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.[1] Most of these patients eventually undergo ACL reconstruction based on continued instability symptoms or desire for future participation in cutting or pivoting sports. Although

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This project was partially funded by grants 5R01 AR053684 (Kurt P. Spindler) and K23 AR063767 (R.A.M.) from the National Institutes of Health/National Institute of Arthritis and Musculoskeletal and Skin Diseases and by grant 5U18-HS016075 (Robert G. Marx) from the Center for Education and Research on Therapeutics (Agency for Healthcare Research and Quality). The project was also supported by the Vanderbilt Sports Medicine Research Fund. Vanderbilt Sports Medicine received unrestricted educational gifts from Smith & Nephew Endoscopy and DonJoy Orthopaedics.

The authors report the following potential conflict of interest or source of funding: D.C.F. receives support from Sanofi and Smith & Nephew. M.H.J. receives support from National Institutes of Health, Smith & Nephew Endoscopy, and DonJoy Orthopaedics and unrestricted research support funding from DJO Surgical, Breg, Arthrex, Smith & Nephew, and Stryker. C.C.K. receives support from Biomet Sports Medicine.

Received February 19, 2013; accepted August 21, 2013.

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0749-8063/13130/$36.00

http://dx.doi.org/10.1016/j.arthro.2013.08.025

bone–patellar tendon–bone autograft has traditionally been the gold standard for reconstruction, quadrupled hamstring tendon has become a popular autograft option.[2] Quadrupled hamstring tendon is biomechanically 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 diameter 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 prospectively 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 database provides demographic information, intraoperative findings (meniscus and cartilage status), surgical technique, and patient-reported outcome scores (Knee Injury and Osteoarthritis Outcome Score [KOOS][11] and International Knee Documentation Committee [IKDC] subjective score[12]) 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 reconstruction 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 transtibial 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 combination depending on surgeon preference. Graft tensioning 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 postoperatively was determined by multiple linear regression 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 preoperative 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 variables, and the Fisher exact test for dichotomous variables. The relatively small number of events (revision operations) in the series precluded modeling of the revision data by logistic regression analysis. The relations 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 25.6 ± 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) ($P < .0001$).

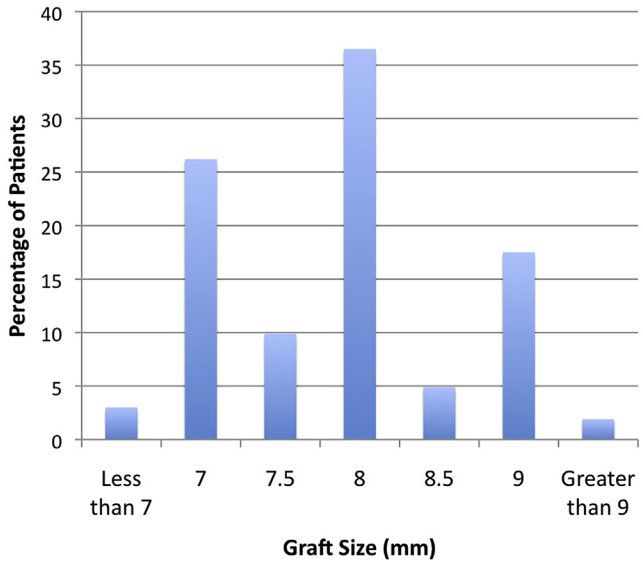

Fig 1. Histogram showing distribution of graft size among patients included in study. The mean graft size was 7.8 mm.

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 ($P = .17$).

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

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

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

Table 2. Revision Rates by Graft Size for Total Cohort

	No.	Revisions	% Revised
Graft size			
>8 mm	64	0	0
≤8 mm	199	14	7.0
All	263	14	5.3

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 3. Patient Characteristics by Graft Size

	Graft Size		
	≤8 mm (n = 199)	>8 mm (n = 64)	Significance
Age [median (IQR)] (yr)	21 (17-28.5)	27 (19.8-35.2)	$P = .0014$*
Female sex	110 (55.3%)	9 (14.1%)	$P < .001$*
BMI (mean ± SD) (kg/m^2)	24.4 ± 4.3	28.1 ± 5.1	$P < .001$*
Graft type: quadrupled semitendinosus	31 (15.6%)	30 (46.9%)	$P < .001$*
Femoral tunnel drilling technique: transtibial	130 (65.3%)	33 (51.6%)	$P = .035$*

IQR, interquartile range.
*Statistically significant.

Table 4. Revision Rates by Graft Size for Patients Aged 18 Years or Younger

	No.	Revisions	% Revised
Graft size			
>8 mm	14	0	0
≤8 mm	71	13	18.3
Total	85	13	15.3

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 risk. 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.

Table 5. ACL Graft Revision Rates According to Patient Age and Graft Size

	Patient Age	
Graft Size	≤18 yr	>18 yr
>8 mm	0 of 14 (0%)	0 of 47 (0%)
≤8 mm	13 of 71 (18.3%)	1 of 131 (0.8%)

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.

Acknowledgment

The authors thank the following MOON members, without whom the data used in this study would not exist: Kurt P. Spindler, M.D., Warren R. Dunn, M.D., M.P.H., and Laura J. Huston, M.S. (Vanderbilt University School of Medicine); Rick W. Wright, M.D., Matthew J. Matava, M.D., and Robert H. Brophy, M.D. (Washington University School of Medicine at Barnes-Jewish Hospital); Eric C. McCarty, M.D., Armando Vidal, M.D., and Michelle Wolcott, M.D. (University of Colorado School of Medicine); Robert G. Marx, M.D., M.Sc. (Hospital for Special Surgery); and Annunziato Amendola, M.D., and Brian R. Wolf, M.D., M.S. (University of Iowa).

The authors thank the following research coordinators, analysts, and support staff from the MOON sites, whose efforts make this consortium possible: Lynn Borzi, Julia Brasfield, Maxine Cox, Michelle Hines, Pam Koeth, and Leah Schmitz (Cleveland Clinic Foundation); Kari Stammen (Ohio State University); Carla Britton and Catherine Fruehling-Wall (University of Iowa); Christine Bennett and Paula Langner (University of Colorado); Linda Burnworth, Robyn Gornati, and Amanda Haas (Washington University in St Louis); Brian Boyle, Patrick Grimm, Kaitlynn Lillemoe, and Lana Verkuil (Hospital for Special Surgery); and Emily Reinke, John Shaw, Suzet Galindo-Martinez, Zhouwen Liu, Thomas Dupont, Erica Scaramuzza, and Lynn Cain (Vanderbilt University).

References

1. Hewett TE, Schultz SJ, Griffin LY, eds. *Understanding and preventing noncontact ACL injuries*. Champaign, IL: Human Kinetics, 2007.
2. Ahlden M, Samuelsson K, Sernert N, Forssblad M, Karlsson J, Kartus J. The Swedish National Anterior Cruciate Ligament Register: A report on baseline variables and outcomes of surgery for almost 18,000 patients. *Am J Sports Med* 2012;40:2230-2235.
3. Hamner DL, Brown CH Jr, Steiner ME, Hecker AT, Hayes WC. Hamstring tendon grafts for reconstruction of the anterior cruciate ligament: Biomechanical evaluation of the use of multiple strands and tensioning techniques. *J Bone Joint Surg Am* 1999;81:549-557.
4. Wilson TW, Zafuta MP, Zobitz M. A biomechanical analysis of matched bone-patellar tendon-bone and double-looped semitendinosus and gracilis tendon grafts. *Am J Sports Med* 1999;27:202-207.
5. Ma CB, Keifa E, Dunn W, Fu FH, Harner CD. Can preoperative measures predict quadruple hamstring graft diameter? *Knee* 2010;17:81-83.
6. Schwartzberg R, Burkhart B, Lariviere C. Prediction of hamstring autograft diameter and length for anterior cruciate reconstruction. *Am J Orthop* 2008;37:157-159.
7. Treme G, Diduch DR, Billante MJ, Miller MD, Hart JM. Hamstring graft size prediction: A prospective clinical evaluation. *Am J Sports Med* 2008;36:2204-2209.
8. Tuman JM, Diduch DR, Rubino LJ, Baumfeld JA, Nguyen HS, Hart JM. Predictors for hamstring graft diameter in anterior cruciate ligament reconstruction. *Am J Sports Med* 2007;35:1945-1949.
9. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy* 2012;28:526-531.
10. Park SY, Oh H, Park S, Lee JH, Lee SH, Yoon KH. Factors predicting hamstring tendon autograft diameters and resulting failure rates after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2013;21:1111-1118.
11. Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): From joint injury to osteoarthritis. *Health Qual Life Outcomes* 2003;1:64.
12. Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the international knee documentation committee subjective knee form. *Am J Sports Med* 2001;29:600-613.
13. Wright RW, Magnussen RA, Dunn WR, Spindler KP. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: A systematic review. *J Bone Joint Surg Am* 2011;93:1159-1165.
14. Wright RW, Dunn WR, Amendola A, et al. Risk of tearing the intact anterior cruciate ligament in the contralateral knee and rupturing the anterior cruciate ligament graft during the first 2 years after anterior cruciate ligament reconstruction: A prospective MOON cohort study. *Am J Sports Med* 2007;35:1131-1134.
15. Wright RW. Knee injury outcomes measures. *J Am Acad Orthop Surg* 2009;17:31-39.

16. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International Knee Documentation Committee subjective knee form. *Am J Sports Med* 2006;34: 1567-1573.
17. Shelbourne KD, Gray T, Haro M. Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med* 2009;37:246-251.
18. Barrett AM, Craft JA, Replogle WH, Hydrick JM, Barrett GR. Anterior cruciate ligament graft failure: A comparison of graft type based on age and Tegner activity level. *Am J Sports Med* 2011;39:2194-2198.
19. Kaeding CC, Aros B, Pedroza A, et al. Allograft versus autograft anterior cruciate ligament reconstruction: Predictors of failure from a MOON Prospective longitudinal cohort. *Sports Health* 2011;3:73-81.
20. Borchers JR, Pedroza A, Kaeding C. Activity level and graft type as risk factors for anterior cruciate ligament graft failure: A case-control study. *Am J Sports Med* 2009;37:2362-2367.
21. Reinke EK, Spindler KP, Lorring D, et al. Hop tests correlate with IKDC and KOOS at minimum of 2 years after primary ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1806-1816.