Original Article

Previous Knee Surgery, Anteromedial Portal Drilling, Quadriceps Tendon Autograft, and Meniscal Involvement Associated With Delayed Return to Sport After Anterior Cruciate Ligament Reconstruction in Amateur Athletes

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Purpose: To identify prognostic factors associated with a delayed return-to-sport (RTS) time in amateur athletes who return to full participation after a primary isolated anterior cruciate ligament (ACL) reconstruction. **Methods:** A retrospective review was performed among athletes who underwent ACL reconstruction between October 2014 and October 2021. Inclusion criteria were any amateur athletes with an ACL reconstruction who had a documented RTS and greater than 1-year follow-up. Nonathletes, those with multiligamentous knee injury, and those missing documented RTS timelines were excluded. RTS was defined as participation in athletics at a level equivalent to or greater than the preinjury level participation. Demographic and prognostic factors, including previous knee surgery, meniscal involvement, level of participation, surgical approach, and graft type, were recorded along with RTS time and analyzed via Poisson regression. **Results:** In total, 91 athletes, average age 18.8 (± 6.7) years, who underwent ACL reconstruction at a single institution from 2014 to 2021 were identified with an average follow-up time of 4.6 (± 2.5) years (range 1.1, 9.0). Meniscal involvement (1.11; 95% confidence interval [CI] 1.08-1.15, $P < .001$) and previous knee surgery (1.43; 95% CI 1.29-1.58; $P < .001$) were related to a delayed RTS. Quadriceps tendon and bone–patellar tendon–bone autografts, as well as allograft, showed a significant association with a longer RTS time when compared with hamstring autograft (1.16, 95% CI 1.13-1.20, $P < .001$; 1.04, 95% CI 1.01-1.07, $P = .020$; 1.11, 95% CI 1.03-1.19, $P = .004$, respectively), as did anteromedial portal drilling, when compared with the outside in approach for femoral drilling (1.19, 95% CI 1.16-1.23, $P < .001$). **Conclusions:** Previous knee surgery, anteromedial femoral drilling, quadriceps tendon autograft, and meniscus tear were most associated with a delayed timeline for RTS among young athletes who were able to return. **Level of Evidence:** Level IV, prognostic case series.

Anterior cruciate ligament (ACL) injury is one of the most commonly studied injuries in orthopaedics, with an annual incidence of 0.15% to 3.67% in athletes, or approximately 1 in 29 female and 1 in 50 male athletes.[1-6] After these injuries, athletes who undergo surgery have to balance minimizing secondary reinjury with confidence in their return to sport (RTS).[7] In general, RTS is characterized by full and unrestricted participation equal to the preinjury level of the sport; however, there is variation in the criteria used after ACL reconstruction.[8-10] Similarly, there is variability among the time to RTS, generally ranging from 9 to 12 months.[8,11]

Despite the range at which athletes return and the variability of criteria, RTS is critical, as it serves as one of the final benchmarks for athletes as a successful outcome after ACL reconstruction. Depending on the sport and level of participation, the RTS rate in athletes is between 48% and 87%.[12-14] Given the importance placed on RTS by athletes, factors affecting their ability and time to RTS are necessary to characterize as part of

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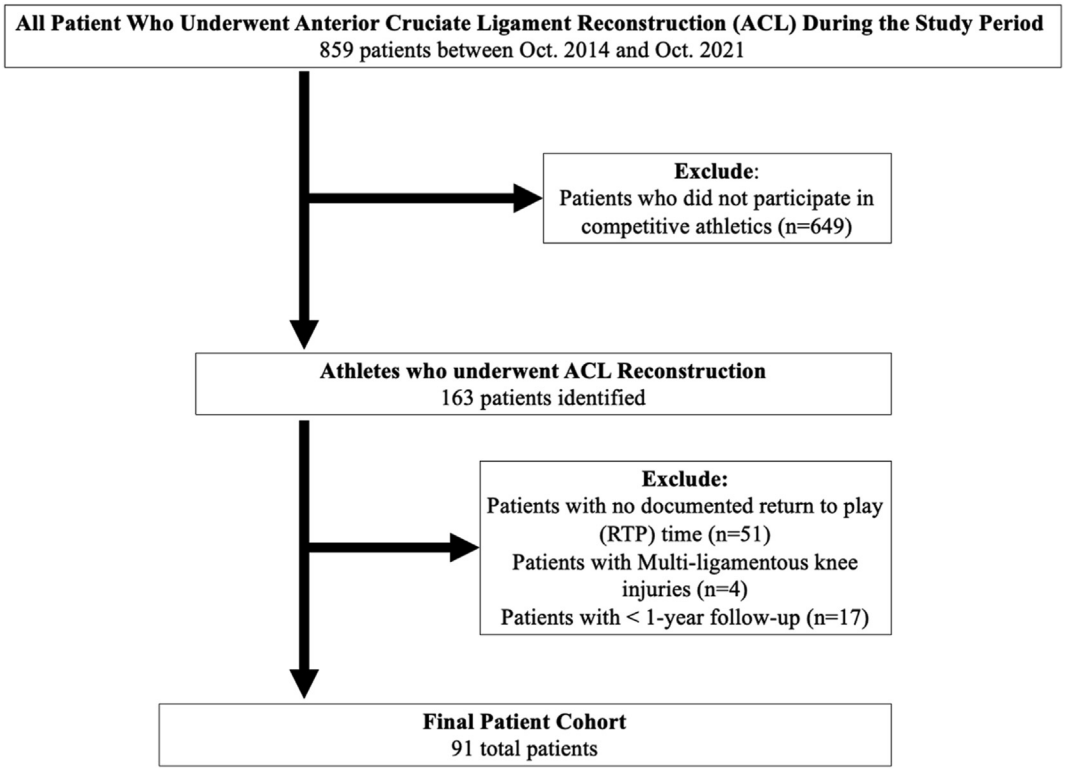

Fig 1. Patient cohort selection for patients with anterior cruciate ligament (ACL) reconstruction enrolled in this study consistent with the STROBE guidelines. (STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.)

the shared decision-making process for concerns such as graft choice, risk of reinjury, and athletic goals.

Although the preoperative, surgical, and postoperative management of ACL injuries has evolved, the characteristics factors that are associated with athletes' abilities to achieve a RTS have remained a topic of uncertainty.[15,16] Despite evidence showing that factors like physical therapy and type of sport affect both the ability and time to RTS, other variables such as surgical approach, graft type, or concomitant injuries are not well characterized in the current literature.[1,17-19] The purpose of this study was to identify prognostic factors associated with a delayed RTS time in amateur athletes who return to full participation after a primary isolated ACL reconstruction. It was hypothesized that meniscal involvement and previous knee surgery would predict a prolonged RTS time for amateur athletes, with no significant difference between graft choice or level of participation.

Methods

Study Design

After institutional review board approval, a retrospective review of consecutive prospectively collected data was conducted for patients who underwent primary ACL reconstruction at a single institution from October 2014 to October 2021. Inclusion criteria required that patients were amateur athletes in an organized sport who underwent primary ACL reconstruction with greater than 1-year follow-up and a documented RTS time. Patients were excluded if they had concomitant ligamentous injuries that would dictate their expected physical therapy progression, such as a multiligament knee injury. Patients also were excluded from the study if they did not have a documented RTS time, as characterization of only those patients with RTS times were the focus of this study (Fig 1). Given previous studies that focus on determining prognostic indicators for RTS times after knee and lower-extremity injuries via regression models, the goal sample size for this cohort was >90 patients.[20-22]

All operations were conducted at a single institution by 1 of 3 sports medicine fellowship-trained orthopaedic surgeons (N.A.T., B.R.W.) via arthroscopic ACL reconstruction. Indications for surgery were ACL insufficiency with a high-grade or full-thickness tear of the ACL. There were 2 approaches used in this study. Tunnels were drilled using either an outside-in drilling technique via retrograde reamers or independent anteromedial drilling for femoral socket.[23,24] ACL grafts included quadriceps autograft, bone–patellar tendon–bone (BPTB) autograft, hamstring autograft, or allograft.

Data collection was done via manual assembly (M.A.G., N.P., D.E.R., J.D.S.) from the electronic medical record collected with a minimum 1-year follow-up

postoperatively. This was in line with Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Fig 1).[25] Postoperative visits were standard at 2 weeks, 6 weeks, 3 months, and 6 months with a final clinic visit for RTS clearance. Demographic characteristics collected included race, gender, body mass index (BMI), and RTS time. Other data collected included sport, level of participation, previous knee injury, necessary ipsilateral revisions, meniscal involvement, and graft type.

Patients followed a standardized postoperative rehabilitation protocol (Appendix Fig 1, available at www.arthroscopyjournal.org), with minor variation in timing for meniscal involvement, and underwent RTS testing before being cleared for full activity via Functional Testing Protocol (Appendix Fig 2, available at www.arthroscopyjournal.org). Although there is some variation in the definition of RTS after ACL reconstruction in the literature, for this study, RTS was defined as the athlete's ability to participate in athletics at the level equivalent to or greater than the preinjury level.[8-10] This is consistent with the consensus statement on RTS by the World Congress in Sports Physical Therapy.[8] To test for RTS ability before participation, all patients were expected to reach a 90% limb symmetry value (or <10% deficit) criterion in the Functional Testing Protocol, such that the athlete may not meet minor subsets of the test within the 90% rule but may still be cleared based on the overall performance showing a deficit less than 10% (Appendix Fig 2). Once achieved, the athlete was cleared to RTS and upon completion or first day of full participation, whichever was documented first, was considered the athlete's RTS time.

Prognostic Factors

Factors to be analyzed for possible prognostic associations with RTS in patients included both those related to demographics and those related to ACL injury. Age in years, gender, BMI, presence of any previous ipsilateral knee surgery other than that of the ACL, and competition level (middle school, high school, college, or recreational athletes) were demographic prognostic factors. Potential prognostic factors relating to the injury included meniscal involvement (defined by radiographical or arthroscopic evidence of meniscal tear), operative technique, and ACL graft type. Other factors collected, but not analyzed for possible prognostic effects, included surgeon and race.

Statistical Analyses

Before analyses missing data were analyzed. Missing data prevalence was minimal, with a mechanism of missing at random (Appendix Fig 3, available at www.arthroscopyjournal.org). Complete case analyses were performed.

Table 1. Demographic Data for Patients (n = 91) in This Cohort

Variable, Average ± SE	Measure
Patients	N = 91
BMI	24.8 ± 0.55
Follow-up, yr	4.6 ± 0.20
Age, yr	18.8 ± 0.70
Return to play, mo	8.9 ± 0.28
Reported gender	n (%)
Male	52 (57)
Female	39 (43)
Reported race	n (%)
White	60 (66)
Black	20 (22)
Hispanic or Latino	7 (8)
Other	4 (4)
Surgeon	n (%)
1	52 (57)
2	25 (28)
3	14 (15)
Approach	n (%)
Outside-in	57 (63)
Anteromedial portal drilling	31 (34)
Unspecified	3 (3)
Graft type	n (%)
Hamstring autograft	48 (53)
Patellar tendon autograft	23 (25)
Quadriceps tendon autograft	17 (19)
Allograft	3 (3)
Level of participation	n (%)
Middle school	11 (12)
High school	49 (54)
Collegiate	14 (15)
Recreational	17 (19)

BMI, body mass index; SE, standard error.

Continuous variables were calculated and reported as mean ± standard deviation and count variables as count (%). Reinjury rates were calculated per 1,000 athlete exposure days. Reinjury prevalence with 95% confidence intervals (95% CIs) was calculated using the Clopper-Pearson method.

To assess potential prognostic factors for days to RTS, a series of Poisson regressions were performed for nominal prognostic factors. All analyses included an offset of days from injury to surgery. For continuous prognostic factors, log-transformed linear regressions were performed. Log-transformed regressions are interpreted as percent change. All potential prognostic factors were univariably assessed due to the potential for collider bias, and in alignment with recommendations by Altman and Lyman[26] for initial prognostic factor analyses. Although there is anecdotally wide variation in amateur sports season, ranging from 2 to 4 months, clinically significant delay to RTS was deemed to be approximately half the length of an amateur sports season, or >1.5 months delay. All analyses were performed in R Core Team (2021) (R: A language and environment for

Table 2. Estimate of the Percent Change in Return-to-Sport Times and 95% CIs for Variables Analyzed Via Poisson Regression

Variable	Estimate	95% CI	*P* Value
Gender (male)	0.99	0.96-1.01	.329
Previous knee surgery	1.43	1.29-1.58	**<.001**
Meniscus tear	1.11	1.08-1.15	**<.001**
Technique (anteromedial portal drilling)	1.19	1.16-1.23	**<.001**
Graft type (% change related to hamstring autograft)			
Quadriceps tendon	1.16	1.13-1.20	**<.001**
Bone−patella tendon −bone	1.02	1.00-1.06	**.020**
Allograft	1.11	1.03-1.19	**.004**
Competition level (% change in relation to high school)			
Middle school	1.05	1.01-1.09	**.002**
College	0.97	0.94-1.00	.489
Recreational	0.90	0.87-0.94	**<.001**
Continuous variables			
Age (% increase)	−0.10	−0.36 to 0.07	.189
BMI (% increase)	−0.08	−0.40 to 0.24	.620

NOTE. Reinjury rates were calculated per 1,000 athlete exposure days. Reinjury prevalence with 95% CIs was calculated using the Clopper Pearson method. Age in years. Bold *P* values denote significance of <.05.

BMI, body mass index; CI, confidence interval; RTS, return to sport.

Table 3. Demographic Data of Patients With Revision Required and Those With No Required Revision

Variable, Average ± SE	Revision Required (n = 16)	No Revision (n = 75)	*P* Value
Age, yr	16.3 ± 0.50	19.4 ± 0.83	**.002**
Gender, male/female	8/8	44/31	.585
BMI	23.9 ± 1.3	24.9 ± 0.60	.489
RTS time, mo	9.1 ± 0.65	8.9 ± 0.32	.755
Months to reinjury	20.8 ± 3.3	–	–
Months to revision	23.0 ± 3.7	–	–
Graft type	n (%)	n (%)	
Hamstring autograft	8 (50)	40 (53)	.102
Quadriceps autograft	3 (19)	14 (19)	
Bone−patellar tendon−bone autograft	5 (31)	18 (24)	
Allograft	0 (0)	3 (4)	
Drilling technique	n (%)	n (%)	
Outside-in	11 (69)	46 (61)	.064
Anteromedial portal drilling	5 (31)	26 (35)	
Unspecified	0 (0)	3 (4)	

NOTE. The Welch test was used to compare means and Fisher exact test or χ^2 tests were used for categorical data. Bold *P* values denote significance of <.05.

BMI, body mass index; RTS, return to sport; SE, standard error.

statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/). The *naniar* package was used for missing data analyses, the *dyplr* package for cleaning and coding, and the *glm* function for analyses.

Results

Demographics

Of the 91 patients in this cohort, the average age was 18.8 (± 0.70) years, with an average follow-up time of 4.6 (± 0.20, range 1.08-9.02) years (Table 1). Most athletes were at the high school level (54%) and underwent ACL reconstruction with a hamstring autograft (53%) via an all-inside approach (63%) at an average of 86 days to undergo surgery after their injury (Table 1). The BMI for this cohort was 24.8 (± 0.55). Postoperatively, a mean RTS time of 8.9 (± 2.8, range 5.22-16.7) months was identified.

Graft Type and Operative Approach

Relative to hamstring autografts, quadriceps tendon and BPTB autografts, as well as the use of an allograft, showed a significantly longer timeline for RTS (1.16, 95% CI 1.13-1.20, $P < .001$; 1.02, 95% CI 1.00-1.06, $P = .020$, 1.11, 95% CI 1.03-1.19, $P = .004$, respectively) (Table 2). Anteromedial portal drilling, when compared with the outside-in approach for femoral drilling, showed a significant increase in the RTS time by approximately 19% (1.5 months) (1.19, 95% CI 1.16-1.23, $P < .001$).

Competition Level

The level of competition was compared with the mode, high school athletes, as the standard for this prognostic factor. No significant difference was identified for college-level athletes (0.97, 95% CI 0.94-1.00, $P = .489$). However, recreational athletes returned sooner than high school athletes, with a 10% (about 26 days) reduction (0.90, 95% CI 0.87-0.94, $P < .001$) and middle school athletes returned slightly later (1.05, 95% CI 1.01-1.09, $P = .002$).

Other Prognostic Variables

Previous knee surgery was associated with delayed RTS at a 43% (about 3.8 months) increase in RTS time (1.43, 95% CI 1.29-1.58, $P < .001$). Male and female athletes showed no significant differences in the RTS timeline (0.99, 95% CI 0.96-1.01, $P = .329$). The presence of concomitant meniscal tears, irrespective of treatment, was associated with a delayed RTS (1.11, 95% CI 1.08-1.15, $P < .001$). Further, no significant association was identified between BMI or age and RTS.

Second Injury Epidemiologic Results

Of the 91 patients included in this study, 16 patients (17.6%) required a second ACL reconstruction as the result of ACL graft disruption (Table 3, Appendix Fig 4, available at www.arthroscopyjournal.org). The average age of those requiring a revision was 16.3 (± 2.0) years with a mean RTS time of 9.1 (± 2.6) months, in comparison with the nonrevision subgroup with an average age of 19.4 (± 0.83) years and a mean RTS of 8.9 (± 0.32) months ($P = .002$, $P = .755$, respectively) (Table 3).

Discussion

This study demonstrates that previous knee surgery and anteromedial portal drilling are most strongly associated with delayed RTS times after ACL reconstruction, with >1.5 months delay in athlete's return. Other factors that may contribute to a delayed RTS were meniscal involvement, quadriceps tendon, and BPTB autografts, as well as allograft for ACL reconstruction. There was no association between gender, age, or BMI and RTS for this cohort.

Consistent with the hypothesis, previous ipsilateral knee surgery was associated with a prolonged RTS time of almost 4 months, the longest delay for prognostic factors in this study. This finding is likely multifactorial, considering the wide range of factors that may impact the need for previous surgery. These include an increased proclivity for injury after the primary event, alterations in native biomechanics that increase the risk of future injury, such as pre-existing conditions like hypermobility syndromes, or psychological factors limiting current RTS progression.[27,28] Although not a clinically meaningful difference in the context of this study, amateur athletes with concomitant meniscal tears were delayed to return by approximately 1 month. This association is expected, particularly for those treated with partial menisectomy, who portend worse outcomes in terms of function and pain of the lateral aspect of the knee.[29,30]

The second factor most associated with a delayed RTS was anteromedial portal drilling, with over a month and a half delay compared with those who underwent an outside-in approach. This may be the result of intraoperative factors or individual variability in relative femoral tunnel position. Femoral tunnel placement and preparation are critical, and overall ACL function may be affected by the following: socket aperture, depth, and position (e.g., anatomic single bundle, anteromedial footprint, isometric position); graft bending angle; graft-tunnel interface for healing; performance of a notchplasty; and/or method of fixation. Although these variables were not specifically analyzed, any tunnel compromise during surgery may prolong RTS for the aforementioned reasons.[30-32] Although most surgeons in this study use independent anteromedial tunnels routinely for all graft types, there is still subtle variability among tunnel placement and technique across surgeons. Therefore, further research on the reconstruction approach with a more heterogeneous sample regarding graft choice for ACL reconstruction is necessary to analyze these subtleties and their associations with RTS.

Graft choice was another prognostic factor associated with a delayed RTS. Specifically, BPTB and quadriceps tendon autografts, along with allograft, correlated with delayed RTS in comparison with hamstring autograft. However, the average times delayed based upon graft choice in this cohort were not greater than 1.5 months. Still, these associations are an extension to current literature suggesting that patients who receive BPTB and quadriceps tendon autografts are slower to progress through rehabilitation milestones, despite comparable biomechanical properties to hamstring autograft.[33,34] Further analysis is required improve certainty on the impact that graft choice has on RTS time for patients after ACL reconstruction, especially given that the associations in this cohort did not appear to be clinically meaningful.

Although recreational athletes return sooner and middle school athletes return later than high school athletes in this cohort, the findings were not clinically significant. These associations may exist due to several factors, such as variation in rigorous physical demand within the seasons, the amount of training required to participate, or the variable number of events/games necessary to play. Further, collegiate athletes, although more developed than their high school counterparts, showed no significant difference in their RTS timeline. Collegiate athletes likely deal with the rigors of a greater level of play and elevated concern of reinjury that keep their RTS times consistent with those in high school athletics.[35]

Other factors that were not associated with delayed RTS included gender, BMI, and age. Previous research suggests that there are evidence-based differences in female and male landing mechanics, quadriceps-to-hamstring activation ratios, rotational malalignment, as well as aberrant muscle activation patterns during exercise at baseline and after ACL reconstruction.[36-40] Despite these biomechanical factors that may play a role in RTS, a delay was not identified for females in this study. Further research is necessary to determine whether gender differences should affect variations in rehabilitation and RTS testing between male and female athletes. Other factors have been associated with RTS not included in this study. Although much of the literature focuses on psychological readiness factors, such as self-reported symptoms and function, other factors include the ability to complete RTS testing or an elite level of competition.[41-44] Thus, acknowledging that there are factors not assessed in the current study helps to contextualize these results.

The prevalence of athletes from this cohort who required revision surgery was consistent with previously established revision rates of approximately 15% to 25%.[3,27] Those who underwent a revision did not RTS, on average, faster than those without a required revision. The injury mechanism was variable, ranging from intraseason injuries to chronic pain during activities of daily living. To combat reinjury rates, focus should be placed on objective measures for RTS rather than time-based protocols, especially considering a 51% decrease in the risk of injury for every month of delayed RTS that may otherwise be missed in a time-based rehabilitation plan.[45,46] Examples of objective measures include the RTS functional testing that was used in this study before clearance such that strength and function, measured by exercises such as single-leg press or Y-balance, compares the injury knee to the contralateral knee as a benchmark for recovery (Appendix Fig 2). This approach allows for athlete-specific rehabilitation and avoids the constraints of time-based RTS clearance. Further considerations include the use of functional bracing after ACL reconstructions. Functional bracing has been shown to reduce the rates of graft retear in the pediatric population, improve knee kinematics, protect the ACL graft during exercise, and may aid athletes in confidence to RTS.[46,47] However, some literature suggests that there is no significant difference in RTS times, pain, range of motion, or re-injury with bracing.[48,49] As such, athletes should be treated on an individualized basis, with functional bracing serving as an adjunct to objective rehabilitation and functional testing to RTS in the right athlete.

Limitations

There are some limitations with this study. First, for this cohort, greater than half of the average amateur sports season (about 1.5 months) was determined to be clinically significant. However, what delineates a clinically significant difference in RTS time and if this difference should be appropriately accounted for in rehabilitation and RTS protocols requires further research. Second, given the range of RTS times, some athletes may have followed return-to-play protocol early in their rehabilitation course yet returned to full participation on their own before full clearance. Despite this issue, a documented clearance for full participation was the most consistent and objective means of calculating an athlete's RTS time. Third, independent anteromedial tunnels were generally used for BPTB, whereas an all-inside approach was mainly used in quadriceps and hamstring tendon autografts. These are not mutually exclusive but follow the trend of surgeons' preference at the institution. Although this tendency may introduce a confounding variable in this study, each prognostic factor was analyzed independently to avoid collider bias. In addition, there is concern for the small sample size of patients who underwent an anteromedial portal drilling approach. Due to this concern, it may be difficult to make definitive statements about the results of the surgical approach's association with delayed RTS. Next, although missing data was minimal (Appendix Fig 3), it was present in this study, which may bias the results. Lastly, the sample size was based upon previous studies following regression models to predict return to play after lower-extremity injuries. As such, there were no a priori power analyses, so the study may be underpowered and at risk for a type II error.

Conclusions

Previous knee surgery, anteromedial femoral drilling, quadriceps tendon autograft, and meniscus tear were most associated with a delayed timeline for RTS among young athletes who were able to return.

Disclosures

The authors report the following potential conflicts of interest or sources of funding: B.R.W. reports publishing royalties from *Arthroscopy* and Elsevier; consulting fees from DePuy and FH Ortho; paid presenter for Arthrex and Vericel; stock or stock options from Kaliber AI, Sparta, and Vivorte; and other financial or material support from the Musculoskeletal Transplant Foundation and Smith & Nephew, outside the submitted work; board member of American Academy of Orthopaedic Surgeons, American Orthopaedic Society for Sports Medicine, American Shoulder and Elbow Surgeons, *Arthroscopy*, and AANA; and editorial or governing board for *Video Journal of Sports Medicine*. All other authors (M.A.G., J.D.S., N.P., D.E.R., G.S.B., N.A.T.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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