# Influence of graft diameter on patient reported outcomes after hamstring autograft anterior cruciate ligament reconstruction

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## Abstract

Several studies have identified graft diameter as a risk factor for failure following anterior cruciate ligament reconstruction (ACLR). The purpose of this study was to evaluate the effect of graft diameter on patient reported outcome measures (PROMS) following ACLR. We performed a retrospective review of prospectively collected data using a global surgical registry. 153 of 287 patients (53.3%) had complete data for each timepoint. Effect of graft diameter, graft type, femoral tunnel drilling technique, patient age, sex, and body mass index were evaluated.

At 1-year post-operatively, a 1-mm increase in graft diameter was found to correlate with a 5.7-point increase in the Knee Injury and Osteoarthritis Outcome Score (KOOS) activity of daily living score (P=0.01), a 10.3-point increase in the sport score (P=0.003), and a 9.8-point increase in the quality of life score (P=0.013). At 2-years post-operatively, a 1-mm increase in graft size was found to be marginally correlated with KOOS symptoms and sport scores. Patients undergoing hamstring autograft ACLR, increasing graft diameter can result in improved PROMS, specifically improved KOOS subscale scores at 1 and 2-years post-operative.

## Introduction

Anterior cruciate ligament reconstruction (ACLR) is one of the most common orthopedic sports medicine procedures, with nearly 130,000 performed each year in the United States.[1] There is considerable variation in procedural technique including the graft type, bone tunnel drilling, and methods of fixation. Surgeons have a number of autograft and allograft options. Autograft bone-patellar tendon-bone (BTB) has historically been considered the gold standard.[2,3] Though, within the past decade the use of autologous hamstrings has increased in popularity among surgeons.[2,3] Increased prevalence of donor site morbidity in BTB autografts and concurrent improvements in hamstring tendon graft fixation techniques, hamstring tendon graft quadrupling, and robust literature showing comparable outcomes in both BTB and hamstring grafts has spurred this popularity.[1-4] Despite the success of autograft hamstring for ACLR, graft diameter can be variable and is a major factor in graft failure in biomechanical and clinical studies.[5-10] Several recent studies investigating the influence of graft diameter have shown increased risk of failure with graft diameter <8 mm and a strong correlation between graft diameter with patient reported outcome measures (PROMs).[5-8]

New techniques for quadrupled hamstring with a single tendon have led to increased graft diameter with autograft hamstring ACLR.[11] Traditional fixation methods for hamstring ACLR include suspensory femoral fixation and interference screw for tibial fixation. Lubowitz *et al.* described the all-inside quadrupled tendon technique, which utilizes suspensory fixation for the femur and tibia.[12] This technique utilizes a quadrupled single tendon (semitendinosus) and may be augmented with a second tendon (gracilis) if needed to increase graft diameter. To our knowledge, there has been no studies to evaluate the influence of graft size on the functional outcomes in patients undergoing ACLR with traditional hamstring autograft *versus* all-inside quadrupled tendon technique. The purpose of this study was 1) to evaluate the effect of hamstring graft diameter and 2) to compare traditional hamstring technique to all-inside quadrupled tendon ACLR on PROMs at one and two years post-operatively. We hypothesized that increasing graft diameter and the use of all-inside quadrupled tendon reconstruction technique correlates with improved PROMs.

## Materials and Methods

We performed a retrospective review of prospectively collected cohort data using a specialized Health Insurance Portability and Accountability Act (HIPAA) compliant global registry, Surgical Outcomes System (SOS; Arthrex, Naples, FL) and obtained IRB approval for this study through our institution. Use of the global registry was reviewed and approved by our institutional review board. SOS is a comprehensive database that collects patient demographics, diagnostic data, detailed surgical data and validated PROMs. On March 13, 2018 the data from a total of 194 surgeons was queried for all patients who underwent single bundle ACLR with hamstring autograft, and 287 patients were identified with a minimum two years of follow-up. Patients were excluded if they did not have complete data for ACL graft diameter, pre-operative, and two-year post-operative PROMs. We also excluded patients who had other major knee ligament (posterior cruciate ligament, medial collateral ligament, lateral collateral ligament, or posterolateral corner) repair or reconstruction at the time of ACLR.

The measures used in this study include visual analogue scale for pain (VAS), Veterans RAND 12-Item Health Survey (VR-12 Physical and VR-12 Mental), Marx Activity Scale, Knee Injury and Osteoarthritis Outcome Score (KOOS) pain, KOOS symptoms, KOOS activity of daily living (ADL), KOOS sports/recreation, and KOOS quality of life (QOL).[13,14]

Descriptive statistics were calculated to determine the sociodemographic

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and clinical characteristics of patients. Differences in patient demographics, characteristics of ACLR, and PROMs were compared using an independent t-test or Mann-Whitney's U-test for continuous data, based on the distribution of data as determined by the Shapiro-Wilk test. Categorical data was assessed utilizing the Chi-square test. For multiple linear regression models, categorical variables were coded as dummy variables (*i.e.,* for sex, 0 represented male and 1 represented female). Models included patient age, sex, BMI, femoral tunnel drilling technique, graft type and size, and pre-operative PROM as the independent variables. One and two-year post-operative PROM scores served as dependent variables. All statistical analyses were performed in SPSS for Mac (Version 23.0. SPSS Inc., Chicago, Illinois). Significance was set at P<0.05.

## Results

Complete data, including graft size, pre-operative, and two-year post-operative outcomes scores were available in 153 of 287 patients (53.3%). Patient demographic data is summarized in Table 1. Of the included patients, 54 were male (35.3%) and 99 were female (64.7%) with a mean age of 27.5±11.8 (range, 12 to 60) years and a mean BMI of 26.6±5.2 kg/m². There were no significant differences between the demographic data of both groups.

Surgical data is summarized in Table 2. There were 69 traditional hamstrings (45.1%) and 84 (54.9%) all-inside quadrupled tendon ACLRs. The graft size of the traditional hamstring group ranged from 6.5 to 10.0 mm with a mean graft size of 8.1±0.9 mm, which was significantly smaller than the all-inside group, which ranged from 7.0 to 11.5 mm with a mean graft size of 9.0±0.9 mm (P<0.0001). There was also a difference between the femoral tunnel drilling technique for each group, as the all-inside group had significantly more outside-in retrograde drilling technique in 47 patients *versus* 11 patients (P<0.0001) in the hamstrings group.

A majority of patients had additional surgical procedures at the time of ACLR, including anterolateral ligament (ALL) reconstruction, partial meniscectomy, meniscus repair, chondroplasty, and osteochondral autograft transfer (OATS). There were no significant differences between the number of concomitant procedures in the two groups (Table 2). In a subgroup analysis, comparing patients who had no additional procedures with patients who had concomitant surgery, we only found a significant difference in the pre-operative Marx activity scale and found no significant differences in any PROMs at two years post-operative (Table 3).

After controlling for age, sex, BMI, femoral tunnel drilling technique, graft choice, and pre-operative PROMs graft diameter was found to be significantly correlated with several PROMs at one year, and marginally correlated with KOOS sport/recreation and KOOS symptoms scores at two years post-operatively (Table 4). At one year post-operatively a 1 mm increase in graft diameter was found to correlate with a 5.7-point increase in the KOOS ADL score (P=0.01), a 10.3-point increase in the KOOS sport/recreation score (P=0.003), and a 9.8-point increase in the KOOS QOL score (P=0.013). At two years post-operatively, a 1 mm increase in graft size was found to be marginally correlated with a 4.4-point increase in KOOS symptoms score (P=0.058), and a 6.4-point increase in the KOOS sport/recreation score (P=0.051). When comparing traditional hamstring graft *versus* all-inside quadrupled tendon reconstructions at one and two years post-operatively we did not find any statistically significant differences between outcomes scores (Table 5). Though, we did find a trend towards improved KOOS QOL (69.9±24.7 *versus* 63.9±22.9, P=0.058) in the all-inside *versus* traditional hamstrings, respectively.

## Discussion

While graft diameter was shown to be correlated with graft failure in a number of studies, the influence of a diminutive graft on PROMs has only been reported in one previous report.[5] The most important finding of the present study was that ACL graft diameter is significantly correlated with PROMs at one year post-operatively, and associated with outcome scores at two years. While the results of our multiple linear regression did not achieve statistical significance at two years of follow-up, the data does show graft diameter is strongly correlated with PROMs after ACL reconstruction. Of the variables in our regression model for two-year PROMs, graft diameter had the strongest correlation with KOOS pain, symptoms, ADL, and sport/recreation subscales.

The results of our multiple linear regression analysis found that a 1-mm increase in graft diameter correlates with a 10.3-point increase in KOOS sport/recreation, 9.8-point increase in KOOS QOL, and 5.6-point increase in KOOS ADL at one year post-operatively. At two years, a 1-mm

**Table 1. Patient demographic data.**

| Patient characteristics | Hamstring | All-inside | P |
|---|---|---|---|
| N. | 69 (45.1%) | 84 (54.9%) | |
| Age, years; Mean± SD | 28.9±13.5 | 26.3± 10.1 | 0.215 |
| Females | 45 (65%) | 54 (66%) | 0.763 |
| BMI, kg/m²; Mean±SD | 26.8± 5.0 | 26.4±5.3 | 0.433 |
| Smokers | 1 (1.4%) | 1 (1.2%) | 0.808 |
| Worker's Compensation | 1 (1.4%) | 1 (1.2%) | 0.840 |

**Table 2. Surgical data.**

| Surgical characteristics | Hamstring (%) | All-inside (%) | P |
|---|---|---|---|
| N. | 69 (45.1) | 84 (54.9) | |
| Graft Diameter, mm; Mean ± SD | 8.1±0.9 | 9.0±0.9 | <0.001 |
| Femoral Tunnel Drilling Technique | | | |
| Outside-in Retrograde Flipcutter | 11 (15.9) | 47 (56.0) | <0.001 |
| Anteromedial Portal | 43 (62.3) | 31 (36.9) | 0.001 |
| Transtibial | 12 (17.4) | 0 | <0.001 |
| Unknown | 3 (4.3) | 6 (7.1) | |
| Concomitant Surgical Procedures | | | |
| Anterolateral ligament reconstruction | 2 (2.9) | 3 (3.6) | 0.816 |
| Partial meniscectomy | 22 (31.9) | 22 (26.2) | 0.439 |
| Meniscus repair | 16 (23.1) | 22 (26.2) | 0.669 |
| Chondroplasty | 4 (5.8) | 8 (9.5) | 0.394 |
| Osteochondral autograft transfer | 1 (1.4) | 0 | 0.268 |

**Table 3. Subgroup analysis of concomitant surgical procedures.**

| Outcome Score | No concomitant procedures | Partial meniscectomy | P* | Meniscus repair | P* | Chondroplasty | P* | ALL Reconstruction | P* |
|---|---|---|---|---|---|---|---|---|---|
| N. | 69 | 44 | | 38 | | 12 | | 5 | |
| VAS Pain | | | | | | | | | |
| Pre-operative | 2.4±2.1 | 2.6±2.2 | 0.669 | 2.3±2.1 | 0.953 | 2.9±2.9 | 0.661 | 1.7±1.6 | 0.893 |
| 2-years post-op | 0.9±1.6 | 1.1±1.6 | 0.283 | 1.0±1.3 | 0.359 | 1.4±2.0 | 0.207 | 1.2±1.3 | 0.435 |
| VR-12 Physical | | | | | | | | | |
| Pre-operative | 37.2±9.0 | 36.9±8.5 | 0.920 | 36.6±8.8 | 0.897 | 39.3±5.8 | 0.288 | 39.6±12.1 | 0.828 |
| 2-years post-op | 51.9±7.0 | 50.7±7.0 | 0.180 | 51.0±8.9 | 0.750 | 50.2±7.3 | 0.173 | 49.7±6.5 | 0.962 |
| VR-12 Mental | | | | | | | | | |
| Pre-operative | 52.3±11.2 | 51.3±9.8 | 0.413 | 48.9±14.3 | 0.359 | 54.1±10.1 | 0.550 | 49.4±7.8 | 0.407 |
| 2-years post-op | 54.7±9.1 | 54.0±10.0 | 0.876 | 54.7±9.1 | 0.964 | 51.8±8.8 | 0.186 | 58.0±9.0 | 0.930 |
| Marx Activity Scale | | | | | | | | | |
| Pre-operative | 11.7±4.8 | 9.9±5.1 | 0.028 | 11.9±5.3 | 0.604 | 5.6±6.1 | 0.002 | 7.0±6.6 | 0.492 |
| 2-years post-op | 8.2±5.2 | 7.7±5.3 | 0.754 | 9.7±5.0 | 0.151 | 5.3±5.8 | 0.099 | 5.4±6.2 | 0.079 |
| KOOS Pain | | | | | | | | | |
| Pre-operative | 62.8±19.9 | 63.8±16.7 | 0.627 | 63.5±16.1 | 0.874 | 66.2±17.2 | 0.646 | 61.1±23.2 | 0.807 |
| 2-years post-op | 88.4±14.8 | 86.1±12.3 | 0.153 | 86.0±15.7 | 0.687 | 87.0±12.2 | 0.560 | 82.2±13.7 | 0.830 |
| KOOS Symptom | | | | | | | | | |
| Pre-operative | 60.1±16.9 | 55.0±17.5 | 0.096 | 57.7±20.7 | 0.442 | 59.5±18.7 | 0.863 | 53.6±9.4 | 0.511 |
| 2-years post-op | 80.2±14.4 | 74.9±18.6 | 0.160 | 78.2±15.2 | 0.524 | 71.1±19.9 | 0.137 | 68.6±28.3 | 0.642 |
| KOOS ADL | | | | | | | | | |
| Pre-operative | 71.8±20.7 | 72.9±18.2 | 0.974 | 70.0±21.6 | 0.708 | 75.6±12.0 | 0.730 | 69.1±30.3 | 0.690 |
| 2-years post-op | 94.4±12.6 | 93.0±10.5 | 0.176 | 91.3±17.0 | 0.740 | 93.4±9.9 | 0.177 | 93.2±8.4 | 0.487 |
| KOOS Sport | | | | | | | | | |
| Pre-operative | 32.1±27.8 | 33.6±25.4 | 0.605 | 29.5±24.5 | 0.765 | 33.8±27.4 | 0.805 | 41.0±29.0 | 0.788 |
| 2-years post-op | 81.1±23.0 | 74.8±24.3 | 0.123 | 78.8±27.4 | 0.955 | 74.2±23.0 | 0.272 | 70.0±27.6 | 0.888 |
| KOOS QOL | | | | | | | | | |
| Pre-operative | 27.4±17.2 | 24.1±14.0 | 0.354 | 22.8±17.4 | 0.220 | 19.8±13.5 | 0.173 | 17.5±14.3 | 0.240 |
| 2-years post-op | 68.4±23.0 | 64.9±25.9 | 0.540 | 67.8±24.2 | 0.862 | 62.0±28.0 | 0.400 | 48.8±34.0 | 0.927 |

*All p-values are compared to the no concomitant procedures cohort.

**Table 4. Multivariable linear regression analysis: correlation of graft diameter with patient reported outcome measures at 1 and 2 years post-operatively.**

| | Regression coefficient of graft diameter | Std. Error | P |
|---|---|---|---|
| First Year Outcomes | | | |
| VAS | -0.126 | 0.306 | 0.683 |
| VR-12 Physical | 2.156 | 1.309 | 0.111 |
| VR-12 Mental | 2.492 | 1.285 | 0.063 |
| Marx Activity Scale | -0.061 | 0.998 | 0.952 |
| KOOS Pain | 3.319 | 2.523 | 0.199 |
| KOOS Symptoms | 5.036 | 3.263 | 0.134 |
| KOOS ADL | 5.659 | 2.056 | 0.01* |
| KOOS Sport | 10.316 | 3.202 | 0.003* |
| KOOS QOL | 9.812 | 3.671 | 0.013* |
| Second Year Outcomes | | | |
| VAS | -0.216 | 0.184 | 0.247 |
| VR-12 Physical | 0.260 | 0.940 | 0.783 |
| VR-12 Mental | 1.592 | 1.105 | 0.156 |
| Marx Activity Scale | 0.068 | 0.711 | 0.924 |
| KOOS Pain | 2.855 | 1.692 | 0.098 |
| KOOS Symptoms | 4.351 | 2.245 | 0.058 |
| KOOS ADL | 2.165 | 1.308 | 0.104 |
| KOOS Sport | 6.359 | 3.177 | 0.051 |
| KOOS QOL | 3.582 | 3.170 | 0.264 |

*Significant association with P<0.05.

increase in graft size is correlated with a 6.4-point increase in KOOS sport/recreation and 4.4-point increase in KOOS symptom scores. While this correlation is marginally significant it is an important finding. The minimal clinically important difference (MCID) has not yet been established for ACL reconstruction outcomes at two years post-operatively, though a change in the KOOS subscales of 8-10 points has been generally accepted as the MCID for knee injuries.[14,15] Within this context, comparing an 8-mm ACL graft *versus* a 10-mm ACL graft, one would expect a 20.6-point increase in the KOOS sport/recreation at one year, and a 12.8-point increase in the KOOS sport/recreation at two years post-operative, which is well above the MCID. These findings are similar to the previous report by Mariscalco *et al*., which found that a 2-mm increase in graft size correlates with a 10.3-point increase in KOOS sport/recreation, a 4.0-point increase in KOOS ADL, and a 6.5-point increase in KOOS pain scores at two years post-operative.[5] In contrast to this report, we also evaluated the influence of concomitant surgical procedures.

In order to assess the influence of concomitant procedures we compared the outcomes of patients undergoing each procedure with our cohort of patients who had no concomitant procedures at the time of ACLR. We found no significant differences in PROMs between patients who had no concomitant procedures *versus* patients who had either partial meniscectomy, meniscus repair, chondroplasty, or ALL reconstruction. We did not include OATS in this analysis, as only one patient had this concomitant procedure. These findings are also important in that patients undergoing ACLR with concomitant meniscus and cartilage injuries had similar outcomes at two years post-operatively to patients undergoing isolated ACLR. A recent study with ten-year follow-up identified lateral meniscectomy and cartilage injury of Outerbridge grade 3 or 4 as significant risk factors for inferior outcomes after ACLR.[16]

When comparing the two-year outcomes of traditional hamstring *versus* all-inside ACLR, we did not find statistically significant differences between the groups, though the all-inside cohort trended towards better PROMs and were marginally significant for the KOOS QOL (P=0.058). These findings are important in that the all-inside technique performs at least as well as traditional hamstring autograft ACLR techniques in this cohort of patients at two years post-operatively.

The major strength of this study is the large patient cohort from a large sampling of different surgeons. However, there are several limitations. First, our data did not include information on failures or need for revision surgery. This has been one of the most important areas of investigation when evaluating graft diameter. Park *et al*. in a cohort of 296 patients undergoing ACL reconstruction with hamstring autograft found in patients with a graft diameter of less than 8 mm a revision risk of 5.2% *versus* 0% in patients with graft diameter greater than 8 mm.[17] In a retrospective review of 256 patients, Magnussen *et al*. found 16 of 18 revisions occurred in patients with a hamstring autograft with a diameter of 8 mm or less.[6] Mariscalco *et al.* performed a retrospective review of 263 patients and similarly found the risk of revision 7% in patients with grafts 8 mm or less *versus* 0% in patients with grafts greater than 8 mm.[5] Spragg *et al*. found that in patients with grafts ranging from 7 to 9 mm for every 0.5-mm increase in graft diameter they have a 0.82 times lower likelihood of requiring revision ACL reconstruction.[8] While these study findings are significant, it is also important to consider that patients with a diminutive graft may have a poorly functioning ACLR that does not go on to failure or revision surgery, which can still have a substantial impact on that patient's quality of life.

## Limitations

There are limitations inherent to the use of a large global registry. A substantial number of patients were lost to follow-up, which could introduce selection bias. The patients who have gone on to fail or undergo revision surgery within two years after ACLR are likely not completing the two-year post-operative survey in this registry implying a selection bias towards higher post-operative PROMs. As these patients are expected to

**Table 5. Hamstring vs all-inside patient reported outcomes.**

| Outcome Score | Hamstring Mean ± SD | All-inside Mean ± SD | P |
|---|---|---|---|
| VAS Pain | | | |
| Pre-operative | 2.2±1.8 | 2.6±2.4 | 0.714 |
| 1-year post-op | 1.0±1.4 | 1.1±1.5 | 0.659 |
| 2-years post-op | 1.0±1.5 | 0.9±1.5 | 0.863 |
| VR-12 Physical | | | |
| Pre-operative | 35.6±9.5 | 38.1±7.8 | 0.071 |
| 1-year post-op | 50.1±8.4 | 50.7±6.2 | 0.875 |
| 2-years post-op | 50.9±7.2 | 51.6±7.8 | 0.216 |
| VR-12 Mental | | | |
| Pre-operative | 52.8±9.8 | 50.4±12.4 | 0.402 |
| 1-year post-op | 54.0±10.0 | 55.3±7.8 | 0.63 |
| 2-years post-op | 55.2±9.5 | 54.1±9.1 | 0.441 |
| Marx Activity Scale | | | |
| Pre-operative | 11.0±5.3 | 11.1±5.2 | 0.809 |
| 1-year post-op | 8.0±5.3 | 8.7±5.4 | 0.447 |
| 2-years post-op | 7.6±5.2 | 9.0±5.3 | 0.114 |
| KOOS Pain | | | |
| Pre-operative | 62.7±17.3 | 63.7±19.3 | 0.784 |
| 1-year post-op | 87.4±14.3 | 86.0±14.7 | 0.354 |
| 2-years post-op | 86.2±15.3 | 88.1±13.5 | 0.393 |
| KOOS Symptom | | | |
| Pre-operative | 56.4±16.8 | 59.7±19.0 | 0.261 |
| 1-year post-op | 76.9±16.0 | 76.1±15.5 | 0.569 |
| 2-years post-op | 77.0±17.3 | 79.5±15.0 | 0.496 |
| KOOS ADL | | | |
| Pre-operative | 69.8±18.7 | 73.0±21.8 | 0.187 |
| 1-year post-op | 92.6±13.2 | 91.7±16.0 | 0.677 |
| 2-years post-op | 92.2±14.6 | 94.1±12.0 | 0.375 |
| KOOS Sport | | | |
| Pre-operative | 27.3±23.6 | 36.0±28.0 | 0.066 |
| 1-year post-op | 76.1±20.6 | 75.8±22.1 | 0.996 |
| 2-years post-op | 75.9±26.9 | 80.7±22.3 | 0.366 |
| KOOS QOL | | | |
| Pre-operative | 25±17.1 | 25.5±15.9 | 0.689 |
| 1-year post-op | 63.8±21.2 | 62.2±22.1 | 0.619 |
| 2-years post-op | 63.9±22.9 | 69.9±24.7 | 0.058 |

underperform in the two-year PROMs, the significance in these outcomes would likely increase. The SOS registry does not include information on surgeon experience or rehabilitation protocols that may influence PROMs. Also, we do not have post-operative physical examination, or instrumented laxity assessment. Therefore, it is unknown if patients with smaller diameter grafts exhibit increased laxity and whether this correlates with outcomes.

## Conclusions

While our study has limitations the major strength and contribution to the current literature on this topic is the influence of ACL graft diameter on various PROMs, including VAS pain, VR-12, Marx activity scale and the five KOOS subscales. Our data shows that in patients undergoing hamstring autograft ACLR with either traditional or all-inside technique, increasing graft diameter results in improved PROMs at one- and two-years post-operative, specifically improved KOOS subscale scores at one- and two-years post-operative. Additionally, all-inside ACLR results in PROMs that are similar to traditional hamstring autograft ACLR at two years post-operatively. Further studies are needed with larger sample size to confirm these findings.

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