Advanced Patellar Tendinopathy Is Associated With Increased Rates of Bone–Patellar Tendon–Bone Autograft Failure at Early Follow-up After Anterior Cruciate Ligament Reconstruction

Alexander L. Lazarides,* MD, Eduard Alentorn-Geli,*†‡§ MD, MSc, PhD, Emily N. Vinson,‖ MD, Thomas W. Hash II,‖§ MD, Kristian Samuelsson,‖§ MD, MSc, PhD, Alison P. Toth,* MD, Claude T. Moorman III,*‖§ MD, William E. Garrett,* MD, PhD, and Dean C. Taylor,*†‡ MD

Investigation performed at the James R. Urbaniak, MD, Sports Sciences Institute, Duke University, Durham, North Carolina, USA

Background: Revision anterior cruciate ligament (ACL) reconstruction can be potentially devastating for a patient. As such, it is important to identify prognostic factors that place patients at an increased risk for graft failure. There are no data on the effects of patellar tendinopathy on failure of ACL reconstruction when using a bone–patellar tendon–bone (BPTB) autograft.

Purpose/Hypothesis: The purpose of this study was to investigate the association of patellar tendinopathy with the risk of graft failure in primary ACL reconstruction when using a BPTB autograft. The hypothesis was that patellar tendinopathy would result in higher rates of graft failure when using a BPTB autograft for primary ACL reconstruction.

Study Design: Cohort study; Level of evidence, 3.

Methods: All patients undergoing ACL reconstruction at a single institution from 2005 to 2015 were examined. A total of 168 patients undergoing primary ACL reconstruction with a BPTB autograft were identified. Patients’ magnetic resonance imaging scans were reviewed for the presence and grade of patellar tendinopathy by 2 musculoskeletal fellowship–trained radiologists; both were blinded to the aim of the study, patient demographics, surgical details, and outcomes. Patients were divided into 2 groups: failure (defined as presence of symptomatic laxity or graft insufficiency) and success of the ACL graft. Statistical analyses were run to examine the association of patellar tendinopathy with failure of ACL reconstruction using a BPTB autograft.

Results: At a mean follow-up of 18 months, there were 7 (4.2%) patients with graft failure. Moderate or severe patellar tendinopathy was associated with ACL graft failure ($P = .011$). Age, sex, and side of reconstruction were not associated with the risk of graft failure, although the majority of patients who failed were younger than 20 years. The use of patellar tendons with moderate to severe tendinopathy was associated with a relative risk of ruptures of 6.1 (95% CI, 1.37-27.34) as compared with autograft tendons without tendinopathy.

Conclusion: Moderate or severe patellar tendinopathy significantly increases the risk of graft failure when using a BPTB autograft for primary ACL reconstruction. Patellar tendinopathy should be considered when determining the optimal graft choice for patients undergoing primary ACL reconstruction with autograft tendons.

Keywords: patellar tendinopathy; bone–patellar tendon–bone autograft; graft failure; anterior cruciate ligament reconstruction

Graft failure after primary anterior cruciate ligament (ACL) reconstruction is a dreaded complication, often requiring revision surgery. While ACL reconstruction is a common operative procedure in the United States, with nearly 200,000 cases performed annually, the failure rate for primary ACL reconstruction using an autograft is reported at an average of 3.6%. Primary ACL reconstruction has reported rates of satisfaction of greater than 90%; however, the outcomes for revision surgery, such as return to play, patient satisfaction, and functional testing scores, are typically worse. As such, efforts have been made to identify the predictors of graft failure after primary ACL reconstruction.
Failure of ACL reconstruction has been considered as the presence of pain, stiffness, and/or persistent instability, leading to abnormal activities of daily living or sports performance. A number of factors have been associated with failure. Patient factors including younger age, higher activity levels, use of allografts, meniscal deficiency, and cutting sports are associated with an increased rate of failure. Technical factors, such as tunnel malpositioning, laxity, impingement, and infections, among others, are also associated with higher rates of graft failure. Graft selection has also been proposed as a possible predictor of ACL graft failure. While it is well established that, in both the primary and revision setting, autografts remain the superior choice over allografts, the specific choice of autograft remains murky. Some studies indicate that the bone–patellar tendon–bone (BPTB) autograft has lower overall rates of failure than reconstruction with a hamstring autograft or allograft. Recent work has emphasized that smaller hamstring grafts are related to increased failure rates, however, the quality of patellar tendon autografts and its impact on outcomes are unclear.

Prior literature has established a correlation between tendonopathy and native tendon ruptures, including the extensor carpi ulnaris and Achilles tendons, which has been hypothesized to be caused by tendon degeneration and breakdown. While anterior knee pain and patellar tendonopathy are recognized complications after the use of a BPTB autograft, the role of patellar tendonopathy before ACL reconstruction is not as well elucidated. The relationship between patellar tendonopathy and outcomes in ACL reconstruction with BPTB has not been extensively studied. The goal of this study was to investigate the influence of patellar tendonopathy on the rate of graft failure in ACL reconstruction when using a BPTB autograft. We hypothesized that patellar tendonopathy would result in higher rates of graft failure, possibly because of a weaker tendon secondary to chronic degenerative changes within the autograft.

METHODS

Procedures

This retrospective study received approval from an institutional review board. Between January 2005 and January 2015, the charts of all patients undergoing ACL reconstruction by 1 of 3 fellowship-trained sports medicine surgeons were reviewed. Patients were included if they (1) had undergone primary ACL reconstruction using a BPTB autograft from the central third of the patellar tendon of the ipsilateral leg, (2) had preoperative magnetic resonance imaging (MRI) scans of the primary ACL reconstruction site available for review, and (3) had a minimum follow-up of 6 months (or earlier in cases of graft failure).

Cases of primary ACL reconstruction that did not use a BPTB autograft, such as hamstring autografts or tendon allografts, were excluded. Once the patients were identified, a data collection spreadsheet was created to obtain demographic information (age, sex, side of reconstruction), imaging history (preoperative MRI scans available), length of follow-up, presence of graft failure, and details on subsequent surgical interventions. Although failure of ACL reconstruction has been considered to be the presence of pain, stiffness, and/or persistent instability, leading to abnormal activities of daily living or sports performance, for the purpose of this study, failure was considered to be the presence of symptomatic laxity or graft insufficiency (by physical examination or MRI). A separate spreadsheet with the MRI-related variables for patellar tendonopathy, not including the other study variables, was created for the radiologists’ blinded evaluation.

Patients

A total of 168 patients met the inclusion criteria. The mean follow-up was 18 months (range, 6-120 months), with a mean age of 21.8 years. There were 106 male patients (63.1%) and 62 female patients (36.9%) (Table 1). Surgery
was performed on 79 right knees (47.0%) and 89 left knees (52.9%) (Table 1). The surgical procedures were performed by 3 different surgeons (A.P.T., C.T.M., and D.C.T.). In all cases, single-bundle anatomic reconstruction was performed by either a transtibial technique or by independent drilling of the femoral tunnel. The harvest site was the ipsilateral knee in all cases.

MRI Evaluation

Two fellowship-trained musculoskeletal radiologists independently evaluated preoperative MRI scans of patients undergoing ACL reconstruction with a BPTB autograft. The radiologists were blinded to the study purpose, patients' treatment, and failures or complications. They were told that a study on patellar tendinopathy was being planned and that their job would consist of reaching a consensus on the reading and classification of this condition, assessing a number of MRI scans independently, and filling a data collection spreadsheet. The radiologists evaluated for the presence or absence of bone bruising (at the patellar or tibial tubercle sites) and patellar tendinopathy in the middle third (harvest area) as defined by the following procedure: First, images were evaluated for the absolute presence or absence of tendinopathy in the proximal part, middle part, distal part, or diffuse. Then, images were graded from 0 to 3 in accordance with the scheme established by Johnson et al16 (Figure 1), where grade 0 represents a normal tendon appearance, grade 1 (mild) represents signal intensity in <25% of the axial cross-sectional tendon width, grade 2 (moderate) represents signal intensity in 25% to 50% of the axial cross-sectional tendon width, and grade 3 (severe) represents signal intensity in >50% of the cross-sectional tendon width. Any images suggesting a tendon tear and its location were also collected. Once the 2 independent radiologists completed data collection, the researchers checked the evaluation of patellar tendinopathy for each case. Cases were excluded from statistical analyses when there was no consensus between the radiologists. Success or failure of the graft was compared according to age (stratified), sex, side of reconstruction, presence/absence of patellar tendinopathy, and classification of patellar tendinopathy (grades 0 or 1 vs grades 2 or 3).

Statistical Analysis

Descriptive statistics were used to summarize the variables collected for this study. The agreement in the classification of patellar tendinopathy for each patient between the 2 independent radiologists was evaluated using the kappa coefficient. A univariate analysis using the chi-square test was conducted to compare the subgroups. Multivariate methods were used to create a model controlling for sex, age, follow-up time, and tendinopathy in examining the association with the failure rate. All statistical analyses were carried out using JMP (SAS Institute). The alpha level was set at 0.05.

RESULTS

Of the 168 study patients, 7 (4.2%) had graft failure. Four failures occurred from a contact injury, while 3 occurred from a noncontact mechanism of injury. The kappa coefficient of agreement between both radiologists for bone edema of the patella, bone edema of the tibial tubercle, or partial tendon tears on MRI was 0.38, 0.41, and 0.65, respectively (P < .001 for each); this indicated weak, minimal, and moderate agreement, respectively. Radiologist 1 identified 10 (6.1%) cases of bone edema in the patella, 6 (3.6%) cases of bone edema in the tibial tubercle, and 8 (4.8%) cases of a partial tendon tear on MRI; there were no statistically significant differences in their distribution between the success and failure groups.
TABLE 2
Outcomes Stratified by Classification of Tendinopathy (*

| Tendinopathy          | Success, n | Total, n | P |
|-----------------------|------------|----------|---|
| Moderate to severe    | Yes 7      | No 2     | 9 | .01 |
| None to mild          | 133        | 5        | 138 | |
| Total                 | 140        | 7        | 147 | |

*Includes 147 patients for whom a consensus between the 2 radiologists could be reached.

(P = .46, .57, and .30, respectively). Radiologist 2 identified 9 (5.5%) cases of bone edema in the patella, 5 (3.1%) cases of bone edema in the tibial tubercle, and 10 (6.1%) cases of a partial tendon tear on MRI; there were no statistically significant differences in their distribution between the success and failure groups (P = .38, .61, and .59, respectively).

When patellar tendinopathy was classified as none or mild versus moderate or severe, there was still a statistically significant difference in concordance (kappa = 0.39; P < .001). Twenty-one patients (12.5%) were excluded from this subgroup comparison because no consensus between the radiologists could be reached on the degree of patellar tendinopathy (Table 2). When comparing the remaining 147 patients with none to mild patellar tendinopathy versus those with moderate to severe patellar tendinopathy, there was a statistically significant difference in the failure rate, with patients with moderate to severe tendinopathy having higher rates of failure (P = .011) (Table 2). The risk of ruptures for patients with moderate to severe tendinopathy was 6.1 (95% CI, 1.37-27.34) times greater than for those with none to mild tendinopathy. Even after controlling for sex, age, and follow-up time, tendinopathy remained statistically significant (P = .017).

DISCUSSION

The principal finding of this study was that moderate or severe patellar tendinopathy is associated with an increased risk of graft failure when using a BPTB autograft for primary ACL reconstruction. Therefore, a contralateral BPTB autograft or other tendon autograft is recommended in cases of moderate or severe patellar tendinopathy.

Previous studies have identified a number of risk factors for graft failure, such as younger age, higher activity levels, use of allografts, smaller graft size, concomitant meniscal deficiency, and patient sex.1,3,5,6,17,26-28 A study by Ponce et al28 retrospectively analyzed 2898 patients to identify risk factors for revision surgery in ACL reconstruction; they found that female sex was significantly correlated with higher rates of revision surgery. This has been suggested by other studies as well.1,6,14 In a study of the MOON (Multicenter Orthopaedic Outcomes Network) cohort however, female sex was not correlated with either ipsilateral or contralateral ACL disruption after ACL reconstruction. Still other studies have supported the notion that, although female sex seems to be associated with higher rates of native ACL disruption, female patients do not appear to have higher rates of graft failure.5,12,27,36 Our study did not find an association between sex and graft failure in 168 patients undergoing ACL reconstruction using a BPTB autograft.

Younger age and higher activity levels have also been correlated with higher rates of revision surgery after ACL reconstruction, as Kaeding et al18 reported after prospectively examining 2488 patients from the MOON cohort. This finding has been confirmed by other authors,36 including a study utilizing a large cohort from the Norwegian Cruciate Ligament Registry.27 While previous studies have demonstrated meniscal deficiency and allograft use as predictive of graft failure,17,26 our study was not specifically designed to evaluate these factors.

Tendinopathy has been proposed as a contributing factor for ruptures in other tendons. A study by McQueen et al23 used MRI to evaluate the prognostic significance of extensor carpi ulnaris tendinopathy in 42 patients with rheumatoid arthritis; they found that higher tendinopathy scores correlated with tendon ruptures at 6 years. Achilles tendinopathy has also been proposed as a contributing factor for ruptures.34 As such, it stands to reason that pathological changes in the patellar tendon before implantation may compromise the integrity of reconstruction using an autograft. Work by Alentorn-Geli et al5 supports this notion, suggesting that patellar tendinopathy indeed increases the rate of BPTB failure. Our findings support this premise and agree with the findings of this prior study. It should be noted that, while moderate to severe patellar tendinopathy was associated with graft failure, 77.8% of patients with moderate to severe patellar tendinopathy did not have evidence of failure. In comparison, however, only 3.6% of patients with none to mild patellar tendinopathy failed, which is consistent with the reported rates of failure in the literature,25 further supporting the notion that failure is associated with more severe patellar tendinopathy. It is also possible that patellar tendinopathy may be a surrogate for other factors, such as jumping sports or overtraining, that may predispose to graft failure.

When considering tendinopathy as a possible risk factor for graft ruptures when using a BPTB autograft, it is also pertinent to discuss graft healing. BPTB grafts have been found to heal by a process of ligamentization.4 Initially, the healing response is marked by an inflammatory phase in which the graft undergoes necrosis and becomes hypocellular. This results in the release of inflammatory markers and cytokines that signal for an influx of inflammatory cells and the beginning of the healing response.4,7,8,19 Subsequently, the graft enters a proliferative phase at 1 to 3 months, in which it undergoes revascularization and recellularization.15,21,32 It is during the proliferative phase that the graft is felt to be at its weakest; some studies have suggested that this process of revascularization may even take up to 1 year to complete.25 Finally, at approximately 3 to 6 months, the graft begins to undergo ligamentization, in which it is remodeled to have similar biomechanical strength and morphology of a normal cruciate ligament.4,31
It is unclear what effect the healing process would have on an autograft that had previously demonstrated tendinopathy and vice versa. Certainly, it is possible that the effects of tendinopathy are mitigated by the actual healing response of the graft, which would diminish the effect of tendinopathy on long-term rupture rates. Unfortunately, we did not have data on the time to graft failure in our patients, so we could not determine whether patellar tendinopathy affected a specific period in the ligamentization process. What is certain is that there is a lack of data investigating the role of tendinopathy on graft healing in both humans and animal models.

This study is not without its limitations. First, the study was retrospective in design, which poses a risk of selection bias. Data on failure were gleaned from a retrospective chart review and clinical data from clinic visits; follow-up questionnaires and radiographic assessments were not utilized. Second, an a priori power analysis was not conducted for this study, which entails a theoretical risk of type II errors. Data on the expected rate of failure for patients with patellar tendinopathy is not well established. While our sample size was smaller than in previous studies using the Norwegian27 or Scandinavian13 registries, with 12,643 and 45,998 patients, respectively, these large registry studies were not specifically conducted to evaluate the role of patellar tendinopathy as a risk factor for graft failure. While an insufficient sample size could affect nonsignificant findings, ours is the first study to report on such a topic and provides an estimate for more highly powered studies in the future.

Third, it was observed in this study that patellar tendinopathy may be a challenge to grade, even for fellowship-trained musculoskeletal radiologists. We attempted to control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. We attempted to set the grading control for this factor by excluding patients in whom agreement-trained musculoskeletal radiologists. What is more, the development of a more reliable and reproducible classification system may be of benefit. Fourth, the present study did not control for the many other possible causes of graft failure. Therefore, it might be argued that graft failure was not only explained by the presence of patellar tendinopathy but also related to other factors. As such, future studies in the form of prospective comparative analyses with even larger patient cohorts are warranted to help examine the role of patellar tendinopathy in graft failure after ACL reconstruction using a BPTB autograft.

Despite these limitations, we feel that this study has merit. Importantly, it is the first to observe that patellar tendinopathy may affect the outcomes of primary ACL reconstruction when using a BPTB autograft. This has clinical relevance, as obvious patellar tendinopathy changes (moderate or severe) can be readily identified on all preoperative MRI scans and can be used to influence decision making in terms of graft selection. Given the potentially devastating impact of revision ACL surgery, this is an important prognostic factor to consider.

CONCLUSION

Moderate or severe patellar tendinopathy has a significant association with an increased risk of graft failure when using a BPTB autograft for primary ACL reconstruction. Therefore, we recommend that an alternative graft (hamstring tendon, contralateral patellar tendon, quadriceps tendon, etc) be considered for cases of moderate or severe patellar tendinopathy. Future studies with larger sample sizes and prospective study designs are warranted to help examine the role of patellar tendinopathy in graft failure after ACL reconstruction using a BPTB autograft.

REFERENCES

1. Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in National Collegiate Athletic Association basketball and soccer: a 13-year review. Am J Sports Med. 2005;33(4):524-530.
2. Alentorn-Geli E, Gotchea D, Steinbacher G, et al. The presence of patellar tendinopathy in the bone-patellar tendon-bone autograft may increase the risk of anterior cruciate ligament graft failure [published online August 23, 2018]. Knee Surg Sports Traumatol Arthrosoc. doi: 10.1007/s00167-018-5066-4
3. Allen CR, Giffin JR, Harner CD. Revision anterior cruciate ligament reconstruction. Orthop Clin North Am. 2003;34(1):79-98.
4. Amiel D, Klein JB, Roux RD, Harwood FL, Akeson WH. The phenomenon of “ligamentization”: anterior cruciate ligament reconstruction with autogenous patellar tendon. J Orthop Res. 1986;4(2):162-172.
5. Andermord D, Bjornsson H, Petzold M, et al. Surgical predictors of early revision surgery after anterior cruciate ligament reconstruction: results from the Swedish National Knee Ligament Register on 13,102 patients. Am J Sports Med. 2014;42(7):1574-1582.
6. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. Am J Sports Med. 1995;23(6):694-701.
7. Arnoczky SP, Tarvin GB, Marshall JL. Anterior cruciate ligament replacement using patellar tendon: an evaluation of graft revascularization in the dog. J Bone Joint Surg Am. 1982;64(2):217-224.
8. Bosch U, Kaspersczyk WJ. Healing of the patellar tendon autograft after posterior cruciate ligament reconstruction: a process of ligamentation? An experimental study in a sheep model. Am J Sports Med. 1992;20(5):558-566.
9. Bottini CR, Smith EL, Shaha J, et al. Autograft versus allograft anterior cruciate ligament reconstruction: a prospective, randomized clinical study with a minimum 10-year follow-up. Am J Sports Med. 2015;43(10):2501-2509.
10. Chen JL, Allen CR, Stephens TE, et al. Differences in mechanisms of failure, intraoperative findings, and surgical characteristics between single- and multiple-revision ACL reconstructions: a MARS cohort study. Am J Sports Med. 2013;41(7):1571-1578.
11. Conte EJ, Hyatt AE, Gatt CJ, Dhawan A. Hamstring autograft size can be predicted and is a potential risk factor for anterior cruciate ligament reconstruction failure. Arthroscopy. 2014;30(7):882-890.
12. Ferrari JD, Bach BR Jr, Bush-Joseph CA, Wang T, Bojchuk J. Anterior cruciate ligament reconstruction in men and women: an outcome analysis comparing gender. Arthroscopy. 2001;17(6):588-596.
13. Gilfedter T, Foss OA, Engebretsen L, et al. Lower risk of revision with patellar tendon autografts compared with hamstring autografts: a registry study based on 45,998 primary ACL reconstructions in Scandinavia. Am J Sports Med. 2014;42(10):2319-2328.
14. Gwinn DE, Wilckens JH, McDevitt ER, Ross G, Kao TC. The relative importance of graft healing in both humans and animal models. The Orthopaedic Journal of Sports Medicine Patellar Tendinopathy and ACL Failure
15. Jackson DW, Grood ES, Goldstein JD, et al. A comparison of patellar tendon autograft and allograft used for anterior cruciate ligament replacement with autogenous patellar tendon. Am J Orthop Res. 1986;4(2):162-172.
16. Andernord D, Bjornsson H, Petzold M, et al. Surgical predictors of early revision surgery after anterior cruciate ligament reconstruction: results from the Swedish National Knee Ligament Register on 13,102 patients. Am J Sports Med. 2014;42(7):1574-1582.
17. Andermor D, Bjornsson H, Petzold M, et al. Surgical predictors of early revision surgery after anterior cruciate ligament reconstruction: results from the Swedish National Knee Ligament Register on 13,102 patients. Am J Sports Med. 2014;42(7):1574-1582.
18. Chen JL, Allen CR, Stephens TE, et al. Differences in mechanisms of failure, intraoperative findings, and surgical characteristics between single- and multiple-revision ACL reconstructions: a MARS cohort study. Am J Sports Med. 2013;41(7):1571-1578.
19. Conte EJ, Hyatt AE, Gatt CJ, Dhawan A. Hamstring autograft size can be predicted and is a potential risk factor for anterior cruciate ligament reconstruction failure. Arthroscopy. 2014;30(7):882-890.
20. Ferrari JD, Bach BR Jr, Bush-Joseph CA, Wang T, Bojchuk J. Anterior cruciate ligament reconstruction in men and women: an outcome analysis comparing gender. Arthroscopy. 2001;17(6):588-596.
21. Gilfedter T, Foss OA, Engebretsen L, et al. Lower risk of revision with patellar tendon autografts compared with hamstring autografts: a registry study based on 45,998 primary ACL reconstructions in Scandinavia. Am J Sports Med. 2014;42(10):2319-2328.
22. Gwinn DE, Wilckens JH, McDevitt ER, Ross G, Kao TC. The relative importance of graft healing in both humans and animal models. The Orthopaedic Journal of Sports Medicine Patellar Tendinopathy and ACL Failure
23. Jackson DW, Grood ES, Goldstein JD, et al. A comparison of patellar tendon autograft and allograft used for anterior cruciate ligament replacement with autogenous patellar tendon. Am J Orthop Res. 1986;4(2):162-172.
reconstruction in the goat model. Am J Sports Med. 1993;21(2):176-185.
16. Johnson DP, Wakeley CJ, Watt I. Magnetic resonance imaging of patellar tendinitis. J Bone Joint Surg Br. 1996;78(3):452-457.
17. 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(1):73-81.
18. Kaeding CC, Pedroza AD, Reinke EK, Huston LJ, Consortium M. Spindler KP. Risk factors and predictors of subsequent ACL injury in either knee after ACL reconstruction: prospective analysis of 2488 primary ACL reconstructions from the MOON cohort. Am J Sports Med. 2015;43(7):1583-1590.
19. Kleiner JB, Amiel D, Roux RD, Akeson WH. Origin of replacement cells for the anterior cruciate ligament autograft. J Orthop Res. 1986;4(4):466-474.
20. Kraeutler MJ, Bravman JT, McCarty EC. Bone-patellar tendon-bone autograft versus allograft in outcomes of anterior cruciate ligament reconstruction: a meta-analysis of 5182 patients. Am J Sports Med. 2013;41(10):2439-2448.
21. Krych AJ, Jackson JD, Hoskin TL, Dahm DL. A meta-analysis of patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction. Arthroscopy. 2008;24(3):292-298.
22. 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(4):526-531.
23. McQueen F, Beckley V, Crabbe J, Robinson E, Yeoman S, Stewart N. Magnetic resonance imaging evidence of tendinopathy in early rheumatoid arthritis predicts tendon rupture at six years. Arthritis Rheum. 2005;52(3):744-751.
24. Morgan JA, Dahm D, Levy B, Stuart MJ, Group MS. Femoral tunnel malposition in ACL revision reconstruction. J Knee Surg. 2012;25(5):361-368.
25. Ntoulia A, Papadopoulou F, Ristanis S, Argyropoulou M, Georgoulis AD. Revascularization process of the bone–patellar tendon–bone autograft evaluated by contrast-enhanced magnetic resonance imaging 6 and 12 months after anterior cruciate ligament reconstruction. Am J Sports Med. 2011;39(7):1478-1486.
26. Parkinson B, Robb C, Thomas M, Thompson P, Spalding T. Factors that predict failure in anatomic single-bundle anterior cruciate ligament reconstruction. Am J Sports Med. 2017;45(7):1529-1536.
27. Persson A, Fjeldsgaard K, Gjertsen JE, et al. Increased risk of revision with hamstring tendon grafts compared with patellar tendon grafts after anterior cruciate ligament reconstruction: a study of 12,643 patients from the Norwegian Cruciate Ligament Registry, 2004-2012. Am J Sports Med. 2014;42(2):285-291.
28. Ponce BA, Cain EL Jr, Pfugner R, et al. Risk factors for revision anterior cruciate ligament reconstruction. J Knee Surg. 2016;29(4):329-336.
29. Rosenberg TD, Franklin JL, Baldwin GN, Nelson KA. Extensor mechanism function after patellar tendon graft harvest for anterior cruciate ligament reconstruction. Am J Sports Med. 1982;20(5):519-525.
30. Samitier G, Marcano AI, Alentorn-Geli E, Cugat R, Farmer KW, Moser MW. Failure of anterior cruciate ligament reconstruction. Arch Bone Jt Surg. 2015;3(4):220-240.
31. Scheffler SU, Schmidt T, Gangey I, Dustmann M, Unterhauser F, Weiler A. Fresh-frozen free-tendon allografts versus autografts in anterior cruciate ligament reconstruction: delayed remodeling and inferior mechanical function during long-term healing in sheep. Arthroscopy. 2008;24(4):448-458.
32. Scheffler SU, Unterhauser FN, Weiler A. Graft remodeling and ligationastization after cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosoc. 2008;16(9):834-842.
33. Schliaty ND, Bates NA, Sanders TL, Krych AJ, Stuart MJ, Hewett TE. Incidence of second anterior cruciate ligament tears (1990-2000) and associated factors in a specific geographic locale. Am J Sports Med. 2017;45(7):1567-1573.
34. Sharma P, Maffulli N. Tendon injury and tendinopathy: healing and repair. J Bone Joint Surg Am. 2005;87(1):187-202.
35. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE Jr. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring. Does it really matter? A systematic review. Am J Sports Med. 2004;32(8):1986-1995.
36. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. Am J Sports Med. 2016;44(11):2827-2832.
37. Wright RW, Gill CS, Chen L, et al. Outcome of revision anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am. 2012;94(8):531-536.
38. Yabroudi MA, Bjernsson H, Lynch AD, et al. Predictors of revision surgery after primary anterior cruciate ligament reconstruction. Orthop J Sports Med. 2016;4(9):2325967116666039.