

The Affect of Patient Sex and Graft Type on Postoperative Functional Outcomes After Primary ACL Reconstruction

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Background: Graft choice in anterior cruciate ligament reconstruction (ACL) and postoperative rehabilitation may affect strength recovery differently in men than women and therefore affect a timely and successful return to sport.

Purpose: To compare knee extensor and flexor strength between men and women who underwent isolated ACLR with either patellar tendon or hamstring tendon (HST) autografts.

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

Methods: A total of 166 patients (87 women, 79 men) with primary unilateral and uncomplicated ACLRs were recruited for participation. A total of 100 patients had bone–patellar tendon–bone (BPTB) autografts and 66 had HST autografts. At 6 months postoperatively, all patients completed the Tegner activity scale and International Knee Documentation Committee Subjective Knee Evaluation as well as underwent bilateral isokinetic (90 deg/s) tests of the knee extensor and flexor groups. Outcomes were recorded in a single session as part of a return-to-sport test battery. Surgical notes were obtained to determine the type of autograft and nerve block used at the time of ACLR.

Results: There was a significant sex × graft type interaction for mass-normalized knee flexor torque ($P = .017$). Female patients with an HST graft had a significantly lower knee flexor torque compared with female patients with a BPTB graft (0.592 ± 0.49 N·m/kg vs 0.910 ± 0.24 N·m/kg; Cohen d [95% CI] = 0.91 [0.45, 1.36]). They also had a significantly lower knee flexor torque when compared with male patients with an HST graft (0.592 ± 0.49 N·m/kg vs 0.937 ± 0.35 N·m/kg; Cohen d [95% CI] = 0.88 [0.45, 1.31]). There were significant main effects for graft type with knee flexion ($P = .001$) and extension ($P = .008$) symmetry. Patients with a BPTB graft demonstrated lower knee extensor symmetry ($65.7\% \pm 17.0\%$) and greater knee flexor symmetry ($98.7\% \pm 18.0\%$) compared with patients with an HST graft (extension: $77.1\% \pm 32\%$, Cohen d [95% CI] = 0.47 [0.16, 0.79]; flexion: $82.9\% \pm 33.3\%$, Cohen d [95% CI] = 0.63 [0.31, 0.95]). We also observed a significant main effect for sex ($P = .028$) and graft type ($P = .048$) for mass-normalized knee extensor strength. Female participants and patients of either sex with BPTB grafts had lower knee extensor strength compared with male participants and patients with HST grafts, respectively.

Conclusion: At approximately 6 months after ACLR, female patients reconstructed with HST autografts demonstrated weaker HST strength compared with female patients with a BPTB autograft. There were no differences in HST strength between graft types in male patients. Female patients appear to be recovering HST strength differently than male patients when using an HST autograft. These findings may have implications in surgical planning, postoperative rehabilitation, and return-to-sport decision making.

Keywords: hamstring autograft; bone–patellar tendon–bone autograft; hamstring strength; return to sport

Over the past 40 years, adolescent and young adult sport participation has significantly increased. Since the enactment of Title IX, high school athletic participation rose from 3,960,932 students in 1972 to 7,980,886 students in 2018,³⁶ with a concurrent 25% increase in female college

athletic participation between 2005-2006 and 2015-2016 academic years.⁴⁷ This shift was predominantly driven by an 11-fold increase in female participation over this time period.³⁶ With the growing number of athletes, the number of sport-related injuries has also significantly increased. Anterior cruciate ligament (ACL) tears are one of the most common sport-related injuries, requiring up to 130,000 reconstructive procedures annually in the United States.²⁹ The most commonly reported risk factors for ACL injuries

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are young age, female sex, and participation in sports that require cutting and pivoting.^{2,14,18,22,34,40,55} ACL injuries are approximately 3 to 6 times more common in female participants compared with their male counterparts who participate in similar levels of activity.^{2,16,20,21,37,44} The cause of ACL injuries is multifactorial, including both intrinsic and extrinsic risk factors. Certain anatomic variants such as narrow intracondylar notch,⁵⁷ generalized joint laxity,⁵⁸ and increased posterior tibial slope¹³ are more common in women and are thought to contribute to the higher rate of ACL injuries in them. These intrinsic factors, however, are not modifiable through nonoperative measures. Other biomechanical risk factors such as dynamic knee valgus, limited hip and knee flexion during landing,^{6,15,17,43} high quadriceps to hamstring tendon (HST) contraction ratios,^{3,6,9,19,33,34} and trunk sway during change of direction³ may help explain the discrepancy of ACL injuries in men and women. Neuromuscular training targeting these biomechanical factors through prevention programs has shown to effectively decrease the risk of ACL injury.^{35,54}

At the onset of ACL injury, reconstruction is typically recommended for young and active individuals, with the goal of restoring mechanical stability to return to prior levels of sport.³⁷ The most commonly used graft types for ACL reconstruction (ACLR) are bone–patellar tendon–bone (BPTB) autograft, HST autograft, and/or allograft. Literature^{20,21,27,28} supports the use of autograft in athletes, as the use of allograft has been shown to result in higher failure rates in patients returning to sport. Historically, BPTB has been considered the gold standard for ACLR because of its size, durability, and osseous integration³⁸; however, the HST graft has become more popular recently because of less donor site morbidity³² and now accounts for a little less than half of all of ACLRs in the United States.^{25,32,50} The HST graft has been shown to have increased laxity after reconstruction,¹² but there is very little difference between grafts when assessing long-term outcomes of patient satisfaction and function.^{32,45,48,49,50,53}

After ACLR, physical therapy assists in progressing through postoperative protocol, with the goal of returning the athlete to preinjury level of activity. The typical rehabilitation for isolated ACLR with autograft consists of 5 progressive phases.³⁰ During the latter phases of rehabilitation, an extensive battery of tests, including strength and functional assessments, is recommended to optimize

clinical decision making about the return-to-sport progression. To date, there is no single test or particular threshold that has been proven to accurately predict which individuals safely and effectively return to sport.^{56,59}

Even after extensive rehabilitation, merely 66% of athletes will return to their preinjury level of activity. Moreover, only about 55% are able to return to competitive level of sport.⁴ Those who do return to preinjury levels of sport are around 6 times more likely to have another ACL injury compared with athletes without history of ACL injuries.³⁹ Ardern et al⁵ performed a meta-analysis of patients who returned to sports after primary ACLR and found an increased risk of graft rupture in patients with weaker HST strength when compared with quadriceps strength. Furthermore, Markolf et al³¹ studied the effect of quadriceps and HST contraction on knee motion and found decreased varus and valgus laxity with increased quadriceps and HST strength. A quadriceps-dominant knee posture is thought to be a cause of the increased risk of ACL injury.⁶⁰ The low HST to quadriceps strength ratio in female patients may be the reason for the increased rates of reinjury in this population.^{52,60} With the large discrepancies between men and women, the effect of graft type on muscle strength should be investigated.

It is important to better understand the interplay between sex, graft choices, and muscle recovery to enhance postoperative rehabilitation and minimize the risk for secondary injury after return to physical activity or sport. Therefore, the purpose of this study was to compare knee extensor and flexor strength between male and female patients undergoing isolated ACLR with either patellar tendon or HST autografts.

METHODS

All participants were referred from a single academic orthopaedic clinic consisting of 5 board-certified, fellowship-trained, sports medicine subspecialist orthopaedic surgeons (D.R.D., S.F.B., M.D.M., F.W.G., B.C.W.) to perform a Lower Extremity Assessment Protocol between 5 and 7 months post-ACLR as part of return-to-play decision making. All the surgeons who referred patients for this study were accustomed to using either BPTB or HST grafts for ACLR. HST grafts were performed according to the technique described by Frank et al.¹⁰ All participants

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were given the same rehabilitation protocol to follow with the therapist of their choice. Participants were included if they had a primary, isolated ACLR. Participants were excluded if they had lower extremity joint surgery before the studied ACLR, multiple ligament reconstruction, history of graft failure, contralateral knee surgery, or history of lower extremity injury within the previous 6 months. Retrospective chart reviews of operative notes were obtained to determine the type of nerve block and graft used during ACLR and to screen for any concomitant procedures that would exclude the patients from the study. Neither meniscal repair nor debridement at the time of ACLR were an exclusion criterion.

Independent variables were sex (female, male) and graft type (BPTB, HST). Dependent variables were mass-normalized isokinetic knee extensor and flexor peak torque, knee extensor and flexor limb symmetry, and International Knee Documentation Committee (IKDC) Subjective Knee Evaluation.

Lower Extremity Assessment Protocol Procedures

Patient-Reported Outcomes

After enrollment, all participants completed the patient-reported outcomes, including the IKDC Subjective Knee Evaluation form, to assess the patient's perceived knee function. Physical activity was quantified through the Tegner activity scale.

Knee Extension and Flexion Strength

Isokinetic, concentric knee extension and flexion strength were measured bilaterally using a Biodex Systems IV dynamometer (Biodex Medical Systems Inc) at a speed of 90 deg/s. The testing was performed on the uninvolved limb, followed by testing on the involved limb. To become familiar with the test, the participants completed practice trials on each limb before formal testing. The participants provided maximal effort of knee extension and flexion through their full range of motion for 8 trials. Measures of peak torque for knee extension and flexion were exported from the multimode dynamometer (Biodex Systems IV; Biodex).

Data Processing

Involved Limb and Symmetry Calculations

All unilateral measures of peak torque were normalized to the body mass (N·m/kg) of the participant. Symmetry measures were calculated using the equation:

$$\text{Limb symmetry} = \frac{\text{Involved limb}}{\text{Uninvolved limb}}$$

Statistical Analyses

Shapiro-Wilk and Levene tests were used to assess the normality and homogeneity of the data. The chi-square test was used to compare the proportions of graft types between men and women. Separate 2 × 2 analysis of covariance (sex

× graft) was used to compare the subjective function and muscle strength between groups. The model covariates were nerve block type and the current self-reported activity level (Tegner rating) to account for potential differences in strength because of nerve block type or activity level. The magnitude of differences was interpreted through Cohen *d* (95% CI) effect sizes. All statistical analyses were performed using SPSS statistical software (Version 24; SPSS Inc). The alpha level for all analyses was set as $P < .05$.

RESULTS

The assumption of normality and homogeneity was not violated for any dependent variables of strength or subjective function (all $P > .05$), so parametric tests were used for analyses. There were a total of 166 ACLR patients included in this study, of which 87 were women and 79 were men; 100 (55 women, 45 men) had BPTB grafts and 66 (32 women, 34 men) had HST grafts. There was no difference in the frequency of graft type between male and female patients ($P = .43$). There were no significant differences in the subjective function between groups (BPTB: 81.0% ± 12.3%; HST: 80.4% ± 11.9%; $P = .77$). Regarding nerve blocks, 37 had only femoral nerve blocks, 43 had combined femoral and sciatic nerve blocks, 61 had combined saphenous and sciatic nerve blocks, and 25 had only saphenous nerve blocks. The mean current activity level for all participants was 6.0 ± 1.8. After adjusting for the type of nerve block and current self-reported activity level, there was a significant main effect for graft type ($F_{(1,149)} = 3.98$; $P = .048$; Cohen *d* [95% CI] = 0.36 [0.05, 0.67]) and sex ($F_{(1,149)} = 4.95$; $P = .028$; Cohen *d* [95% CI] = 0.34 [0.03, 0.64]). Patients with HST grafts exhibited significantly greater mass-normalized knee extensor peak torque (1.66 ± 0.77 N·m/kg) than patients with BPTB grafts (1.45 ± .42 N·m/kg). Further, male patients exhibited significantly greater mass-normalized knee extensor peak torque (1.67 ± 0.60 N·m/kg) than female patients (1.44 ± 0.75 N·m/kg). For knee extensor limb symmetry, there was a significant main effect for graft type ($F_{(1,149)} = 7.20$; $P = .008$; Cohen *d* [95% CI] = 0.47 [0.16, 0.79]), with patients with HST grafts (77.1% ± 32%) demonstrating greater quadriceps strength symmetry than patients with BPTB grafts (65.7% ± 17.0%).

There was also a significant sex × graft type interaction ($F_{(1,149)} = 5.82$; $P = .017$) for knee flexor peak torque (Figure 1). Female patients with an HST graft (0.592 ± 0.49 N·m/kg) had a significantly lower mass-normalized knee flexor peak torque than female patients with a BPTB graft (0.910 ± 0.24 N·m/kg; Cohen *d* [95% CI] = 0.91 [0.45, 1.36]) and a significantly lower mass-normalized knee flexor peak torque compared with male patients (0.937 ± 0.35 N·m/kg; Cohen *d* [95% CI] = 0.88 [0.45, 1.31]). There was no difference in knee flexor strength between male patients with BPTB and HST grafts. There were no significant sex × graft type interactions for knee extension torque. For knee flexor symmetry, there was a significant main effect for graft type ($F_{(1,149)} = 12.39$; $P = .001$; Cohen *d* [95% CI] = 0.63 [0.31, 0.95]), with patients with HST grafts (82.9% ± 33.3%) demonstrating significantly less

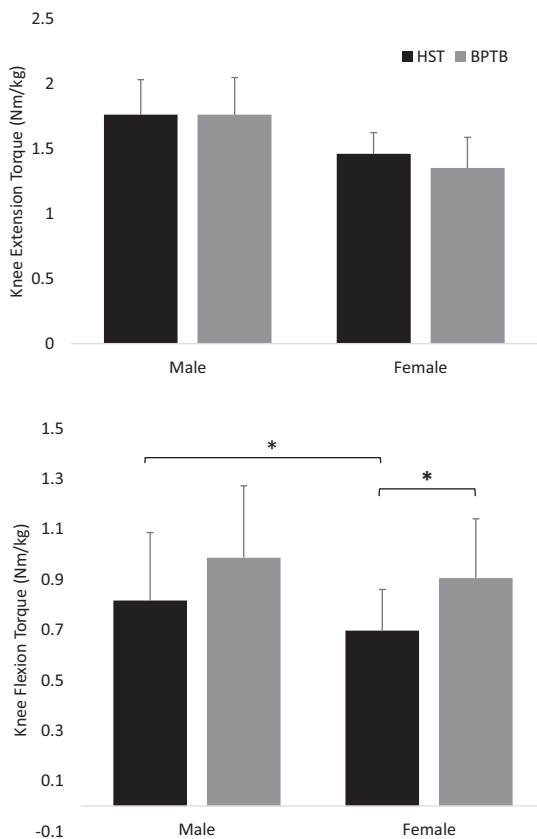


Figure 1. Mean (± 1 SD) normalized knee extension torque and knee flexion torque in men and women by graft type. Asterisk indicates statistically significant differences. BPTB, bone–patellar tendon–bone; HST, hamstring tendon.

knee flexor symmetry than patients with BPTB grafts ($98.7\% \pm 18.0\%$).

DISCUSSION

The primary findings of the study indicate that when adjusting for activity level and nerve block type, female patients with HST grafts recover HST strength differently than male patients with HST grafts and BPTB grafts and female patients with BPTB grafts. This pattern was not observed for knee extensor strength; however, the knee extensor strength and symmetry values indicate that the quadriceps are also weak and asymmetric after ACLR, which is consistent with published literature.^{5,22,42}

The highest risk for ACL graft failure is within the first 12 months after surgery.³⁹ While both HST and BPTB autografts have excellent long-term outcomes, studies^{20,28,45,50} have shown higher risk of failure for HST autografts in the young and active patient population. Maletis et al²⁸ reported a 2.26 times increased risk of failure in female patients with HST autograft compared with those with BPTB autograft. In our study, female patients who underwent ACLR with HST autograft demonstrated significantly weaker peak flexor torque compared with female patients

with BPTB autograft. This association was not seen in male patients, indicating that there is a sex-related difference in the short-term recovery of HST strength. This discrepancy is unlikely caused by quicker HST regeneration in men, as the literature does not show any sex-specific differences in HST regeneration rates.⁵¹ HSTs are a known agonist to the ACL, since they are the primary restraint to anterior tibial translation. Therefore, disproportionate HST weakness may accentuate the quadriceps to HST contraction ratio and predispose female patients with HST autograft to higher risk of injury during the early phases of return to sport.

Our study did find a 0.23 N·m/kg normalized extensor strength deficit between men and women undergoing HST grafts. This deficit is likely related to the underlying body composition. Owing to greater lower extremity muscle mass and larger cross-sectional areas of type IIA fibers, healthy men have been shown to have 1.2 to 1.3 times greater isokinetic strength at baseline compared with healthy women.²³ The noted strength deficit does suggest that graft choice can influence postoperative recovery, and further studies are needed to delineate the specific outcomes with regard to functional abilities and reinjury rates.

Most participants in our study showed significant weakness and asymmetry at 6 months compared with the uninvolved side. This was most pronounced for isokinetic knee extension strength in the BPTB group, but the average limb symmetry for the HST group was still below 80%. The average knee flexor symmetry in the BPTB group was comparable with the uninvolved side, but the HST group still had profound weakness. Our results are comparable with other studies that performed isokinetic evaluations at 6 months.¹ Strength and symmetry deficits have been shown to increase the risk of reinjury and can persist up to 2 years after surgery, despite clearance for full participation in sports.²²

In the current study, we chose to include nerve block type and physical activity level as statistical model covariates. Nerve blockades are frequently used to enhance postoperative pain control after ACLR, but their effect on postoperative strength recovery has been controversial. Femoral nerve blockade has been a popular choice, but recent studies^{7,24,26} have indicated that it can affect knee extensor and flexor strength as well as delay the eventual return to sports. Another factor that has been shown to influence postoperative strength recovery is the participants' activity level. More active individuals have been shown to have better functional and strength performance at baseline compared with nonathletes.²³ Given the range of current activity levels in this study (Tegner range, 2–10) and a moderate, significant relationship between the patient's current activity level and quadriceps and HST strength ($r = 0.40$; $P = .001$), the patient's current activity level was included as a covariate in all analyses.

Our findings are consistent with the results of Gobbi et al¹¹ who also reported a significant decrease of peak torque flexion between 5 months and 1 year after surgery in female patients but not male patients. To our knowledge, no other studies have differentiated between both graft and sex at 6 months after ACLR. The results from our study

would merit modifications of ACL rehabilitation protocol, with a greater focus on HST strengthening for female patients who undergo ACLR with HST autograft. Currently, there are no graft- and sex-specific ACL rehabilitation protocols in the literature, but similar recommendations have been brought forth by previous studies.^{8,41} Further studies are needed to better understand the clinical significance of our findings and the possible implications in ACL rehabilitation protocols.

Limitations to our study included lack of randomization between graft types, lack of neuromuscular evaluation such as electromyography, and lack of distinguishing between isolated gracilis HST graft and combined semitendinosus and gracilis tendon grafts. However, in practice, isolated gracilis tendon grafts are used infrequently. Gracilis preservation has been shown to affect HST strength; however, it remains unclear whether these findings are clinically significant.⁴⁶ Furthermore, all participants were recruited from a single orthopaedic institution and given similar postoperative protocols, but not all patients underwent identical rehabilitation programs, as patients attend multiple, widespread physical therapy clinics, complicating an evaluation of protocol adherence. Further prospective, randomized studies with identical rehabilitation are needed to better evaluate the true effect of sex and graft type on HST strength recovery.

CONCLUSION

At approximately 6 months after ACLR, female patients reconstructed with HST autografts demonstrated a weaker HST strength compared with female patients with BPTB autografts. There were no differences in HST strength between graft types in male patients. These findings may have implications in surgical planning, postoperative rehabilitation, and return-to-sport decision making.

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