

Comparison of Time Needed to Meet Common Rehabilitation Milestones After Anterior Cruciate Ligament Reconstruction According to Graft Type

Quinn Steiner,^{*†} MD, Brian E. Walczak,^{†‡} DO, PhD, Elizabeth Chumanov,[†] DPT, PhD, Kristin Haraldsdottir,[†] PhD, and Andrew M. Watson,[†] MD, MS

Investigation performed at the Departments of Orthopedics and Rehabilitation at the University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin, USA

Background: The use of bone–patellar tendon–bone (BPTB) and hamstring tendon (HT) autografts is common in anterior cruciate ligament reconstruction (ACLR). After ACLR, patients typically progress through specific rehabilitation milestones, and graft type may play a role in patient progression.

Purpose: To compare the time to meet rehabilitation milestones between BPTB and HT autografts after ACLR.

Design: Cohort study; Level of evidence, 3.

Methods: This was a single-institution study on patients who underwent ACLR with either BPTB or HT autograft between June 2018 and July 2021. The primary outcomes were time to meet return-to-sport criteria, including >90% limb symmetry index (LSI) for isokinetic quadriceps and hamstring strength, horizontal hop, 4-crossover hop, and single-hop height. The time to satisfaction of each criterion was compared between graft groups using Wilcoxon tests and Cox proportional hazards models.

Results: Included in the analysis were 410 participants who underwent ACLR with either BPTB (n = 232) or HT (n = 178). The BPTB group took longer to achieve >90% LSI for knee extension than HT (11.1 ± 4.1 vs 7.63 ± 2.8 months; *P* < .001). Similarly, the BPTB group took longer than the HT group to achieve >90% LSI for horizontal hop (11.4 ± 3.5 vs 9.82 ± 2.8 months; *P* < .001), 4-crossover hop (11.8 ± 3.6 vs 10.4 ± 2.8 months; *P* = .002), and single-hop height testing (11 ± 3.7 vs 8.81 ± 3.2 months; *P* < .001). The median time to achieve >90% LSI for hamstring strength was similar between groups (7.18 ± 3 vs 7.56 ± 3.1 months; *P* = .2).

Conclusion: Patients that underwent ACLR with BPTB autograft took longer than patients with HT to meet commonly used post-operative rehabilitation milestones. Clinicians should consider these differences when guiding patients regarding graft choice, postoperative expectations, and rehabilitation.

Keywords: ACLR; graft; return to sport; functional outcomes

Anterior cruciate ligament (ACL) injuries are common in athletes, with an incidence of 68.6 per 100,000 person-years, and these injuries often prevent them from returning to their prior activity level.²⁸ ACL reconstruction (ACLR) is the standard option for athletes that plan to return to sports.²⁷ However, the decision regarding graft type when performing ACLR is still heavily debated.^{15,16,33} Bone–patellar tendon–bone (BPTB) and hamstring tendon

(HT) autografts are the mostly commonly used graft types, although both grafts have complication risks.^{15,33} BPTB grafts are associated with anterior knee pain, damage to the knee extensor mechanism, and infrapatellar contracture.^{13,31} In contrast, HT grafts are associated with dysfunction of the hamstring muscle itself, as well as both tibial and femoral tunnel widening.^{2,4,7,19} Although these complication risks are considered during graft selection, guidelines on when to use specific graft types are still debated.

The expected time needed to safely return a patient to his or her previous level of activity (deemed “return to

The Orthopaedic Journal of Sports Medicine, 12(9), 23259671241274687
DOI: 10.1177/23259671241274687
© The Author(s) 2024

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (<https://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For article reuse guidelines, please visit SAGE’s website at <http://www.sagepub.com/journals-permissions>.

sports" [RTS]) is another key area of consideration when selecting graft type.⁶ After ACLR, patients typically follow specific strength and functional testing timelines and progress as they meet specific criteria. RTS criteria have been defined as a limb symmetry index (LSI) of 90% on all hop tests as well as on isokinetic strength testing,^{10,24,25} where LSI is defined as the value of the involved limb divided by the value of the uninvolved limb multiplied by 100 to obtain a percentage. However, these criteria continue to be an active area of research, and multiple variations of these guidelines have been established.^{6,23,29} Some evidence indicates that recovery time after ACLR is the strongest criterion associated with significant reduction in reinjury, where the lowest reinjury incidence occurs >9 months after ACLR.¹ An LSI of >90% for isokinetic strength testing of the quadriceps and hamstring and for functional testing (single-leg hop, triple hop, crossover hop) has also been suggested.^{11,26} Currently, most practices use some combination of the abovementioned criteria.¹⁶

Using these functional tests as a guide, patients typically improve dramatically during the first 6 months after ACLR, with the majority of improvements occurring within the first 9 months.^{3,8,9} Previous studies examining knee stability and patient-reported outcomes between graft types have not shown significant differences,^{11,31} although some small studies have demonstrated that HT grafts may lead to faster improvements in strength and functional testing.^{13,34} There is currently limited evidence regarding the impact of graft type on the timeline of improvement.

In this study, we aimed to assess the association between time to meet common rehabilitation milestones and ACLR with either BPTB or HT autograft.

METHODS

Cohort Selection

This study was deemed exempt from requiring institutional review board approval given that the data collection was part of the typical postoperative standard of care. The rights of the study patients were protected throughout the entire study. A registry of all ACL surgical procedures using either BPTB or HT at University of Wisconsin Health facilities was searched for patients who underwent ACLR between June 2018 and July 2021. We then identified patients who met >90% LSI for either strength testing, functional testing, or both, as well as those who had ≥6 months of follow-up for our analysis. Additional details

regarding specific participants were obtained through medical records as needed.

Functional Outcome Performance Measurements

Starting at 3 months after ACLR surgery, functional testing was initiated to help objectively guide physical therapy interventions and was repeated approximately every 2 months (typically at 3, 5, 7, 9, and 12 months). At these visits, functional outcome performance testing and quadriceps and hamstring strength measurement testing were performed until passing criteria were met.

Quadriceps and hamstring strength measurements were collected using an isokinetic dynamometer (Biodex Medical Systems) for both the involved and the uninvolved limbs. Prior to isokinetic testing, all patients performed an active warm-up on a stationary bicycle for 5 minutes. For all testing procedures, patients were allowed a graded warm-up before data collection to acclimatize to the effort on the isokinetic dynamometer, then the uninvolved limb was tested first, followed by the involved limb. Isokinetic testing was performed at 60 deg/s, with 5 trials completed. When a patient met ≥70% LSI of the quadriceps peak torque on isokinetic testing, he or she was allowed to advance to impact training in the home program. For most individuals, this occurred at the 5- and 7-month testing time points.

Force plate countermovement jumping was also used during the rehabilitation program to help with offloading and overloading compensations as the patient initiated impact. Once the patient had moved from double-leg to single-leg impact activities in the home program, single-limb impact testing (3 tests) was initiated. A graded warm-up was completed before each maximal impact test. A single-leg hop for height was recorded using force plates (AMTI). Height (in meters) was computed using the time-in-air method, $height = \frac{1}{2}gt^2$, where g is the gravitational constant (9.8 m/s²) and t is the time in the air (in seconds) measured from the force plate. The last 2 single-leg impact tests were the horizontal hop for distance and the 4-crossover hop. For the horizontal hop, patients were instructed to start on 1 foot and hop as far forward as possible, landing on the same leg and stabilizing for 2 seconds. The distance was measured from the start line (toe) to the heel of the landing leg. For the 4-crossover hop, the patient was asked to hop as far as possible on a single leg 4 consecutive times without losing balance, clearing a 4-inch (10-cm) tape on the floor for each hop. These tests were performed with both the uninvolved and the involved

*Address correspondence to Quinn Steiner, MD, University of Wisconsin School of Medicine, Department of Orthopedics and Rehabilitation, Division of Sports Medicine, 1685 Highland Avenue, Madison, WI 53705, USA (email: qsteiner@wisc.edu).

[†]Departments of Orthopedics and Rehabilitation at the University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin, USA.

[‡]Castle Orthopedics & Sports Medicine, Rush Copley Medical Center, Rush University Health, Advancing Translational Orthopedics & Medical Sciences (ATOMs) Laboratory, Chicago, Illinois, USA.

Final revision submitted February 14, 2024; accepted March 5, 2024.

One or more of the authors has declared the following potential conflict of interest or source of funding: B.E.W. has received hospitality payments from Smith + Nephew and Stryker. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was waived by University of Wisconsin Madison.

TABLE 1
Comparison of Demographic and Anthropometric Variables by Graft Type Among the Study Patients (N = 410)^a

Variable	HT Group (n = 178)	BPTB Group (n = 232)	P	ES ^b
Age, y	30.2 ± 12	22.5 ± 8.8	<.01	0.316
BMI	26 ± 4.9	25.2 ± 4	.16	0.069
Tibial length, cm	38.2 ± 12	37.2 ± 13	.35	0.046
Height, cm	172.7 ± 9.7	173.7 ± 9.9	.41	0.041
Weight, kg	77.6 ± 16.8	76.7 ± 16.3	.43	0.039
Leg length, cm	84.3 ± 22	82.8 ± 24	.48	0.035
Side, right	87 (49)	107 (46)	.58	0.055
Sex, female	95 (53)	120 (52)	.74	0.033

^aData are shown as mean ± SD or n (%). Boldface P value indicates statistically significant difference between groups (P < .05). BMI, body mass index; BPTB, bone–patellar tendon–bone; ES, effect size; HT, hamstring tendon.

^bES: <0.2 = small, 0.5 = moderate, >0.8 = large.

leg alternately until the test was correctly performed 3 times. An LSI was then computed.

Statistical Analysis

Data are presented as means ± SDs for continuous variables with a normal distribution and as medians with interquartile ranges for nonnormally distributed continuous variables. Categorical variables are presented as counts and percentages. Wilcoxon rank-sum tests and Wilcoxon effect sizes were used to compare differences between groups for continuous variables. The chi-square test and Cohen *h* effect size were used to compare differences between groups for categorical variables (effect sizes: <0.2 = small, 0.5 = moderate, and >0.8 = large).³² Time-to-event analyses using Cox proportional hazards models and Kaplan-Meier curves were used to compare the probability of achieving >90% LSI over time between groups for all functional outcomes and isokinetic quadriceps and hamstring strength at 60 deg/s. Statistical significance was set at P < .05.

RESULTS

A total of 609 patients were identified as having undergone ACLR. Within this cohort, 410 patients (232 in the BPTB group and 178 in the HT group), met >90% LSI for either strength testing, functional testing, or both and were included in this study. Significant differences were identified between the groups with respect to age, but not with respect to body mass index, weight, sex, leg length, height, or surgical side (Table 1).

Strength Testing

First, we examined the median time to achieve >90% LSI between groups. The BPTB group had a greater median time to achieve >90% LSI for isokinetic quadriceps strength testing compared with the HT group. There was no statistically significant group difference in the median time to achieve >90% LSI for isokinetic hamstring strength testing (Table 2). In our time-to-event comparison

between groups, the HT group had a greater probability of achieving >90% LSI at an earlier time point than the BPTB group with respect to quadriceps strength. Conversely, the BPTB group demonstrated a greater probability of achieving >90% LSI at an earlier time point with respect to hamstring strength testing (Figure 1, A and B).

Functional Testing

The BPTB group took longer than the HT group to achieve >90% LSI for all functional tests (single-hop height, horizontal hop, and 4-crossover hop) (Table 2; Figure 1, C-E).

DISCUSSION

Strength Testing

Our primary finding was patients in the BPTB group took nearly 4 months longer to achieve >90% LSI for quadriceps strength when compared with the HT group. This agrees with previous research. Hart et al¹² demonstrated angle-specific weakness in knee extension in patients with BPTB grafts when compared with those with HT grafts. Among studies with smaller sample sizes, Miles et al²¹ (n = 22) and Cristiani et al⁵ (n = 40) demonstrated reduced isokinetic quadriceps strength in patients with BPTB grafts compared with those with HT grafts. These results may be due to anterior knee pain after ACLR using BPTB grafts. Anterior knee pain may inhibit performance during functional and strength testing as well as a patient's ability to participate fully in rehabilitation exercises.²⁰ Given that the BPTB graft involves harvesting the middle one-third of the patellar tendon from the distal patellar pole to the tibial tubercle, this may compromise the extensor mechanism leading to residual quadriceps weakness.^{33,34} The BPTB group in the current study did demonstrate a greater probability of achieving >90% LSI at an earlier time point with respect to hamstring strength. However, there was no difference in the median time to meet >90% LSI in hamstring strength between groups when comparing those that ultimately met this criterion. This contrasts with previous literature, as Cristiani et al⁵

TABLE 2
Differences in Time to Achievement of 90% LSI With the Contralateral Limb by Graft Type^a

Variable	HT Group		BPTB Group		P	ES ^b
	n	Mean ± SD	n	Mean ± SD		
Quadriceps strength at 60 deg/s	106	7.63 ± 2.8	58	11.1 ± 4.1	<.001	0.435
Hamstring strength at 60 deg/s	124	7.56 ± 3.1	222	7.18 ± 3	.18	0.072
Single-hop height	96	8.81 ± 3.2	85	11 ± 3.7	<.001	0.366
Horizontal hop	78	9.82 ± 2.8	104	11.4 ± 3.5	<.001	0.273
4-crossover hop	63	10.4 ± 2.8	89	11.8 ± 3.6	.002	0.248

^aBoldface P values indicate statistically significant difference between groups ($P < .05$). BPTB, bone-patellar tendon-bone; ES, effect size; HT, hamstring tendon; LSI, limb symmetry index.

^bES: <0.2 = small, 0.5 = moderate, >0.8 = large.

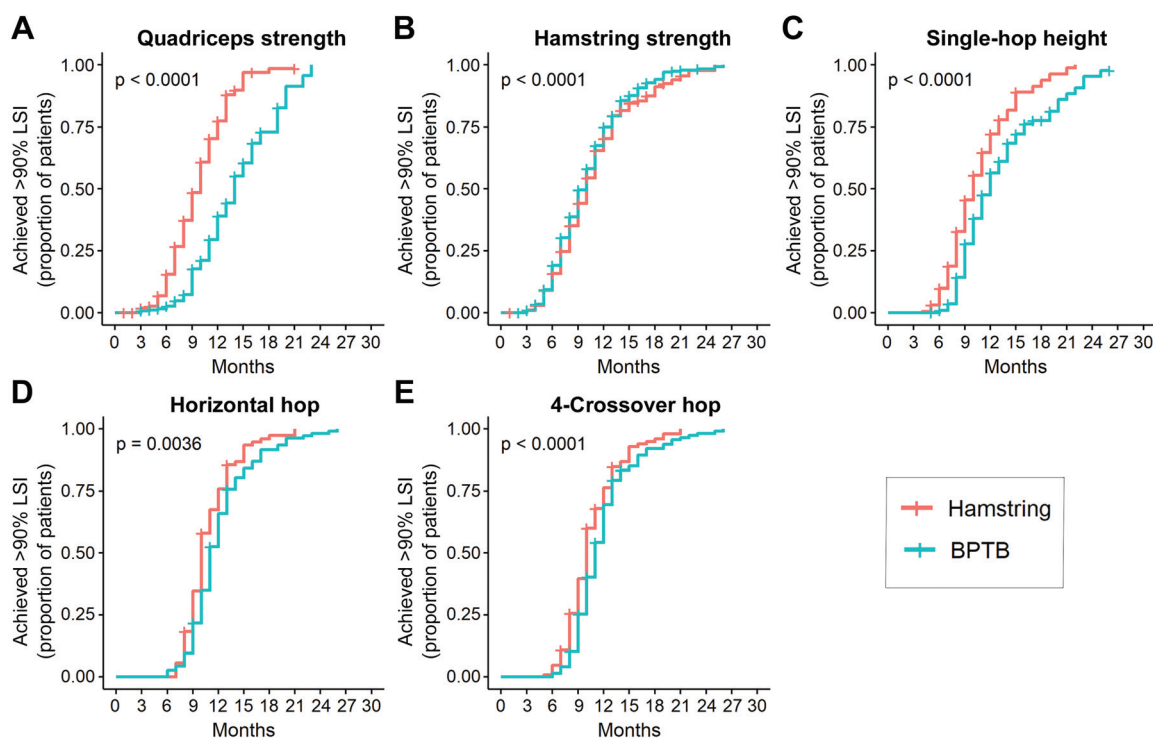


Figure 1. Results of Kaplan-Meier analyses demonstrating time to >90 LSI by graft type for (A) quadriceps strength at 60 deg/s, (B) hamstring strength at 60 deg/s, (C) single-hop height, (D) horizontal hop, and (E) 4-crossover hop. BPTB, bone-patellar tendon-bone; LSI, limb symmetry index.

demonstrated diminished hamstring strength in the HT group compared with the BPTB group, and Lesevic et al¹⁷ showed diminished hamstring strength with HT grafts in female patients only. These findings suggest that while time to recover quadriceps strength after ACLR is greater among patients with BPTB grafts, time to recover hamstring strength may be similar among patients with HT grafts.

Functional Testing

We found that on all 3 functional tests, the patients with HT grafts were more likely to meet >90% LSI at an earlier

time than patients with BTPB grafts. With respect to the mean time to meeting each criterion, the single-leg hop had the largest difference of 2.2 months followed by horizontal hop with 1.6 months and the 4-crossover hop with 1.4 months. Although there are limited studies comparing functional testing between graft types, Cristiani et al⁵ found the BTPB group had significantly lower LSI for single-leg hop at 4 months compared with HT. However, no differences were seen at other time points. Our findings as a whole corroborate a prior study by Smith et al,³⁰ who found that patients with BPTB grafts took longer than patients with HT grafts to meet RTS criteria including strength and functional testing. These discrepancies may be again due to

anterior knee pain, as mentioned above, as well as quadriceps weakness or an increased feeling of knee instability, which could impair functional testing after BPTB. These results reinforce the role of building quadriceps strength in patients early in the postoperative period after ACLR. Additional techniques such as blood flow restriction¹⁴ and neuromuscular electrical stimulation therapies²² have been shown to preserve lower extremity muscle mass. While the evidence is limited, these techniques may be considered as adjunctive options to build and maintain strength and limit potential issues with knee pain and instability that may delay strength and functional outcomes.

Patient Characteristics

Despite the BPTB group's being composed of a younger cohort, they were still slower to reach rehabilitation milestones. Considering the faster recovery of the HT group, HT grafts may be better suited for individuals with lower physical demands, as it may incur a quicker return to work and activity. Although quadriceps strength may lag behind in the BPTB group, this may be a good option for younger athletes due to a potentially stronger graft with a reduced risk of reinjury over the long term.¹⁸

Time to meeting strength and functional rehabilitation outcomes is an important part of decision-making for patients, particularly for those who are looking to return to high-impact activities. This information can aid clinicians as they strive to best educate patients regarding postoperative outcomes and timelines, maximize results during rehabilitation, and help athletes prepare for the demands of RTS.

Limitations

There are several limitations to this study. Most importantly, the groups were not formed randomly and variables that were related to both graft selection and the likelihood of achieving certain RTS criteria may have confounded the results. We also included all patients who underwent ACLR, which allowed a larger sample in the analysis but could potentially be a source of bias if additional variables such as concomitant injuries or recurrent ACL injury are related to both graft type and outcome. In addition, due to variations in patient follow-up, progressive testing was not always done at identical intervals among patients and a number of patients were lost to follow-up, sometimes before satisfying rehabilitation milestones. Our cohort was a combination of athletes and nonathletes with various motivation to meet RTS criteria, and preoperative conditioning was not standardized. The surgical procedures were also performed by multiple surgeons within our health system, who may have different criteria for graft selection.

CONCLUSION

Patients who underwent ACLR with BPTB autograft took longer than patients with HT autograft to meet commonly

used postoperative rehabilitation milestones. Clinicians should consider these differences when guiding patients regarding graft choice, postoperative expectations, and rehabilitation.

REFERENCES

1. Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy*. 2011;27(12):1697-1705. doi:10.1016/j.arthro.2011.09.009
2. Beard DJ, Anderson JL, Davies S, Price AJ, Dodd CAF. Hamstrings vs. patella tendon for anterior cruciate ligament reconstruction: a randomised controlled trial. *Knee*. 2001;8(1):45-50. doi:10.1016/S0968-0160(01)00062-X
3. Brinlee AW, Dickenson SB, Hunter-Giordano A, Snyder-Mackler L. ACL reconstruction rehabilitation: clinical data, biologic healing, and criterion-based milestones to inform a return-to-sport guideline. *Sports Health*. 2022;14(5):770-779. doi:10.1177/19417381211056873
4. Clatworthy MG, Annear P, Bulow JU, Bartlett RJ. Tunnel widening in anterior cruciate ligament reconstruction: a prospective evaluation of hamstring and patella tendon grafts. *Knee Surg Sports Traumatol Arthrosc*. 1999;7(3):138-145. doi:10.1007/s001670050138
5. Cristiani R, Mikkelsen C, Wange P, Olsson D, Stålmán A, Engström B. Autograft type affects muscle strength and hop performance after ACL reconstruction. A randomised controlled trial comparing patellar tendon and hamstring tendon autografts with standard or accelerated rehabilitation. *Knee Surg Sports Traumatol Arthrosc*. 2021;29(9):3025-3036. doi:10.1007/s00167-020-06334-5
6. Davies GJ, McCarty E, Provencher M, Manske RC. ACL return to sport guidelines and criteria. *Curr Rev Musculoskelet Med*. 2017;10(3):307-314. doi:10.1007/s12178-017-9420-9
7. DeFroda SF, Karamchedu NP, Owens BD, et al. Tibial tunnel widening following anterior cruciate ligament reconstruction: a retrospective seven-year study evaluating the effects of initial graft tensioning and graft selection. *Knee*. 2018;25(6):1107-1114. doi:10.1016/j.knee.2018.08.003
8. Flagg KY, Karavatas SG, Thompson S, Bennett C. Current criteria for return to play after anterior cruciate ligament reconstruction: an evidence-based literature review. *Ann Transl Med*. 2019;7(suppl 7):S252. doi:10.21037/atm.2019.08.23
9. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50(13):804-808. doi:10.1136/bjsports-2016-096031
10. Gustavsson A, Neeter C, Thomeé P, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2006;14(8):778-788. doi:10.1007/s00167-006-0045-6
11. Harris JD, Abrams GD, Bach BR, et al. Return to sport after ACL reconstruction. *Orthopedics*. 2014;37(2):e103-e108. doi:10.3928/01477447-20140124-10
12. Hart LM, Izri E, King E, Daniels KAJ. Angle-specific analysis of knee strength deficits after ACL reconstruction with patellar and hamstring tendon autografts. *Scand J Med Sci Sports*. 2022;32(12):1781-1790. doi:10.1111/sms.14229
13. Hui C, Salmon LJ, Kok A, Maeno S, Linklater J, Pinczewski LA. Fifteen-year outcome of endoscopic anterior cruciate ligament reconstruction with patellar tendon autograft for "isolated" anterior cruciate ligament tear. *Am J Sports Med*. 2011;39(1):89-98. doi:10.1177/0363546510379975
14. Jack RA, Lambert BS, Hedt CA, Delgado D, Goble H, McCulloch PC. Blood flow restriction therapy preserves lower extremity bone and muscle mass after ACL reconstruction. *Sports Health*. 2023;15(3):361-371. doi:10.1177/19417381221101006

15. Kautzner J, Kos P, Hanus M, Trc T, Havlas V. A comparison of ACL reconstruction using patellar tendon versus hamstring autograft in female patients: a prospective randomised study. *Int Orthop*. 2015;39(1):125-130. doi:10.1007/s00264-014-2495-7
16. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med*. 2016;50(15):946-951. doi:10.1136/bjsports-2015-095908
17. Lesevic M, Kew ME, Bodkin SG, et al. The effect of patient sex and graft type on postoperative functional outcomes after primary ACL reconstruction. *Orthop J Sports Med*. 2020;8(6):2325967120926052. doi:10.1177/2325967120926052
18. Lin KM, Boyle C, Marom N, Marx RG. Graft selection in anterior cruciate ligament reconstruction. *Sports Med Arthrosc Rev*. 2020;28(2):41-48. doi:10.1097/JSA.0000000000000265
19. Marder RA, Raskind JR, Carroll M. Prospective evaluation of arthroscopically assisted anterior cruciate ligament reconstruction. *Am J Sports Med*. 1991;19(5):478-484. doi:10.1177/036354659101900510
20. Marques FDS, Barbosa PHB, Alves PR, et al. Anterior knee pain after anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2020;8(10):2325967120961082. doi:10.1177/2325967120961082
21. Miles JJ, King E, Falvey EC, Daniels KAJ. Patellar and hamstring autografts are associated with different jump task loading asymmetries after ACL reconstruction. *Scand J Med Sci Sports*. 2019;29(8):1212-1222. doi:10.1111/sms.13441
22. Moran U, Gottlieb U, Gam A, Springer S. Functional electrical stimulation following anterior cruciate ligament reconstruction: a randomized controlled pilot study. *J Neuroeng Rehabil*. 2019;16(1):89. doi:10.1186/s12984-019-0566-0
23. Myer GD, Martin L, Ford KR, et al. No association of time from surgery with functional deficits in athletes after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2012;40(10):2256-2263. doi:10.1177/0363546512454656
24. Neeter C, Gustavsson A, Thomeé P, Augustsson J, Thomeé R, Karlsson J. Development of a strength test battery for evaluating leg muscle power after anterior cruciate ligament injury and reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2006;14(6):571-580. doi:10.1007/s00167-006-0040-y
25. Østerås H, Augestad LB, Tøndel S. Isokinetic muscle strength after anterior cruciate ligament reconstruction. *Scand J Med Sci Sports*. 1998;8(5):279-282. doi:10.1111/j.1600-0838.1998.tb00483.x
26. Petersen W, Taheri P, Forkel P, Zantop T. Return to play following ACL reconstruction: a systematic review about strength deficits. *Arch Orthop Trauma Surg*. 2014;134(10):1417-1428. doi:10.1007/s00402-014-1992-x28
27. Sanders JO, Brown GA, Murray J, Pezold R, Sevarino KS. Treatment of anterior cruciate ligament injuries. *J Am Acad Orthop Surg*. 2016;24(8):e81-e83. doi:10.5435/JAAOS-D-16-00154
28. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction. *Am J Sports Med*. 2016;44(6):1502-1507. doi:10.1177/0363546516629944
29. Schmitt LC, Paterno MV, Ford KR, Myer GD, Hewett TE. Strength asymmetry and landing mechanics at return to sport after anterior cruciate ligament reconstruction. *Med Sci Sports Exerc*. 2015;47(7):1426-1434. doi:10.1249/MSS.0000000000000560
30. Smith AH, Capin JJ, Zarzycki R, Snyder-Mackler L. Athletes with bone-patellar tendon-bone autograft for anterior cruciate ligament reconstruction were slower to meet rehabilitation milestones and return-to-sport criteria than athletes with hamstring tendon autograft or soft tissue allograft: secondary analysis from the ACL-SPORTS Trial. *J Orthop Sports Phys Ther*. 2020;50(5):259-266. doi:10.2519/jospt.2020.9111
31. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring. *Am J Sports Med*. 2004;32(8):1986-1995. doi:10.1177/0363546504271211
32. Tomczak M, Tomczak E. The need to report effect size estimates revisited. An overview of some recommended measures of effect size. *Trends Sport Sci*. 2014;1(21):19-25.
33. Xie X, Liu X, Chen Z, Yu Y, Peng S, Li Q. A meta-analysis of bone-patellar tendon-bone autograft versus four-strand hamstring tendon autograft for anterior cruciate ligament reconstruction. *Knee*. 2015;22(2):100-110. doi:10.1016/j.knee.2014.11.014
34. Yasuda K, Ohkoshi Y, Tanabe Y, Kaneda K. Muscle weakness after anterior cruciate ligament reconstruction using patellar and quadriceps tendons. *Bull Hosp Jt Dis Orthop Inst*. 1991;51(2):175-185.