Inacio, M. C. S., Paxton, E. W., Maletis, G. B., Csintalan, R. P., Granan, L.-P., Fithian, D. C., Funahashi, T. T. (2012). Patient and Surgeon Characteristics Associated With Primary Anterior Cruciate Ligament Reconstruction Graft Selection. *American Journal of Sports Medicine, 40*, 339-345.

Patient and Surgeon Characteristics Associated with Primary Anterior Cruciate Ligament Reconstruction Graft Selection

Maria C.S. Inacio, Elizabeth W. Paxton, Gregory B. Maletis, Rick P. Csintalan, Lars-Petter Granan, Donald C. Fithian, Tadashi T. Funahashi

Maria C.S. Inacio, MS
Surgical Outcomes and Analysis Department
Kaiser Permanente

Elizabeth W. Paxton, MA
Surgical Outcomes and Analysis Department
Kaiser Permanente

Gregory B. Maletis, MD
Department of Orthopaedic Surgery
Southern California Permanente Medical Group
Baldwin Park, California

Rick P. Csintalan, MD
Department of Orthopaedic Surgery
Southern California Permanente Medical Group
Orange County, California

Lars-Petter Granan, MD, PhD
Oslo Sports Trauma Research Center, Norway.
Department of Physical Medicine and Rehabilitation, Oslo University Hospital, Norway

Donald C. Fithian, MD
Department of Orthopaedic Surgery
Southern California Permanente Medical Group
San Diego, California

Tadashi T. Funahashi, MD
Department of Orthopaedic Surgery
Southern California Permanente Medical Group
Orange County, California

Institution where study was performed:
Surgical Outcomes and Analysis Department
Kaiser Permanente
3033 Bunker Hill St.
San Diego, CA 92109

Acknowledgments: We acknowledge all the Kaiser Permanente orthopaedic surgeons who contribute to the ACLR Registry and the Surgical Outcomes and Analysis Department which coordinates Registry operations. We also acknowledge Tom S. Huon, BS for his support with the data management and preparation for the study, and Chris Ake, PhD and Mary Lou Kiley, LCSW, MBA for their assistance with manuscript editing.

Abstract

Background: It has been suggested that a surgeon's experience and training are the most important factors associated with graft selection, but no studies have qualified this association. Graft usage prevalence has not been described for large anterior cruciate ligament reconstruction (ACLR) populations in the United States.

Hypothesis/Purpose: To describe the prevalence of graft usage in a large community based practice and evaluate the association of patient, surgeon, and site characteristic with choice of primary ACLR graft.

Study Design: Cross sectional.

Methods: Primary ACLRs performed between 02/2005-6/2010 were selected for the study. A community based ligament registry was used to identify cases and variables used for analysis. Graft choice (any allograft, hamstring (HS) autograft, and bone-patellar tendon-bone (BPTB) autograft) was compared by patient characteristics, and surgeon and site characteristics. Associations between independent variables and graft choice were evaluated using a polychotomous regression model.

Results: Of the 9849 patients included in the study 64% were male and overall median age was 28 years. Of these, 2796 (28.4%) received BPTB autografts, 3013 (30.6%) HS autografts, and 4040 (41.0%) allografts. The prevalence of graft source by patients' gender, race, age, BMI, as well as surgeons' fellowship training status, average volume, and site volume were significantly different (all $P<0.001$). Adjusted models showed that patients' gender ($P<0.001$), race ($P=0.018$), age ($P<0.001$), BMI ($P<0.001$), and surgeons' fellowship training status ($P<0.001$) and volume ($P<0.001$), as well as site volume ($P<0.001$) are associated with graft selection. Older patients, with lower BMI, of female gender were more likely to receive allografts and HS autografts than BPTB autografts. Cases performed by non-fellowship trained surgeons, lower volume sites and/or lower volume surgeons were also more likely to be performed with allograft or HS autograft than BPTB autografts.

Conclusion: Certain patient characteristics may be important to surgeons making graft selection choices. Gender, age, race, as well as facility and surgeon characteristics such as volume and location, may influence graft choices.

Key terms: ACL reconstruction, graft, selection, surgeon, patient

What is known about this topic?

Literature suggests that surgeon experience and training are the most important factors associated with graft selection, but no studies have quantified this association. Graft usage prevalence has not been described for large anterior cruciate ligament reconstruction (ACLR) populations in the US. The purpose of this study is to describe the prevalence of graft usage in a large community based practice and evaluate the association of patient, surgeon, and site characteristics with choice of primary ACLR graft.

To our knowledge two previous studies have attempted to describe variables associated with graft selection from a patient's perspective.[1-2] A cross-sectional study of patients from one medical center with 5 surgeons asked patients what factors influenced their graft selection decision.[1] While this study described that surgeons' opinions influence the overall decision, it did not attempt to describe what patient factors are associated with that decision. Similarly, another cross-sectional study by Cheung et al[2] found that 75% of patients relied on surgeons' suggestions.

What this study adds to existing knowledge?

This study contributes to two gaps of knowledge in the field of ACL reconstruction surgery utilization:

References for questions:

[1] **Cheung, S. C.; Allen, C. R.; Gallo, R. A.; Ma, C. B.; and Feeley, B. T.:** Patients' attitudes and factors in their selection of grafts for anterior cruciate ligament reconstruction. *Knee*, 2011.

[2]**Cohen, S. B.; Yucha, D. T.; Ciccotti, M. C.; Goldstein, D. T.; Ciccotti, M. A.; and Ciccotti, M. G.:** Factors affecting patient selection of graft type in anterior cruciate ligament reconstruction. *Arthroscopy,* 25(9): 1006-10, 2009.

1. It describes the prevalence of graft usage in a large cohort of patients, performed by a diverse group of surgeons in several locations.

2. It describes pre-operative patient, surgeon and site characteristics associated with graft selection.

Introduction

Anterior cruciate ligament reconstruction (ACLR) graft selection is usually based on the surgeon's professional experience, understanding of the literature, and patient preference.[21] Factors considered by the surgeon during graft selection for a procedure may include reported graft failure rates, donor site morbidity, familiarity with graft, surgical time, patient reported functional and quality of life outcomes, as well as possible post-operative complications, and associated costs.[6-8,21] However, the most appropriate type of graft for any given patient population continues to be a debated topic in the orthopedic community; with several systematic literature reviews and meta-analyses published and no definitive conclusions reached. [3-5,10-12,19]

While surgeons' experience and training may be the most common factors associated with graft selection, no studies have attempted to quantify this association. With the lack of large clinical studies, observational cohorts, and administrative information in this population, not even prevalence of graft usage has been described for a large community based sample in this country or countries without ligament registries. Furthermore, few studies have investigated other factors that could be associated with determination of a graft source.[6,7] Given the current dilemma surrounding the optimal graft selection for any given patient population, we decided to evaluate pre-operative variables available to surgeons that may be associated with graft choice. Understanding the influence of patient, surgeon, and site factors in the variability of graft selection might help to explain the most important determinants in graft selection.

The purpose of this study is to describe the prevalence of the type of graft used during primary ACLR surgery in a large community based practice setting. In addition, we have evaluated the associations of patients' sex, age, race, BMI, surgeon training, and yearly average volume of surgeon and hospital in the choice of hamstring autograft, bone-patellar tendon-bone (BPTB) autograft, and allograft for a primary ACLR surgery.

Methods

Study Design and Data Collection

A cross sectional study of patients undergoing primary ACLR between 02/01/2005 and 6/30/2010 was conducted. The *** ACLR Registry was used to identify all primary ACLRs performed during the study period. The Registry has 42 contributing medical centers and 214 contributing surgeons which are part of a large integrated healthcare delivery system. The *** ACLR Registry collects comprehensive intra-operative and post-operative information on all ACLRs performed at the participating sites.[18] The participating sites are located in California, Colorado, Hawaii, Pacific Northwest, and Mid-Atlantic states. Intra-operative information is collected by the surgeon at the point of care using a paper based three page form. Upon completion, the form is sent to the ACLR Registry data repository center where the information is entered into an SQL database and data quality control routines are applied. Institutional Internal Review Board approval for the study was obtained prior to study commencement.

Study Population

All patients in the registry were eligible for inclusion in the study. Patients were included in the study if the procedure was the primary ACLR in the operated knee. Patients were excluded if they had any concomitant ligament injury (medial collateral, lateral collateral, or posterior cruciate) at the time of surgery.

Exposure Assessment

Patient characteristics (BMI, age, sex, race), as well as grafts used during the procedure were obtained from the *** ACLR Registry. Surgeon training (current fellow or completed sports medicine fellowship) was ascertained using an email and telephone based survey.

Annual ACLR volumes for surgeon and site were calculated based on the average volume of procedures performed per twelve month period. The independent variables BMI and age were treated as continuous variables. All other independent variables were treated as categorical variables.

Outcome

Graft source was categorized into BPTB autograft, hamstring autograft, and allograft. The allograft category included any of the several graft types used in cases due to the small sample size in each of these subcategories.

Statistical Analysis

Descriptive information on the study population is provided using frequencies, proportions, medians, and standard deviations. Chi-square tests and Fisher's exact test were used to compare proportions of categorical variables across graft choices and analysis of variance (ANOVA) or Mann-Whitney test used to compare continuous variables across graft choices. A polychotomous logistic regression was used to model the three possible graft selection choices: BPTB autograft, hamstring autograft, and allograft. BPTB autograft was used as the reference category for the created models. The following variable association with graft choice were examined: sex (female vs. male), race (White, Asian, Black, Native American, Hispanic, other, and unknown), age (per 1 year increments), BMI (per 1 kg/m^2 increment), surgeon fellowship training (none, current fellow, completed fellowship), surgeon average yearly volume (small, medium, large), site yearly volume (small, median, large). Categorical cut-offs for small, medium and large surgeon volumes (<6 cases/year, 6-51 cases/year, >=52 cases/year) and site volumes (<24 cases/year, 24-124 cases/year, >=125 cases/year) were obtained from a previous published study.[16] Bivariate models of each of the independent variables were tested to determine associations with graft selection. All independent variables found to be significantly associated with graft selection (all $P<0.05$) were included in the final fully adjusted model.   The variable BMI had missing values which were excluded from the final model, missing observations are reported, and possible bias due to exclusion of cases with missing values was also evaluated. Collinearity of variables was evaluated using tolerance values <0.10 as threshold. Outliers were assessed statistically and then manually reviewed. Odds ratios (OR) for the association of the independent variables with graft choice and 95% confidence intervals (CI) are provided. The Wald Chi-square test P value is also provided for each variable. All reported P values were considered statistically significant when less than 0.05. All analyses were performed using SAS for Windows 9.1.3 (Cary, NC, USA).

Results

There were 11093 ACLRs registered during the study period. After excluding subjects that had other concurrent ligament injuries and revision cases (N=1081) as well as patients with grafts other than the three being evaluated in this study (N=163), 9849 patients remained to be studied. The study cohort had 64.3% males and the median age was 27.7 years (SD=11.4). Of these, 2796 (28.4%) received BPTB autografts, 3013 (30.6%) hamstring autografts, and 4040 (41.0%) allografts. See Table 1 for details on graft usage by population characteristics.

Prevalence of graft source was different between patients' gender, race, age, and BMI categories studied. The proportion of males was 69.4% in BPTB autograft group, 60.3% in the hamstring autograft group, and 63.7% in the allograft group ($P<0.001$). The median age of the BPTB autograft patients (22.9 years, SD=9.1) was significantly lower than either hamstring autograft (25.2 years, SD=10.6) or allograft (34.0 years, SD=11.9). Race distribution was significantly different across grafts, with 56.7% of allograft being performed in white patients compared to 49.0% of the BPTB autograft group and 55.2% of the hamstring autograft group. BMI was also significantly different, with those receiving hamstring autografts having the lowest median BMI (25.6 kg/m^2, SD=4.8) and patients receiving allografts (26.5 kg/m^2, SD=5.2) and BPTB autografts (26.2 kg/m^2, SD=5.1) having higher but similar median BMI.

Table 2 describes the surgeon and site specific variables by graft source chosen. Surgeon training ($P<0.001$), average yearly site volume ($P<0.001$), and surgeon volume ($P<0.001$), had significantly different distributions amongst graft source. Surgeons that had fellowship training (38.6% of contributing surgeons who performed 66.4% of the cases) performed 39.1% of their operations with allografts , 31.1% with hamstring autograft, and 29.8% with BPTB autograft, whereas surgeons with no fellowship training performed at least 28.9% of the cases and used allografts most frequently (49.6% of their cases). Only 3.1% of the cases were performed by low volume surgeons, and these surgeons preferred allografts (53.9%), followed by hamstring autograft (29.4%), and lastly BPTB autograft (16.7%). Medium volume surgeons (76.6% of the total number of surgeons) used allograft 44.0% of the time, 30.0% hamstring autograft, and 26.0% BPTB autograft. High volume surgeons (2.3% of the surgeons, with 11.4% of cases) used BPTB autograft most commonly (46.4%) followed by hamstrings autograft (36.4%), and allograft (17.2%). Graft distribution was also significantly different between different site volumes, with the lowest volume sites (9.5% of the sites with 3.1% of the cases) doing the highest proportion of allograft cases per yearly volume (53.9%). The high volume sites (23.8% of the sites and 47.5% of the cases) performed the highest proportion of BPTB autograft (34.4%).

Table 3 describes the fully adjusted final model of variables associated with graft selection. The individual Wald Chi-square tests indicated that sex (P<0.001), race (P=0.018), age (<0.001), BMI (P<0.001), surgeon training (P<0.001), site volume (P<0.001) and surgeon volume (P<0.001) were associated with graft selection when adjusted for other variables.

Fully adjusted models suggest patients receiving allografts have higher odds of being female (OR=1.47, 95%CI 1.30-1.66); higher odds of being older (OR=1.08, 95% CI 1.07-1.09); and lower odds of having higher BMI (OR=0.98, 95%CI 0.97-0.99). Allograft recipients have 1.38 (95%CI 1.21-1.58) higher odds of surgery being performed by a surgeon with no fellowship training, while having 0.24 (95%CI 0.18-0.33) odds of being performed by a surgeon in current fellowship training; 1.93 (95% CI 1.71-2.17) higher odds of being from a medium volume site and 3.30 (95% CI 2.28-4.77) higher odds of being from a low volume site. There are higher odds of allografts having been performed by a medium volume surgeon (OR=4.97, 95% CI 4.05-6.09) or a low volume surgeon (OR=3.31, 95% CI 2.18-5.04) compared to a high volume surgeon.

Patients receiving hamstring autograft (in relationship to patients with BPTB autograft) have 1.44 (95% CI 1.29-1.63) higher odds of being female in comparison to male; have higher odds of being older (OR=1.03, 95% CI 1.02-1.03); lower odds of being heavier (OR=0.97, 95% CI 0.96-0.98); 1.27 (95%CI 1.10-1.45) higher odds of surgery performed by a surgeon with no fellowship training while having 0.48 (95%CI 0.38-0.61) lower odds of being performed by a surgeon in current fellowship training; be from a medium (OR=1.25, 95% CI 1.11-1.41) or low volume site (OR=1.55, 95% CI 1.05-2.82) rather than from a high volume site; and surgery be performed by a medium (OR=1.45, 95%CI 1.23-1.71) volume surgeon rather than a high volume surgeon. Patients receiving hamstring autograft, have lower odds of being of an unknown (OR=0.69, 95% CI 0.57-0.84) or other (OR=0.76, 95% CI 0.63-0.93) race as compared to white, than patients receiving BPTB autografts.

Discussion

This analysis describes the prevalence of primary ACLR graft usage and quantifies the association of certain patient, surgeon, and site characteristics collected by a large community based registry with graft selection choice. The findings show a diverse pattern in graft usage in the large community based sample and suggest certain patient and surgeon characteristics may influence a surgeon's decision making process when making a graft selection.

The prevalence of graft usage in this large sample covering 9849 procedures, 214 surgeons, in 42 locations throughout the country show that allograft is the most commonly used graft (41%), followed by hamstring autograft (30.6%) and BPTB autograft (28.4%). This is a significantly different pattern of graft usage than reported by other relatively large cases series, multi site cohorts, or national ligament registries.[1,13,14,17,20] In a study on ACLR surgical site infection Greenberg et al reports on a large cases series of ACLR procedures at the University of Missouri.[14] In this series of 861 patients, the proportion of allograft usage was 74%. Conversely, in a large series of 3126 patients from the Hospital for Special Surgery (HSS), the reported usage of allograft was 43%, BPTB autograft 46%, and hamstring autograft only 11%.[1] The Multicenter Orthopaedic Outcomes Network cohort has several studies published on their large cohort of patients and report similar number of BPBT autograft but inverse proportion of hamstring autograft to allograft as compared to the HSS cohort (approximately 42% BPTB autograft, 44% hamstring autograft, and 13% allograft).[17,20] Scandinavian countries have national ligament registries and have determined their population graft prevalence. Their national registries report hamstring autograft to be the most common type of graft used (61%-86% hamstring autograft prevalence depending on the country), and the variation between the countries to be possibly due to surgeon's personal choice, financial considerations, or a combination of these.[13]

To our knowledge two previous studies have attempted to describe variables associated with graft selection from a patient's perspective. A cross-sectional study of patients from one medical center with five surgeons asked patients what factors influenced their graft selection decision.[7] This study reported that surgeon's recommendation accounted 74% of the selections. While this study described that surgeon's opinions influence the overall decision, it did not attempt to describe what patient factors are associated with that decision. Similarly, another cross-sectional study by Cheung et al found that 75% of patients relied on surgeons' suggestions.[6] To our knowledge there are no published studies describing pre-operative patient, surgeon and site characteristics associated with graft selection as described in this study.

The patterns of association with graft choice found in this study are most likely representative of the current understanding of the literature by our surgeons and the current practices in this country. Studies with large ACLR cohorts have reported consistently that allograft patients are typically older.[2,9,15]However, these studies are not consistent in the distribution of gender by graft source, with one reporting higher allograft prevalence in women[2] and one in men,[9] again indicating variation of graft selection patterns in the community. Since no other studies, to our knowledge, have commented on graft distribution of large ACLR cohort by gender, BMI, surgeon fellowship training, surgeon volume, and site volume, this is the first analysis describing the prevalence of graft source by these population characteristics. Some of these associations are interesting to highlight such as the lowest volume site, non fellowship trained surgeons, and lowest volume sites are doing the highest proportion of surgeries with allografts. Also, current fellows in this cohort are trained at two locations, both of which use BPTB autograft predominately, explaining why a strong inverse association of current fellows with the choice of hamstring autograft and allograft is observed. This suggests the possibility that graduates of these fellowships will most likely continue to use this in their future practice and is in accordance with the findings in this study that fellowship trained surgeons are more likely to choose BPTB autograft. This study does not allow us to determine the reasons for these findings due to its cross-sectional nature and lack of detailed information on other variables important to ascertain the reasons for this graft selection but we can speculate that these differences are related to surgeons' perceived understanding of graft failure rates, familiarity with graft, associated costs, surgical time, and other similar variables.

This study has several potential limitations including the inability to measure surgeon self reported preferences, lack of pre-operative patient reported quality of life (both general and knee specific), inability to assess patient activity level, lack of ACLR outcome measures, the inclusion of all allograft types under one category, and the obvious limitations involved with using cross sectional data. Our study utilized data collected by the *** ACLR Registry for its analysis. These data are limited due to the scope of the Registry and do not include reported preferences of the surgeon. Since it has been reported that surgeons' preferences are major contributors in the patient's decision of graft selection, this variable is most certainly important in the decision making process. This study did not attempt to describe surgeon preferences, but only examined the existing data from a large ALCR Registry. Pre-operative general and knee specific patient reported quality of life and patient activity level are arguably other factors influencing the surgeons' graft selection process but again this was beyond the scope of this study. Another limitation of this study is the lack of association of graft choice and outcomes of the procedures. Outcomes associated with procedures are factors used by surgeons to decide on graft selection, however, this is also out of the scope of this project. The lack of detail on the type of allograft chosen in our study is also a limitation. Surgeons' preference and graft availability are probably drivers of the type of allograft used. Including different types of allograft in this analysis would create many subcategories, some with a low volume of cases, causing our power to estimate associations to decrease. This in depth analysis by allograft type will most likely be undertaken once larger numbers of cases are entered into the ACLR Registry. Finally, the cross-sectional nature of this data limits our findings to odds ratios and not risk estimations. Our analysis can only show that certain associations between the independent variables and graft choice exist, no statement can be made on the temporal associations between these variables.

Strengths of this study include the high volume of ACL reconstructions being analyzed, the generalizibility of the study findings due to its community based setting, and the unbiased sample of surgeons included in the analysis. The volume of cases in this analysis allowed us to study the associations of many variables simultaneously in the graft selection process while adjusting for confounding effects of other variables. Univariate associations (i.e. females get more of certain graft) can be confounded by other variables (i.e. all females are younger and therefore are getting a certain graft, suggesting age is also a factor in the choice) and should always be evaluated to prevent misinterpretation of results. Also, the large number of contributing medical centers (42) and surgeons (214) captures a representative sample of community based practitioners. Inclusion of many centers reduces the bias introduced by studying just a limited number of locations and surgeons that may behave similarly due to proximity and other correlated characteristics. In addition, due to the financial structure of this organization, a staff model health maintenance organization, there is an inherent lack of incentive for greater surgeon volume or choice of specific graft, leading us to believe that there is no financial bias in graft selections made by participating surgeons.

This study has demonstrated that there are many variables associated with graft selection for ACL reconstruction procedures. The results from this study are informative to the larger orthopedic community as it describes the current prevalence of graft usage in a large community based patient population and it also describes basic patient and surgeon characteristics associated with the procedure's graft selection.

References

1. **Barker, J. U.; Drakos, M. C.; Maak, T. G.; Warren, R. F.; Williams, R. J., 3rd; and Allen, A. A.:** Effect of graft selection on the incidence of postoperative infection in anterior cruciate ligament reconstruction. *Am J Sports Med*, 38(2): 281-6, 2010.
2. **Barrett, G. R.; Luber, K.; Replogle, W. H.; and Manley, J. L.:** Allograft anterior cruciate ligament reconstruction in the young, active patient: tegner activity level and failure rate. *Arthroscopy*, 26(12): 1593-601, 2010.
3. **Biau, D. J. et al.:** Patellar tendon versus hamstring tendon autografts for reconstructing the anterior cruciate ligament: a meta-analysis based on individual patient data. *Am J Sports Med*, 37(12): 2470-8, 2009.
4. **Biau, D. J.; Tournoux, C.; Katsahian, S.; Schranz, P. J.; and Nizard, R. S.:** Bone-patellar tendon-bone autografts versus hamstring autografts for reconstruction of anterior cruciate ligament: meta-analysis. *BMJ*, 332(7548): 995-1001, 2006.
5. **Carey, J. L.; Dunn, W. R.; Dahm, D. L.; Zeger, S. L.; and Spindler, K. P.:** A systematic review of anterior cruciate ligament reconstruction with autograft compared with allograft. *J Bone Joint Surg Am*, 91(9): 2242-50, 2009.
6. **Cheung, S. C.; Allen, C. R.; Gallo, R. A.; Ma, C. B.; and Feeley, B. T.:** Patients' attitudes and factors in their selection of grafts for anterior cruciate ligament reconstruction. *Knee*, 2011.
7. **Cohen, S. B.; Yucha, D. T.; Ciccotti, M. C.; Goldstein, D. T.; Ciccotti, M. A.; and Ciccotti, M. G.:** Factors affecting patient selection of graft type in anterior cruciate ligament reconstruction. *Arthroscopy*, 25(9): 1006-10, 2009.
8. **Cole, D. W.; Ginn, T. A.; Chen, G. J.; Smith, B. P.; Curl, W. W.; Martin, D. F.; and Poehling, G. G.:** Cost comparison of anterior cruciate ligament reconstruction: autograft versus allograft. *Arthroscopy*, 21(7): 786-90, 2005.
9. **Dunn, W. R., and Spindler, K. P.:** Predictors of activity level 2 years after anterior cruciate ligament reconstruction (ACLR): a Multicenter Orthopaedic Outcomes Network (MOON) ACLR cohort study. *Am J Sports Med*, 38(10): 2040-50, 2010.
10. **Foster, T. E.; Wolfe, B. L.; Ryan, S.; Silvestri, L.; and Kaye, E. K.:** Does the graft source really matter in the outcome of patients undergoing anterior cruciate ligament reconstruction? An evaluation of autograft versus allograft reconstruction results: a systematic review. *Am J Sports Med*, 38(1): 189-99, 2010.
11. **Freedman, K. B.; D'Amato, M. J.; Nedeff, D. D.; Kaz, A.; and Bach, B. R., Jr.:** Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. *Am J Sports Med*, 31(1): 2-11, 2003.
12. **Goldblatt, J. P.; Fitzsimmons, S. E.; Balk, E.; and Richmond, J. C.:** Reconstruction of the anterior cruciate ligament: meta-analysis of patellar tendon versus hamstring tendon autograft. *Arthroscopy*, 21(7): 791-803, 2005.
13. **Granan, L. P.; Forssblad, M.; Lind, M.; and Engebretsen, L.:** The Scandinavian ACL registries 2004-2007: baseline epidemiology. *Acta Orthop*, 80(5): 563-7, 2009.
14. **Greenberg, D. D.; Robertson, M.; Vallurupalli, S.; White, R. A.; and Allen, W. C.:** Allograft compared with autograft infection rates in primary anterior cruciate ligament reconstruction. *J Bone Joint Surg Am*, 92(14): 2402-8, 2010.
15. **Katz, L. M.; Battaglia, T. C.; Patino, P.; Reichmann, W.; Hunter, D. J.; and Richmond, J. C.:** A retrospective comparison of the incidence of bacterial infection

following anterior cruciate ligament reconstruction with autograft versus allograft. *Arthroscopy*, 24(12): 1330-5, 2008.

16. **Lyman, S.; Koulouvaris, P.; Sherman, S.; Do, H.; Mandl, L. A.; and Marx, R. G.:** Epidemiology of anterior cruciate ligament reconstruction: trends, readmissions, and subsequent knee surgery. *J Bone Joint Surg Am*, 91(10): 2321-8, 2009.
17. **Magnussen, R. A. et al.:** Cross-cultural comparison of patients undergoing ACL reconstruction in the United States and Norway. *Knee Surg Sports Traumatol Arthrosc*, 18(1): 98-105, 2010.
18. **Paxton, E. W. et al.:** A prospective study of 80,000 total joint and 5000 anterior cruciate ligament reconstruction procedures in a community-based registry in the United States. *J Bone Joint Surg Am*, 92 Suppl 2: 117-32, 2010.
19. **Reinhardt, K. R.; Hetsroni, I.; and Marx, R. G.:** Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. *Orthop Clin North Am*, 41(2): 249-62, 2010.
20. **Spindler, K. P. et al.:** The prognosis and predictors of sports function and activity at minimum 6 years after anterior cruciate ligament reconstruction: a population cohort study. *Am J Sports Med*, 39(2): 348-59, 2011.
21. **West, R. V., and Harner, C. D.:** Graft selection in anterior cruciate ligament reconstruction. *J Am Acad Orthop Surg*, 13(3): 197-207, 2005.

Table 1. Comparison of Study Population Characteristics by Graft Type.

	BPTB *Autograft*	*Hamstrings Autograft*	*Allograft*	*Total*	*P Value*
	N (%)	**N (%)**	**N (%)**	**N (%)**	
Total N	2796 (28.4)	3013 (30.6)	4040 (41.0)	9849	
Gender					
Females	857 (30.6)	1196 (39.7)	1465 (36.3)	3518 (35.7)	<0.001
Males	1939 (69.4)	1817 (60.3)	2575 (63.7)	6331 (64.3)	
Race					
White	1371 (49.0)	1663 (55.2)	2292 (56.7)	5326 (54.1)	0.018
Asian	257 (9.2)	276 (9.2)	469 (11.6)	1002 (10.2)	
Black	176 (6.3)	203 (6.7)	266 (6.6)	645 (6.5)	
Native American	27 (1.0)	40 (1.3)	47 (1.2)	114 (1.2)	
Other	271 (9.7)	254 (8.4)	310 (7.7)	835 (8.5)	
Unknown	464 (16.6)	335 (11.1)	326 (8.1)	1125 (11.4)	
Hispanic	230 (8.2)	242 (8.0)	330 (8.2)	802 (8.1)	
	Median (SD)	**Median (SD)**	**Median (SD)**	**Median (SD)**	
Age, years	22.9 (9.1)	25.2 (10.6)	34.0 (11.9)	27.7 (11.4)	<0.001
BMI, Kg/m^2 *	26.2 (5.1)	25.6 (4.8)	26.5 (5.2)	26.1 (5.0)	<0.001

*** BMI is missing for 836 cases (8.5%).**

BPTB= bone-patellar tendon-bone; BMI=body mass index; SD=standard deviation.

Table 2. Comparison of Surgeon Training, Surgeon and Site Average Yearly Volume by Graft Type .

	Total Surgeons/Sites	BPTB Autograft	Hamstrings Autograft	Allograft	Total Cases	P Value[3]
	N (%)	**N (%)**	**N (%)**	**N (%)**	**N (%)**	
Total N	214 / 42	2796 (28.4)	3013 (30.6)	4040 (41.0)	9849	
Fellowship Training						
None	121 (56.3)	589 (20.7)	847 (29.7)	1413 (49.6)	2849 (28.9)	<0.001
Current Fellow[1-2]	11 (5.1)	256 (55.7)	131 (28.5)	73 (15.9)	460 (4.7)	
Fellowship Trained	83 (38.6)	1951 (29.8)	2035 (31.1)	2554 (39.1)	6540 (66.4)	
Surgeon Volume (cases/year)						
<6	45 (21.0)	60 (28.6)	47 (22.4)	103 (49.0)	210 (2.1)	<0.001
6-51	164 (76.6)	2214 (26.0)	2556 (30.0)	3743 (44.0)	8513 (86.4)	
>=52	5 (2.3)	522 (46.4)	410 (36.4)	194 (17.2)	1126 (11.4)	
Site Volume (cases/year)						
<24	4 (9.5)	51 (16.7)	90 (29.4)	165 (53.9)	306 (3.1)	<0.001
24-124	28 (66.7)	1141 (23.4)	1489 (30.5)	2249 (46.1)	4879 (49.5)	
>=125	10 (23.8)	1604 (34.4)	1434 (30.7)	1626 (34.9)	4664 (47.5)	

1. **Two locations have contributing current fellows every year.**
2. **One surgeon has been a fellow for a portion of his cases and the fellowship trained for another portion of his cases (N=215).**
3. **P Value compares the distribution of row variables by graft type.**

BPTB= bone-patellar tendon-bone.

Table 3. Polychotomous Logistic Regression Model for the Selection of ACL Reconstruction Graft Type. Odds Ratios, 95% Confidence Intervals, and P Values.

	Graft Type (reference= BPTB Autograft)		
	Allograft OR (95%CI)	**Hamstrings Autograft** OR (95%CI)	**P Value**
Female vs. Male	1.47 (1.30-1.66)	1.44 (1.29-1.63)	<0.001
Race			
White (reference)	1.00	1.00	0.018
Asian vs. White	1.11 (0.92-1.34)	0.85 (0.70-1.03)	
Black vs. White	1.16 (0.93-1.46)	0.95 (0.76-1.19)	
Hispanic vs. White	0.98 (0.80-1.20)	0.88 (0.72-1.07)	
Native American vs. White	1.04 (0.62-1.75)	1.15 (0.69-1.90)	
Other vs. White	0.69 (0.56-0.84)	0.76 (0.63-0.93)	
Unknown vs. White	0.40 (0.32-0.49)	0.69 (0.57-0.84)	
Age, years (1 year increment)	1.08 (1.07-1.09)	1.03 (1.02-1.03)	<0.001
BMI, kg/m^2 (1 unit increment)	0.98 (0.97-0.99)	0.97 (0.96-0.98)	<0.001
Fellowship Training			
Fellowship Trained (reference)	1.00	1.00	<0.001
Current Fellow vs. Fellowship Trained	0.24 (0.18-0.33)	0.48 (0.38-0.61)	
None vs. Fellowship Trained	1.38 (1.21-1.58)	1.27 (1.10-1.45)	
Surgeon Volume (cases/year)			
>=52 (reference)	1.00	1.00	<0.001
6-51 vs. >=52	4.97 (4.05-6.09)	1.45 (1.23-1.71)	
<6 vs. >=52	3.31 (2.18-5.04)	0.79 (0.51-1.23)	
Site Volume (cases/year)			
>=125 (reference)	1.00	1.00	<0.001
24-124 vs. >=125	1.93 (1.71-2.17)	1.25 (1.11-1.41)	
<24 vs. >=125	3.30 (2.28-4.77)	1.55 (1.05-2.82)	

ACL= anterior cruciate ligament; BPTB= bone-patellar tendon-bone; BMI=body mass index; OR=odds ratio; CI=confidence interval.