The Influence of Hamstring Autograft Size on Patient-Reported Outcomes and Risk of Revision After Anterior Cruciate Ligament Reconstruction: A Multicenter Orthopaedic Outcomes Network (MOON) Cohort Study

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Purpose: The purpose of this study was to evaluate the effect of graft size on patient-reported outcomes and revision risk after anterior cruciate ligament (ACL) reconstruction.

Methods: A retrospective chart review of prospectively collected cohort data was performed, and 263 of 320 consecutive patients (82.2%) undergoing primary ACL reconstruction with hamstring autograft were evaluated. We recorded graft size; femoral tunnel drilling technique; patient age, sex, and body mass index at the time of ACL reconstruction; Knee Injury and Osteoarthritis Outcome Score (KOOS) and International Knee Documentation Committee score preoperatively and at 2 years postoperatively; and whether each patient underwent revision ACL reconstruction during the 2-year follow-up period. Revision was used as a marker for graft failure. The relation between graft size and patient-reported outcomes was determined by multiple linear regression. The relation between graft size and risk of revision was determined by dichotomizing graft size at 8 mm and stratifying by age.

Results: After we controlled for age, sex, operative side, surgeon, body mass index, graft choice, and femoral tunnel drilling technique, a 1-mm increase in graft size was noted to correlate with a 3.3-point increase in the KOOS pain subscale ($P = .003$), a 2.0-point increase in the KOOS activities of daily living subscale ($P = .034$), a 5.2-point increase in the KOOS sport/recreation function subscale ($P = .004$), and a 3.4-point increase in the subjective International Knee Documentation Committee score ($P = .026$). Revision was required in 0 of 64 patients (0.0%) with grafts greater than 8 mm in diameter and 14 of 199 patients (7.0%) with grafts 8 mm in diameter or smaller ($P = .037$). Among patients aged 18 years or younger, revision was required in 0 of 14 patients (0.0%) with grafts greater than 8 mm in diameter and 13 of 71 patients (18.3%) with grafts 8 mm in diameter or smaller.

Conclusions: Smaller hamstring autograft size is a predictor of poorer KOOS sport/recreation function 2 years after primary ACL reconstruction. A larger sample size is required to confirm the relation between graft size and risk of revision ACL reconstruction.

Level of Evidence: Level III, retrospective comparative study.

Anterior cruciate ligament (ACL) ruptures have been estimated to occur in 200,000 persons annually in the United States. Most of these patients eventually undergo ACL reconstruction based on continued instability symptoms or desire for future participation in cutting or pivoting sports. Although...
bone—patellar tendon—bone autograft has traditionally
been the gold standard for reconstruction, quadrupled
hamstring tendon has become a popular autograft
option. Quadrupled hamstring tendon is biomechani-
cally equivalent or superior in strength at time 0 when
compared with patellar tendon and can result in less
donor-site morbidity.3,4

Unlike bone—patellar tendon—bone grafts, the diam-
eter of a hamstring autograft is quite variable. Although
difficult to predict accurately, hamstring autograft
diameter has been shown to correlate with patient sex,
height, body mass index (BMI), and thigh circumference.5-8
Previous biomechanical work has shown
hamstring graft strength to increase with increasing
graft diameter.3

Although the ideal hamstring graft size remains
undefined in the literature, recent retrospective studies
have shown increased failure rates in younger patients
with grafts less than or equal to 8 mm in diameter.9,10
The purpose of this study was to evaluate the effect of
graft size on patient-reported outcomes and revision
risk after ACL reconstruction. We hypothesized that
decreased hamstring autograft size was associated with
poorer patient-reported outcome scores and increased
risk of revision 2 years after ACL reconstruction.

Methods

Identification of Patients

Patients were identified through the use of prospec-
tively collected data from the Multicenter Orthopaedic
Outcomes Network (MOON) collected at 2 academic
medical centers. A total of 322 patients who underwent
primary ACL reconstruction with hamstring autograft
between 2007 and 2009 were identified. The data-
base provides demographic information, intraoperative
findings (meniscus and cartilage status), surgical tech-
nique, and patient-reported outcome scores (Knee
Injury and Osteoarthritis Outcome Score [KOOS]11
and International Knee Documentation Committee
[IKDC]
subjective score12) preoperatively and at 2 years
follow-up. The database also contains information on
whether patients underwent repeat ipsilateral knee
surgery, including revision ACL reconstruction. These
data were supplemented by retrospective review of the
operative records to determine the hamstring autograft
size used in each patient. Two skeletally immature
patients who underwent all-epiphyseal ACL recon-
struction were excluded, yielding a total of 320 eligible
patients.

Surgical Technique

Procedures were performed by a total of 5 fellowship-
trained sports medicine surgeons at the 2 institutions.
The hamstrings were harvested by standard techniques,
and 4-strand grafts were used in all cases (either
doubled semitendinosus and gracilis or quadrupled
semitendinosus). ACL reconstruction was performed
with either an all-endoscopic or arthroscopic-assisted
technique. The femoral tunnel was drilled through
a medial portal in 38% of the cases, whereas a trans-
tibial method was used in 62% of the cases. 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 was variable and included interference screw
fixation, suture tied over a post or button, or a combi-
nation depending on surgeon preference. Graft ten-
sioning was not standardized and was performed
according to surgeon preference. A standard accelerated
ACL rehabilitation protocol developed by the MOON
group was used for all patients, with a goal of returning
to sports at 6 months.

Statistics

Summary statistics including means and standard
deviations were calculated for normally distributed
continuous variables. The relation between graft size
and patient-reported outcome scores at 2 years post-
operatively was determined by multiple linear regres-
sion analysis in a model that included graft size, graft
type (quadrupled semitendinosus v doubled gracilis and
semitendinosus), age, sex, operative side, surgeon,
BMI, femoral tunnel drilling technique, and preopera-
tive patient-reported outcome scores. The relation
between graft size and risk of revision was determined
by comparing patients with grafts larger than 8 mm
with patients in whom smaller grafts were used and
stratifying based on patient age as has been performed
in previous work. Characteristics of patients in each
group were compared by use of t tests for normally
distributed continuous variables, Wilcoxon rank sum
tests for non—normally distributed continuous vari-
ablesthe Fisher exact test for dichotomous vari-
ablesthe relatively small number of events (revision
operations) in the series precluded modeling of the
revision data by logistic regression analysis. The rela-
tions between revision risk and patient sex, graft type,
operative side, surgeon, and femoral tunnel drilling
technique were evaluated with the Fisher exact test.

Results

Complete data, including graft size and patient-
reported outcomes at 2 years postoperatively, were
available in 263 patients (82.2%). There were 144 male
patients (54.8%) and 119 female patients (45.2%). The
mean patient age was 23.6 ± 10.3 years, and ages
ranged from 13 to 58 years. The mean graft size was 7.8
± 0.8 mm, with a range from 6 to 10 mm (Fig 1), and
was significantly larger in male patients (8.1 ± 0.8 mm)
than in female patients (7.6 ± 0.6 mm) (P < .0001).
After we controlled for age, sex, operative side, surgeon, BMI, femoral tunnel drilling technique, graft choice, and preoperative patient-reported outcome scores, graft size was noted to correlate with a number of patient-reported outcome scores at 2 years postoperatively (Table 1). A 1-mm increase in graft size was noted to correlate with a 3.3-point increase in the KOOS pain subscale \((P = .003)\), a 2.0-point increase in the KOOS activities of daily living subscale \((P = .034)\), a 5.2-point increase in the KOOS sport/recreation function subscale \((P = .004)\), and a 3.4-point increase in the subjective IKDC score \((P = .026)\).

Graft size was also noted to correlate with the need for revision ACL reconstruction. Of the 263 patients, 14 (5.3%) underwent revision ACL reconstruction in the first 2 years postoperatively (Table 2). The mean time from primary to revision ACL reconstruction was 12.7 ± 6.9 months (range, 6 to 25 months). Revision was required in 0 of 64 patients (0.0%) with grafts greater than 8 mm in diameter and 14 of 199 patients (7.0%) with grafts 8 mm in diameter or smaller \((P = .037)\). The group with grafts greater than 8 mm in diameter had a higher mean age and BMI and contained a higher proportion of male patients, patients operated on with a transtibial technique, and patients in whom a quadrupled semitendinosus was used for the graft (Table 3). There was no significant correlation between revision risk and patient sex, operative side, surgeon, graft type, or surgical technique.

Among patients aged 18 years or younger, graft size was also noted to correlate with the need for revision ACL reconstruction. Of the 85 patients aged 18 years or younger, 13 (15.3%) underwent revision ACL reconstruction in the first 2 years postoperatively (Table 4). Revision was required in 0 of 14 patients (0.0%) with grafts greater than 8 mm in diameter and 13 of 71 patients (18.3%) with grafts 8 mm in diameter or smaller. Overall, 13 of the 14 revisions were performed in patients aged 18 years or younger with grafts 8 mm in diameter or less (Table 5). There was no significant difference in the incidence of revision surgery between male and female patients \((P = .17)\).

**Discussion**

Although ACL reconstruction has shown success in restoring knee stability and improving patients’ outcomes, recent studies have shown that ipsilateral graft failure still occurs in 1.8% to 10.4% of cases. \(^{13,14}\) Many factors contribute to the need for revision ACL

### Table 1. Results of Multiple Linear Regression Analyses of Correlation Between Graft Size and Patient-Reported Outcome Scores

<table>
<thead>
<tr>
<th>Outcome Score</th>
<th>Regression Coefficient for Graft Size</th>
<th>SE</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOOS Symptoms</td>
<td>1.31</td>
<td>1.20</td>
<td>.28</td>
</tr>
<tr>
<td>Pain</td>
<td>3.26</td>
<td>1.09</td>
<td>.003*</td>
</tr>
<tr>
<td>ADLs</td>
<td>1.99</td>
<td>0.93</td>
<td>.034*</td>
</tr>
<tr>
<td>Sport/recreation</td>
<td>5.15</td>
<td>1.76</td>
<td>.004*</td>
</tr>
<tr>
<td>QOL</td>
<td>2.82</td>
<td>1.86</td>
<td>.15</td>
</tr>
<tr>
<td>IKDC</td>
<td>3.37</td>
<td>1.43</td>
<td>.026*</td>
</tr>
<tr>
<td>Marx Activity Scale</td>
<td>0.47</td>
<td>0.42</td>
<td>.26</td>
</tr>
</tbody>
</table>

ADLs, activities of daily living; QOL, quality of life.
*Statistically significant.

### Table 2. Revision Rates by Graft Size for Total Cohort

<table>
<thead>
<tr>
<th>Graft Size</th>
<th>No.</th>
<th>Revisions</th>
<th>% Revised</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;8 mm</td>
<td>64</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>≤8 mm</td>
<td>199</td>
<td>14</td>
<td>7.0</td>
</tr>
<tr>
<td>All</td>
<td>263</td>
<td>14</td>
<td>5.3</td>
</tr>
</tbody>
</table>

### Table 3. Patient Characteristics by Graft Size

<table>
<thead>
<tr>
<th></th>
<th>≤8 mm (n = 199)</th>
<th>&gt;8 mm (n = 64)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [median (IQR)] (yr)</td>
<td>21 (17-28.5)</td>
<td>27 (19.8-35.2)</td>
<td>(P = .0014^*)</td>
</tr>
<tr>
<td>Female sex</td>
<td>110 (55.3%)</td>
<td>9 (14.1%)</td>
<td>(P &lt; .001^*)</td>
</tr>
<tr>
<td>BMI (mean ± SD) (kg/m²)</td>
<td>24.4 ± 4.3</td>
<td>28.1 ± 5.1</td>
<td>(P &lt; .001^*)</td>
</tr>
<tr>
<td>Graft type:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>quadrupled semitendinosus</td>
<td>31 (15.6%)</td>
<td>30 (46.9%)</td>
<td>(P &lt; .001^*)</td>
</tr>
<tr>
<td>Femoral tunnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>drilling technique:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>transtibial</td>
<td>130 (65.3%)</td>
<td>33 (51.6%)</td>
<td>(P = .035^*)</td>
</tr>
</tbody>
</table>

IQR, interquartile range.
*Statistically significant.
surgery, and the use of smaller-diameter hamstring grafts may also be a contributor. The most significant findings of our study are significant correlations between increased graft size and improved patient-reported outcome scores, as well as decreased risk of revision surgery.

The results of the linear regression model evaluating the relation between graft size and patient-reported outcome scores show that a 2-mm increase in graft size correlates with a 10.3-point increase in the KOOS sport/recreation function subscale, a 4.0-point increase in the KOOS activities of daily living subscale, a 6.5-point increase in the KOOS pain subscale, and a 6.7-point increase in the subjective IKDC score. These differences are close to and in some cases exceed established clinically significant differences for the KOOS subscales (8 to 10 points)\(^ {11,15}\) and the subjective IKDC score (11.5 points).\(^ {15,16}\) Smaller changes in graft size are unlikely to result in clinically significant changes in patient-reported outcome scores.

Although this study is the first to evaluate the relation between ACL graft size and patient-reported outcome scores, the findings of this study are overall in agreement with previous studies evaluating the relation between graft size and revision rate. In a retrospective analysis of 296 patients undergoing hamstring autograft ACL reconstruction, Park et al.\(^ {10}\) did not observe any failures in patients with graft diameters of 8 mm or more. Among patients with a graft size of less than 8 mm, they noted a revision risk of 5.2%. Magnussen et al.\(^ {9}\) conducted a retrospective study of 256 patients and found that 16 of 18 revision ACL reconstructions occurred in patients with hamstring autografts 8 mm in diameter or less, with a revision risk of 16.5% noted in patients aged younger than 20 years who underwent reconstruction with such grafts. It should be noted that although the prior study by Magnussen et al. shares 1 author with the current study, the studies were performed at separate institutions and involved none of the same patients. This study was undertaken in part to address some limitations of the prior work, namely the short follow-up period in the prior study and the lack of patient-reported outcome measures.

Another key finding of this study is the interaction between age and graft size in determining ACL graft revision rate. The revision risk of ACL grafts 8 mm in diameter or smaller in patients aged younger than 19 years was 15.3%—quite similar to that exhibited in a previous study.\(^ {9}\) More evidence is appearing in the literature that revision is common in this young, active population.\(^ {17-20}\) Although much of the previous ACL literature fails to stratify ACL reconstruction outcomes based on both graft size and patient age, the high prevalence of small grafts in this population may contribute significantly to these high rates. Age itself likely serves as a surrogate marker for activity level because young patients are most likely to return to high-risk cutting/pivoting sporting activities that increase their risk of traumatic graft rupture.

The reasons for poorer outcomes in patients with smaller grafts remain unclear. One could hypothesize that this difference is simply because of the decreased failure load of smaller ACL grafts; however, biomechanical studies have shown strength at least equal to that of patellar tendon grafts at time 0.\(^ {3,4}\) It is possible that the decreased graft strength associated with the ligamentization process may push smaller grafts below a critical strength threshold and contribute to increased risk of failure.

### Limitations

There are several limitations of this study. A significant limitation entails using revision ACL as a marker for graft failure. There likely is a subset of patients who have functional instability or increased laxity ACL (i.e., a failed graft) who have not undergone revision surgery. Therefore the number of revision surgeries may be an underestimation of the actual number of failures. We also lack information on the mechanism of failure of grafts that could potentially shed light on the contribution of graft size to graft failure. An additional limitation is the lack of physical examinations and instrumented laxity assessments at follow-up. Such data may contribute to our understanding of the reasons for poorer patient-reported outcomes among those with smaller grafts. It is unknown, for example, whether the patients with smaller graft sizes exhibited increased laxity at follow-up. It has been shown, however, that patient-reported outcomes do correlate with specific functional assessments such as hop tests.\(^ {21}\) A further limitation is the relatively small sample size. The relatively small number of patients who underwent revision ACL reconstruction precluded the performance of logistic regression modeling on these data. Therefore we are unable to assess the influence of variables other
than patient age (such as patient sex and size, as well as surgical technique) on the findings. We did compare these variables in the patients with larger and smaller grafts and noted a number of significant differences between the groups (Table 5); however, no significant correlation between these variables and revision risk was noted. More studies with larger numbers are needed to elucidate the influence of these factors on revision risk. Further study limitations include the lack of postoperative imaging to assess tunnel position and additional uncontrolled variability in the 5 surgeons’ techniques, including variability in tibial fixation, graft tensioning, and other unrecorded variables. Future ACL studies involving patients undergoing reconstruction with hamstring tendons should record graft size and consider it as a factor in their analyses.

Conclusions

Smaller hamstring autograft size is a predictor of poorer KOOS sport/recreation function 2 years after primary ACL reconstruction. A larger sample size is required to confirm the relation between smaller graft size and increased risk of revision ACL reconstruction.

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References


