20; 95% CI, 1.00 to 4.85; $P = .05$), and increased follow-up time (OR, 1.07; 95% CI, 1.02 to 1.12) to be associated with significantly increased risk of revision. None of the interaction terms that were added to the model were found to be significant predictors of revision. Female gender was not noted to be an independent predictor of revision when patient age, graft size, and follow-up time were taken into account (OR, 1.17; 95% CI, 0.39 to 3.11; $P = .77$). Patient height and weight at the time of surgery were available in 158 patients (61.7%). Height and weight were not noted to be significant predictors of revision when added to the multiple logistic regression model.

The mean ratio of graft diameter to patient weight was 0.11 mm/kg (range, 0.05 to 0.19 mm/kg). The mean ratio of graft diameter to patient height was 4.6 mm/m (range, 3.3 to 5.6 mm/m). The mean ratio of graft diameter to BMI was 0.32 $mm \cdot kg^{-1} \cdot m^{-2}$ (range, 0.16 to 0.49 $mm \cdot kg^{-1} \cdot m^{-2}$). No statistically significant association was noted between either the ratio of graft size to patient weight ($P = .42$), the ratio of graft size to patient height ($P = .10$), or the ratio of graft size to BMI ($P = .70$) and risk of ACL revision.

Table 4. *ACL Graft Revision Rates According to Patient Age and Graft Size*

Graft Size	Patient Age ≥20 yr	Patient Age <20 yr
>8 mm	0/36 (0%)	1/22 (4.5%)
≤8 mm	1/101 (1.0%)	16/97 (16.5%)

DISCUSSION

In this investigation, we show that hamstring autografts 8 mm in diameter or less are at increased risk of revision compared with larger grafts in young patients. There is relatively little literature regarding the recommended size of hamstring grafts for ACL reconstruction, although some authors have recommended grafts of at least 7 mm in diameter.[15,22] Because of the variability in hamstring diameter among patients, authors have described the use of MRI as well as patient height, gender, and weight to predict graft diameter before ACL reconstruction.[14,15,23-25] Biomechanical studies have shown that hamstring graft strength increases with increased graft diameter.[11] Studies in animals show increased anterior-posterior translation immediately postoperatively with small grafts, but this finding disappears with graft remodeling after 6 months.[26,27] Human studies similarly fail to show long-term effects of graft size on knee stability.[28] After detailed review of the literature, we are unable to locate any previous reports noting a correlation between graft size and revision rate.

In this investigation, we focused on the influence of graft size and patient age on outcome in the early postoperative period, because the mean follow-up in our patient cohort was 14 months. We believe that it is in this period that graft size has the most potential impact on outcome. Numerous animal studies have documented changes in graft size as remodeling occurs after ACL reconstruction.[29-31] Cummings et al.[27] showed that ACL reconstruction with 4- or 7-mm grafts in a caprine model resulted in ACL grafts with the same cross-sectional area after 6 months. Similar increases in graft size with time have been shown in MRI studies in humans, with the greatest graft diameter noted 12 months after autograft hamstring ACL reconstruction[32] and more hypertrophy noted in grafts with smaller initial size.[33] These data suggest that any effect of graft size will diminish over time as remodeling occurs.

Shelbourne et al.[20] have reported increased failure rates of ACL reconstruction with patellar tendon grafts in younger patients. Several authors have shown increased rupture rates of various graft types in more active populations.[20,34,35] Increased activity levels of younger patients may contribute to the increased revision rates noted in these patients in our study both by increasing reinjury rates and by increasing the chances of undergoing revision for an unstable knee.

Female gender has been noted by several authors to be a risk factor for hamstring graft failure after ACL reconstruction.[36,37] Rerupture rates have generally not been higher among female patients who underwent reconstruction with patellar tendon grafts.[20,38,39] Similarly, an increased failure rate with hamstring tendon autograft compared with patellar tendon autograft has been noted in women.[40] In our study multiple regression showed that female gender was not an independent predictor of ACL revision surgery. We noted in our series that 90% of female patients and 66% of male patients had grafts at risk for revision based on size (<8.5 mm in diameter). Similarly, Ma et al.[23] showed that hamstring grafts smaller than 8 mm in diameter are obtained in 42% of female patients but only 18% of male patients. This gender-based difference in graft size may affect revision rates of hamstring grafts in numerous comparative studies in which hamstring graft size is variable or not reported.

A limitation of our study is its relatively short follow-up. As discussed earlier, this report focuses on early revisions. Revisions are known to continue to occur well after the follow-up period included in this study.[20] The influence of graft size on these later revisions is unknown and not addressed by our study. Additional limitations include the study's retrospective nature and the use of revision as an endpoint. These limitations may introduce bias into the data collection. It is possible that some patients' grafts have failed but have not undergone revision. Similarly, the loss of some patients to follow-up means that some patients may have undergone revision elsewhere and are not included in the study. In addition, we are unable to control for other possible causes of failure, including tunnel malposition, because we were unable to assess tunnel location in all patients. A significant percentage of patients did report a traumatic injury leading to their revision, but patients often attribute reinjury to trivial trauma, limiting the reliability of such data. We lack data for a detailed analysis of the specific circumstances of each failure and the relation between failures and time to return to sport. Return to sport was generally allowed at 6 months postoperatively. It is unclear at this time whether a more restrictive postoperative regimen would decrease revision rates. Finally, we lack validated patient-oriented outcome scores and postoperative activity level data that could yield more insight into the influence of graft size on outcome. These significant limitations should be taken into account when one is considering the outcomes of this study. Further work is needed to confirm and clarify these results.

CONCLUSIONS

Decreased hamstring autograft size and decreased patient age are predictors of early graft revision. Use of hamstring autografts 8 mm in diameter or less in patients aged under 20 years is associated with higher revision rates.

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