Regarding "No Difference in Complication Rates or Patient-Reported Outcomes Between Bone–Patellar Tendon–Bone and Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction"

I read with great interest the article entitled "No Difference in Complication Rates or Patient-Reported Outcomes Between Bone–Patella Tendon–Bone and Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction" by Hogan et al.,[1] The authors should be commended on publishing among the first studies to directly compare clinical outcomes following anterior cruciate ligament reconstruction (ACLR) using all-soft tissue quadriceps tendon (ASTQT) and bone–patellar tendon–bone (BPTB) autograft, long considered the gold standard and benchmark to which other grafts are compared.[2-5] Despite an increase in the popularity and use of quadriceps tendon (QT) autograft over the past decade,[6] the QT autograft is the least studied among autograft choices for ACLR. The ACL Study Group recently published the findings of their biannual survey of Study Group members, finding an increased use in QT autograft since 2014 and a peak in 2018.[6] By comparison, survey data from the 2010 American Academy of Orthopaedic Surgeons Annual Meeting found that only 1% of surgeons were using QT autograft at that time.[7]

The QT autograft, specifically the ASTQT, has had a renaissance in part due to newer technology, including improved instrumentation for graft harvest[8-10] and suspensory fixation devices.[11,12] These technological advancements have allowed for improved efficiency of ACLR including graft harvest, preparation, and fixation.[8-10] In addition, the authors cited several advantages to the ASTQT compared with BPTB autograft, including a lower incidence of kneeling pain, patella fracture, and numbness related to injury of the infrapatellar branch of the saphenous nerve that often occurs during BPTB harvest.

While concerns about prolonged postoperative quadriceps weakness exist following QT autograft, a recent meta-analysis specifically examining this topic demonstrated no difference in quadriceps strength or time to recovery of quadriceps strength when comparing QT and BPTB autograft.[13] Another study directly comparing QT and BPTB autografts found that the patients who received QT autograft required less pain medication postoperatively,[14] a finding that is not unexpected, given the lack of bone harvest with an ASTQT autograft and consistent with my clinical experience using both of these autograft types. From a biomechanical standpoint, the QT has 20% more collagen fibrils per cross-sectional area than the patellar tendon, an ultimate load to failure that is 70% greater than a similar width patellar tendon graft, and a modulus of elasticity more similar to the native ACL than either BPTB or hamstring graft.[15] Nonetheless, QT remains less commonly used than either hamstring or BTPB autograft.[6]

Interestingly, despite all these positive attributes of the ASTQT, the most recent ACL Study Group survey found a decline in the use of QT between its peak in 2018 in its most recent survey in 2020. The reasons for this observed decrease were not discussed but may have been due, in part, to a Danish registry study that demonstrated a higher revision rate following QT autograft compared with hamstring and BPTB autografts.[16] However, a subsequent study from the same registry found higher revision rates for QT autograft only at sites performing a low volume of ACLR with this graft (<100 from 2012 to 2019), suggesting that learning curve played a role in the inferior outcomes observed in the first study.[17]

As ASTQT appears to have less donor-site morbidity compared with BPTB, favorable biomechanical characteristics, decreased opioid consumption postoperatively, and from the currently available evidence, similar clinical outcomes including objective functional measures,[18-22] patient-reported outcomes,[18,20,21,23] and graft failure rates,[21,22,24] it remains unclear why this graft has not gained more widespread adoption. Current technologies for graft harvest and fixation are user-friendly and allow for a relatively short learning curve.[8-10] So why have we all not made the switch to the ASTQT autograft? Is now the time to make the switch?

In this single-surgeon study over a 9-year period, Hogan et al. reported a minimum of 1-year follow up on 39 patients who underwent primary ACLR with ASTQT autograft and 80 who underwent primary ACLR with BPTB autograft. There was selection bias, as "contact athletes" preferably received BPTB autograft, whereas "young patients with high-athletic demand" preferably underwent ASTQT autograft. These 2 categories are unclear, seem to overlap with one another, and should

be clarified. Furthermore, 38 patients who underwent BPTB autograft had not yet met the 12-month minimum follow-up requirement at the time of data analysis and were excluded, whereas all patients in the ASTQT group met the 12-month minimum follow-up requirement. This suggests that the surgeon may have stopped performing ASTQT for a period of time, which warrants explanation, given the findings and conclusions of the study. While nonsignificant ($P = .06$), the BPTB group had a mean follow-up that was 6.1 months longer than the ASTQT autograft in a study that the authors acknowledged was not adequately powered, indicating that the BPTB group may have had more exposure risk for reinjury. As the authors stated, graft failure is one of the most important outcome measures to consider when comparing ACL graft choices. Few conclusions can be drawn regarding graft failure in this study due to a low number of failures (and a relatively low number of patients overall), although notably, there were early failures that underwent revision in both groups (4.3 months in ASTQT autograft and 2.3 months in BPTB autograft).

Throughout the discussion, the authors state that ASTQT autograft can produce reliable and similar results as compared with BPTB autograft reconstruction, performing comparably with BPTB in patient-reported outcome measures at "mid-term follow-up." With a minimum follow-up of 1 year in both groups and a mean follow-up of less than 2 years in the ASTQT group, this should be considered a short-term follow-up study rather than "mid-term." The authors correctly acknowledge that additional longer-term studies are necessary to identify whether these outcomes diminish over time. I would add that larger, adequately powered studies in the greatest-risk populations, such as young athletes returning to level 1 sports (multidirectional field sports that involve landing, pivoting, or change of direction),[25] will be critical to sufficiently support the notion that the ASTQT can produce similar outcomes and is a safe, reliable, and effective graft as compared with BPTB autograft.

Within their discussion, the authors thoroughly review the existing literature comparing QT with other autografts, with nearly all studies demonstrating no significant difference when comparing QT with BPTB in any clinical outcome measure.[18,20-23,26-31] However, in many of these previous studies, there was heterogeneity in graft fixation methods and whether a bone plug was harvested along with the QT autograft. As such, this is among the first study to directly compare ASTQT with BPTB autograft, and the authors should be commended for this.

Despite all this optimism, we should be cautious in adopting the ASTQT as a one-size-fits-all approach to ACL graft choice. When assessing outcomes following ACLR and comparing graft choices, data should be stratified according to the risk profile of the patients following their return to preinjury activity level. When ACLR is performed in older patients and in nonathletes, the risk of graft failure following appropriate rehabilitation and return to activities is substantially lower than that in high-risk groups including young patients (<18-25 years old) and in those returning to level 1 sports.[3,25,32,33] These factors are considered within the MOON Knee Group's ACL Autograft Retear Risk Calculator, a validated tool that I use to counsel each of my ACL-injured patients.[34] Multiple previous studies, including one from the MOON group, has made it clear that allograft is not an appropriate graft choice for young patients and for athletes who participate in level 1 sports due to a 3-fold risk of failure compared with autograft.[3,35] Autograft literature also continues to evolve. Despite several large meta-analyses that have reported equivalent or near-equivalent clinical outcomes including graft failure rates when comparing hamstring and BPTB autograft,[34,36-39] recent data suggest that BPTB is preferable to hamstring autograft in young athletes. The devil is in the details: Most previous studies comparing hamstring and BPTB autograft that have suggested equivalent outcomes have included allcomers regardless of risk profile and have failed to sufficiently stratify data according to age and activity level.[40] In a mid-term follow-up study that only included patients aged 14-22 years injured in sports, the MOON Knee Group reported a 2.1 times greater odds of ACL graft revision after ACLR with hamstring autograft compared to BPTB at minimum 6-year follow-up.[40] This cohort comprises the greatest-risk group undergoing ACLR and may also represent the group in which graft choice has the largest impact on failure rates following ACLR. While the findings of that study should not be extrapolated to other soft-tissue autografts, a head-to-head comparison of the ASTQT autograft and BPTB autograft in a similar high-risk population has yet to be published. Currently, BPTB autograft remains the most commonly used graft among high-level collegiate and professional athletes as well as among young recreational athletes in the United States.[40-42] It is possible that future studies will show that the ASTQT has equivalent clinical outcomes, including graft failure rates, successful return to sport at the preinjury level, and equivalent patient-reported outcomes as BPTB in these high-risk populations, but these important comparative data are not yet available.

The ASTQT autograft appears to have an increasing role in ACLR, but the specific populations in which it should be the preferred graft remain to be defined. Our choice of graft for each patient should not depend on surgeon preference or comfort level based on exposure during training. Instead, we must continue to evolve based on the best available evidence and provide the most suitable graft for each patient based their risk

profile and post-rehabilitation goals. Future comparative clinical outcomes studies will continue to guide us in selecting the appropriate graft for each patient, and we must remain open and critical in interpreting these studies and applying them to our practices.

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References

1. Hogan DW, Burch MB, Rund JM, et al. No difference in complication rates or patient-reported outcomes between bone-patella tendon-bone and quadriceps tendon autograft for anterior cruciate ligament reconstruction. *Arthrosc Sports Med Rehabil* 2022;4:e417-e424.
2. Carmichael JR, Cross MJ. Why bone—patella tendon—bone grafts should still be considered the gold standard for anterior cruciate ligament reconstruction. *Br J Sports Med* 2009;43:323-325.
3. 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;3:73-81.
4. Magnussen RA, Carey JL, Spindler KP. Does autograft choice determine intermediate-term outcome of ACL reconstruction? *Knee Surg Sports Traumatol Arthrosc* 2011;19:462-472.
5. 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;32:1986-1995.
6. Arnold MP, Calcei JG, Vogel N, et al. ACL Study Group survey reveals the evolution of anterior cruciate ligament reconstruction graft choice over the past three decades. *Knee Surg Sports Traumatol Arthrosc* 2021;29:3871-3876.
7. van Eck CF, Illingworth KD, Fu FH. Quadriceps tendon: The forgotten graft. *Arthroscopy* 2010;26:441-442. author reply 442-443.
8. Slone HS, Xerogeanes JW. Anterior cruciate ligament reconstruction with quadriceps tendon autograft: A minimally invasive harvest technique. *JBJS Essent Surg Tech* 2014;4:e16.
9. Sprowls GR, Robin BN. The quad link technique for an all-soft-tissue quadriceps graft in minimally invasive, all-inside anterior cruciate ligament reconstruction. *Arthrosc Tech* 2018;7:e845-e852.
10. Ollivier M, Cognault J, Pailhe R, Bayle-Iniguez X, Cavaignac E, Murgier J. Minimally invasive harvesting of the quadriceps tendon: Technical note. *Orthop Traumatol Surg Res* 2021;107:102819.
11. Slone HS, Romine SE, Premkumar A, Xerogeanes JW. Quadriceps tendon autograft for anterior cruciate ligament reconstruction: A comprehensive review of current literature and systematic review of clinical results. *Arthroscopy* 2015;31:541-554.
12. Sheean AJ, Musahl V, Slone HS, et al. Quadriceps tendon autograft for arthroscopic knee ligament reconstruction: Use it now, use it often. *Br J Sports Med* 2018;52:698-701.
13. Johnston PT, McClelland JA, Feller JA, Webster KE. Knee muscle strength after quadriceps tendon autograft anterior cruciate ligament reconstruction: Systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc* 2021;29:2918-2933.
14. Joseph M, Fulkerson J, Nissen C, Sheehan TJ. Short-term recovery after anterior cruciate ligament reconstruction: A prospective comparison of three autografts. *Orthopedics* 2006;29:243-248.
15. Xerogeanes JW. Quadriceps tendon graft for anterior cruciate ligament reconstruction: The graft of the future. *Arthroscopy* 2019;35:696-697.
16. Lind M, Strauss MJ, Nielsen T, Engebretsen L. Quadriceps tendon autograft for anterior cruciate ligament reconstruction is associated with high revision rates: Results from the Danish Knee Ligament Registry. *Knee Surg Sports Traumatol Arthrosc* 2020;28:2163-2169.
17. Lind M, Strauss MJ, Nielsen T, Engebretsen L. Low surgical routine increases revision rates after quadriceps tendon autograft for anterior cruciate ligament reconstruction: Results from the Danish Knee Ligament Reconstruction Registry. *Knee Surg Sports Traumatol Arthrosc* 2021;29:1880-1886.
18. Kim SJ, Kumar P, Oh KS. Anterior cruciate ligament reconstruction: Autogenous quadriceps tendon-bone compared with bone-patellar tendon-bone grafts at 2-year follow-up. *Arthroscopy* 2009;25:137-144.
19. Renstrom PA. Eight clinical conundrums relating to anterior cruciate ligament (ACL) injury in sport: Recent evidence and a personal reflection. *Br J Sports Med* 2013;47:367-372.
20. Lund B, Nielsen T, Fauno P, Christiansen SE, Lind M. Is quadriceps tendon a better graft choice than patellar tendon? A prospective randomized study. *Arthroscopy* 2014;30:593-598.
21. Cavaignac E, Coulin B, Tscholl P, Nik Mohd Fatmy N, Duthon V, Menetrey J. Is quadriceps tendon autograft a better choice than hamstring autograft for anterior cruciate ligament reconstruction? A comparative study with a mean follow-up of 3.6 years. *Am J Sports Med* 2017;45:1326-1332.
22. Hurley ET, Calvo-Gurry M, Withers D, Farrington SK, Moran R, Moran CJ. Quadriceps tendon autograft in anterior cruciate ligament reconstruction: A systematic review. *Arthroscopy* 2018;34:1690-1698.
23. Geib TM, Shelton WR, Phelps RA, Clark L. Anterior cruciate ligament reconstruction using quadriceps tendon autograft: Intermediate-term outcome. *Arthroscopy* 2009;25:1408-1414.
24. Crum RJ, Kay J, Lesniak BP, Getgood A, Musahl V, de Sa D. Bone versus all soft tissue quadriceps tendon

autografts for anterior cruciate ligament reconstruction: A systematic review. *Arthroscopy* 2021;37:1040-1052.
25. King E, Richter C, Daniels KAJ, et al. Biomechanical but not strength or performance measures differentiate male athletes who experience ACL reinjury on return to level 1 Sports. *Am J Sports Med* 2021;49:918-927.
26. Gorschewsky O, Klakow A, Putz A, Mahn H, Neumann W. Clinical comparison of the autologous quadriceps tendon (BQT) and the autologous patella tendon (BPTB) for the reconstruction of the anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc* 2007;15:1284-1292.
27. Han HS, Seong SC, Lee S, Lee MC. Anterior cruciate ligament reconstruction: Quadriceps versus patellar autograft. *Clin Orthop Relat Res* 2008;466:198-204.
28. Lee S, Seong SC, Jo H, Park YK, Lee MC. Outcome of anterior cruciate ligament reconstruction using quadriceps tendon autograft. *Arthroscopy* 2004;20:795-802.
29. Runer A, Csapo R, Hepperger C, Herbort M, Hoser C, Fink C. Anterior cruciate ligament reconstructions with quadriceps tendon autograft result in lower graft rupture rates but similar patient-reported outcomes as compared with hamstring tendon autograft: A comparison of 875 patients. *Am J Sports Med* 2020;48:2195-2204.
30. Sofu H, Sahin V, Gursu S, Yildirim T, Issin A, Ordueri M. Use of quadriceps tendon versus hamstring tendon autograft for arthroscopic anterior cruciate ligament reconstruction: A comparative analysis of clinical results. *Eklem Hastalik Cerrahisi* 2013;24:139-143.
31. Fischer F, Fink C, Herbst E, et al. Higher hamstring-to-quadriceps isokinetic strength ratio during the first postoperative months in patients with quadriceps tendon compared to hamstring tendon graft following ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2018;26:418-425.
32. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med* 2016;44:2827-2832.
33. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: A systematic review and meta-analysis. *Am J Sports Med* 2016;44:1861-1876.
34. Tan SHS, Lau BPH, Krishna L. Outcomes of anterior cruciate ligament reconstruction in females using patellar-tendon-bone versus hamstring autografts: A systematic review and meta-analysis. *J Knee Surg* 2019;32:770-787.
35. Spindler KP, Parker RD, Andrish JT, et al. Prognosis and predictors of ACL reconstructions using the MOON cohort: A model for comparative effectiveness studies. *J Orthop Res* 2013;31:2-9.
36. Chen H, Liu H, Chen L. Patellar tendon versus 4-strand semitendinosus and gracilis autografts for anterior cruciate ligament reconstruction: A meta-analysis of randomized controlled trials with mid- to long-term follow-up. *Arthroscopy* 2020;36:2279-2291 e2278.
37. He X, Yang XG, Feng JT, et al. Clinical outcomes of the central third patellar tendon versus four-strand hamstring tendon autograft used for anterior cruciate ligament reconstruction: A systematic review and subgroup meta-analysis of randomized controlled trials. *Injury* 2020;51:1714-1725.
38. Zhao L, Lu M, Deng M, Xing J, He L, Wang C. Outcome of bone-patellar tendon-bone vs hamstring tendon autograft for anterior cruciate ligament reconstruction: A meta-analysis of randomized controlled trials with a 5-year minimum follow-up. *Medicine (Baltimore)* 2020;99:e23476.
39. Samuelsen BT, Webster KE, Johnson NR, Hewett TE, Krych AJ. Hamstring autograft versus patellar tendon autograft for ACL reconstruction: Is there a difference in graft failure rate? A meta-analysis of 47,613 patients. *Clin Orthop Relat Res* 2017;475:2459-2468.
40. MOON Knee Group, Spindler KP, Huston LJ, et al. Anterior cruciate ligament reconstruction in high school and college-aged athletes: Does Autograft choice influence anterior cruciate ligament revision rates? *Am J Sports Med* 2020;48:298-309.
41. Erickson BJ, Harris JD, Fillingham YA, et al. Anterior cruciate ligament reconstruction practice patterns by NFL and NCAA football team physicians. *Arthroscopy* 2014;30:731-738.
42. Farber J, Harris JD, Kolstad K, McCulloch PC. Treatment of anterior cruciate ligament injuries by major league soccer team physicians. *Orthop J Sports Med* 2014;2:2325967114559892.

Author Reply to "Regarding 'No Difference in Complication Rates or Patient-Reported Outcomes Between Bone-Patellar Tendon-Bone and Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction"'

We would like to thank Dr. Joseph Lamplot for his interest, appreciation, and critical review of our article. We agree with his expanded discussion, commentary, and cautious optimism that surrounds the use of all-soft tissue quadriceps autograft (ASTQT) for ACL reconstruction. We feel there are potential benefits of ASTQT in certain patient subsets but agree that we must resist the temptation for a one-size-fits-all approach. Additionally, we fully acknowledge the limitations of our study, namely selection bias for graft choice and relatively short follow-up duration.

We would be remiss if we did not acknowledge that there is always some innate surgeon bias in graft selection based on personal preferences, training biases, our interpretation of the literature, or other factors, particularly, in contact athletes or high-demand individuals. We also acknowledge that our selection criteria for each graft type could have been more