

Performance-Based Outcomes After Anterior Cruciate Ligament Reconstruction in Professional Athletes Differ Between Sports

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Background: Excellent outcomes have been reported for anterior cruciate ligament (ACL) reconstruction (ACLR) in professional athletes in a number of different sports. However, no study has directly compared these outcomes between sports.

Purpose: To determine if differences in performance-based outcomes exist after ACLR between professional athletes of each sport.

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

Methods: National Football League (NFL), National Basketball Association (NBA), National Hockey League (NHL), and Major League Baseball (MLB) athletes undergoing primary ACLR for an acute rupture were identified through an established protocol of injury reports and public archives. Sport-specific performance statistics were collected before and after surgery for each athlete. Return to play (RTP) was defined as a successful return to the active roster for at least 1 regular-season game after ACLR.

Results: Of 344 professional athletes who met the inclusion criteria, a total of 298 (86.6%) returned to play. NHL players had a significantly higher rate of RTP (95.8% vs 83.4%, respectively; $P = .04$) and a shorter recovery time (258 ± 110 days vs 367 ± 268 days, respectively; $P < .001$) than athletes in all the other sports. NFL athletes experienced significantly shorter careers postoperatively than players in all the other sports (2.1 vs 3.2 years, respectively; $P < .001$). All athletes played fewer games ($P \leq .02$) 1 season postoperatively, while those in the NFL had the lowest rate of active players 2 and 3 seasons postoperatively (60%; $P = .002$). NBA and NFL players showed decreased performance at season 1 after ACLR ($P \leq .001$). NFL players continued to have lower performance at seasons 2 and 3 ($P = .002$), while NBA players recovered to baseline performance.

Conclusion: The data indicate that NFL athletes fare the worst after ACLR with the lowest survival rate, shortest postoperative career length, and sustained decreases in performance. NHL athletes fare the best with the highest rates of RTP, highest survival rates, longest postoperative career lengths, and no significant changes in performance. The unique physical demand that each sport requires is likely one of the explanations for these differences in outcomes.

Keywords: anterior cruciate ligament; professional athletes; outcomes; ACL reconstruction; knee injury

Anterior cruciate ligament (ACL) ruptures are one of the most common sports-related musculoskeletal injuries.⁸ In physically active and athletic patients, management typically requires reconstructive surgery to return to baseline levels of activity.¹³ While ACL reconstruction (ACLR) has led to successful outcomes in the general population,^{5,23} clinical success in professional athletes is defined by more stringent outcome measures than postoperative questionnaires. This cohort represents a population with

a high risk of injuries and a greater demand for return from ACL injuries because of the requirements of their profession.² The integrity of the ACL is vital to planting, cutting, pivoting, and jumping,¹² all of which are movements essential to successful return to play (RTP). Thus, the repetitive and high-impact forces that an athlete places on the reconstructed ligament after surgery may affect a variety of performance outcomes in these patients.

Previously published literature has examined the epidemiology and outcomes after ACLR in professional athletes; however, these studies are limited in scope to individual sports and narrow postoperative measures.^{3,5,10} For example, the RTP rates in National Football League (NFL) and National Basketball Association (NBA) athletes have ranged from

63% to 79%^{6,26} and from 78% to 98%,^{5,15} respectively, depending on the study and criteria for return. Studies reporting outcomes from other sports including Major League Baseball (MLB)¹¹ and the National Hockey League (NHL)²⁷ have reported significant performance decreases in subpopulations compared with matched, uninjured controls. However, conclusions regarding the differences between sports have been outside the scope of these publications.

While multisport epidemiological data of ACL injuries have been reported in high school and collegiate athletes,^{18,19,23,24} there are limitations in the use of this information to predict future outcomes. To date, no study has compared the outcomes after ACLR of professional athletes among different sports. Such information may be useful to identify sport-specific differences that may help manage patient expectations and modify rehabilitation protocols. Furthermore, variations in ACL injury rates¹⁸ could be secondary to differences in the mechanism of injury imposed by each sport.^{9,14,21}

We sought to perform a detailed outcomes analysis of professional athletes who underwent ACLR for an acute rupture across 4 major North American professional sports (NFL, NBA, MLB, and NHL). Our hypothesis was that there would be significant differences in performance-based outcomes depending on the sport played.

METHODS

Professional athletes of 4 major sports (NFL, NBA, NHL, and MLB) who underwent ACLR were identified through a well-established, multistep protocol involving the review of archives of public records.^{9,15,16,22,26} Online databases of professional athlete injuries incurred from 1984 to 2013 were queried for search terms including “ACL repair” or “ACL reconstruction.” Players met the inclusion criteria if initial reports of the date and type of surgery were corroborated by at least 2 independent public sources of information. Players with concomitant knee injuries requiring repair (eg, meniscus tear, medial or lateral collateral ligament tear, and articular cartilage injury), when identified, were excluded. Athletes with conflicting medical information from different sources, revision ACLR procedures, unclear pathologies, or unclear procedures were also excluded from the study.

Demographic variables including age, body mass index (BMI), position both before and after surgery, playing experience, date of the injury, date of surgery, date of the first game played after surgery, and retirement date were collected for each player. Regular-season statistics for each athlete were compiled both before and after ACLR. Games played, seasons played, and sport-specific

statistics were recorded before and after surgery. To normalize the data to account for the differences in season and career length based on the individual professional sport (MLB, 162 games and 5.6 years, respectively; NBA, 82 games and 4.8 years, respectively; NHL, 82 games and 5.5 years, respectively; and NFL, 16 games and 3.5 years, respectively),¹⁷ a conversion factor was used to standardize data analysis.

Statistical performance was calculated differently for each athlete depending on the sport played (Appendix Table A1, available in the online version of this article). NFL player performance was measured using a standardized, previously published scoring system based on pertinent statistics important to the individual player’s position.¹⁷ NBA player performance was measured using the player efficiency rating (PER), a measure that accounts for positive and negative playing statistics.⁵ MLB player performance was measured based on the role of either a pitcher or hitter. Similar to previous publications, pitcher performance was assessed using the number of walks plus hits per inning pitched (WHIP).¹² Hitter performance was assessed using the on-base plus slugging percentage (OPS), an accepted sabermetric of a hitter’s ability to get on base and hit for power).²⁰ NHL metrics were calculated by a performance score based on a previously published scoring system reported in the literature to assess performance after orthopaedic procedures.²⁵

Successful RTP was defined as being on the active roster for at least 1 regular or postseason game after treatment. Players who successfully returned to play after surgery were then included in the performance evaluation. A comparison of performance both before and after surgery was conducted. Each athlete’s preoperative (baseline) performance was defined as the season immediately preceding the injury-shortened season. Postoperative season 1 was defined as the first season in which the athlete returned. Postoperative seasons 2 and 3 were defined as those following the return season. These time points were chosen to assess short- and medium-term changes in performance. To standardize relative performance across the 4 sports after treatment, the percentage change in performance compared with preoperative values was used.

Statistical analysis was performed using SPSS software (version 22; IBM). The Fisher exact test was used to analyze categorical data. The continuous variables of each cohort were compared using a 2-tailed Student *t* test for normally distributed data. Each player served as his own control, and a 2-tailed paired *t* test was used to evaluate changes in performance. A Kaplan-Meier survivorship curve with “retirement” as the endpoint was constructed. Statistical significance was accepted at *P* < .05.

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TABLE 1
Characteristics of Athletes Before ACLR^a

	BMI, kg/m ²	Age at Injury, y	Playing Experience (Seasons)
Overall	28.7	26.9	4.2
MLB	26.2	30.0 ^b	6.9 ^b
NBA	24.4	26.2	4.0
NFL	30.9 ^b	26.6	3.4
NHL	27.0	28.1	6.6
P value	<.001	<.001	<.001

^aACLR, anterior cruciate ligament reconstruction; BMI, body mass index; MLB, Major League Baseball; NBA, National Basketball Association; NFL, National Football League; NHL, National Hockey League.

^bNFL athletes had a significantly higher BMI, while MLB athletes were significantly older with more playing experience than the other athletes.

RESULTS

A total of 344 professional athletes (350 knees) from 4 professional sports (NFL, n = 205; NHL, n = 48; MLB, n = 21; and NBA, n = 76) who underwent ACLR between 1984 and 2013 were identified. On a per-sport basis, this equated to 0.42%, 0.64%, 0.09%, and 0.26% of the athletes in the NFL, NBA, MLB, and NHL during this time period, respectively. Demographic differences between cohorts included a significantly higher BMI in NFL players ($P < .001$) and older age and more experience before the injury in MLB athletes ($P < .001$ and $P < .001$, respectively) (Table 1).

Timing of Injury

Timing of the injury with respect to preseason, during the season, or offseason was recorded and analyzed (Appendix Table A2). NFL athletes experienced no significant differences in postoperative performance, RTP rate, recovery time, or career length after ACLR with respect to in-season or off-season injuries ($P = .08-.91$). For MLB, NBA, and NHL athletes, secondary to the sample size, further analysis was not conducted. Additionally, analysis of performance outcomes was conducted based on the decade in which the injury occurred (Appendix Table A3). No significant differences were observed in the RTP rate or performance at either of the time points measured for any of the sports ($P = .72-.98$).

RTP and Career Length

A total of 298 athletes (86.6%) successfully returned after index ACLR. NHL athletes had a significantly higher RTP rate compared with those of all the other sports (95.8% vs 83.4%, respectively; $P = .04$) (Figure 1). The time to recover from surgery and return to a regular-season game was significantly shorter in the NHL athletes (258 days) and longer in the NBA players (424 days) ($P < .001$ and $P = .002$, respectively) (Table 2). Of note, only 1 athlete in this study returned in the same season as his ACLR procedure (NFL). Athletes

Return to Play After ACL Reconstruction

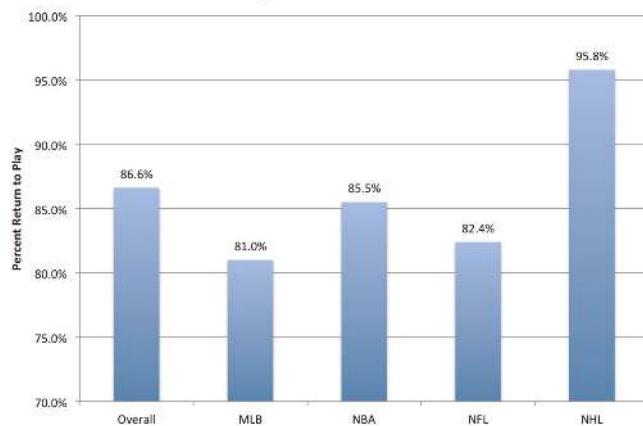


Figure 1. Return-to-play rates after anterior cruciate ligament reconstruction (ACLR) in the 4 major sports. Overall, 86.6% of the athletes returned after ACLR. National Hockey League (NHL) players returned at a significantly higher rate than those of all the other sports ($P = .01$). MLB, Major League Baseball; NBA, National Basketball Association; NFL, National Football League.

TABLE 2
Outcomes After ACLR^a

	Return to Play, d	Career, y	Career (Adjusted), y
Overall	366.7	3.2	2.5
MLB	417.5	2.9	1.9
NBA	423.8 ^b	4.5 ^b	3.2 ^b
NFL	369.3	2.1 ^b	2.1 ^b
NHL	257.6 ^b	4.5 ^b	2.8

^aACLR, anterior cruciate ligament reconstruction; MLB, Major League Baseball; NBA, National Basketball Association; NFL, National Football League; NHL, National Hockey League.

^bNHL athletes experienced the shortest recovery times, while NBA athletes experienced the longest. NFL athletes experienced the shortest careers after surgery, while NBA athletes experienced the longest. $P < .05$.

went on to play a mean 3.2 ± 2.9 years after surgery, with NFL athletes having significantly shorter careers (2.1 ± 2.1 years; $P < .001$). Even after adjusting for expected career lengths (MLB, 5.6 years; NBA, 4.8 years; NHL, 5.5 years; and NFL, 3.5 years),¹⁷ NFL athletes still had significantly shorter careers after surgery ($P = .004$) (Table 2). NBA and NHL athletes had significantly longer careers after ACLR (4.5 ± 3.3 years, $P < .001$ and 4.5 ± 3.1 years, $P = .001$, respectively).

Kaplan-Meier analysis (Figure 2) revealed significant differences in survivorship (defined as retirement) between the 4 sports (log-rank, $P < .001$). Overall, 67% of athletes were still on active rosters 2 and 3 seasons after ACLR (Table 3). NFL players experienced a significant decrease on active rosters 2 and 3 seasons postoperatively compared with athletes of all the other sports ($P < .001$). NHL players experienced significantly increased survivorship, with 98% still on active rosters 2 and 3 seasons postoperatively ($P = .006$).

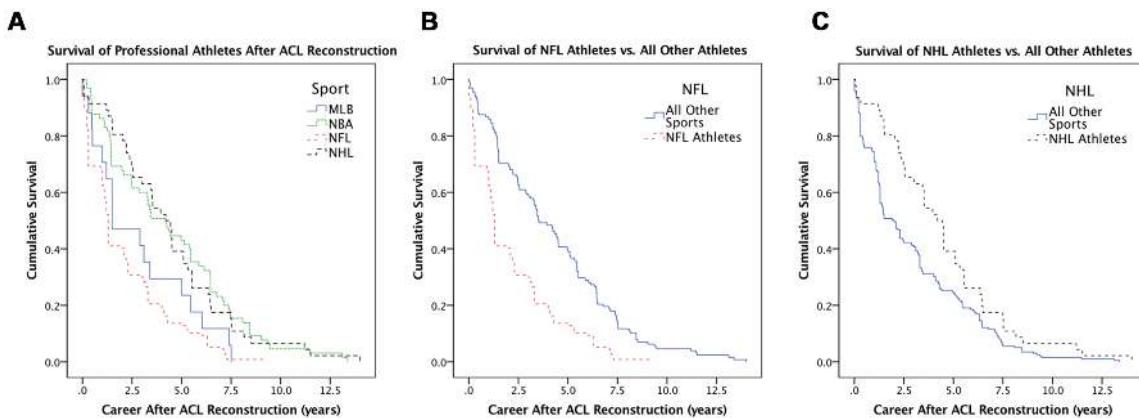


Figure 2. Kaplan-Meier survival analysis of rates of retirement after anterior cruciate ligament (ACL) reconstruction. (A) There was a significant difference in survival between the 4 cohorts (log-rank, $P < .001$). (B) National Football League (NFL) athletes (red) had significantly worse survival than the mean of all the other sports (blue) (log-rank, $P < .001$). (C) National Hockey League (NHL) athletes (black) had significantly better survival than the mean of all the other sports (blue) (log-rank, $P = .006$).

TABLE 3
Players Still on Active Roster 3 Seasons After ACLR^a

Sport	Players on Active Roster, %
Overall	67
MLB	81
NBA	63
NFL	60 ^b
NHL	98 ^b

^aACLR, anterior cruciate ligament reconstruction; MLB, Major League Baseball; NBA, National Basketball Association; NFL, National Football League; NHL, National Hockey League.

^b $P < .05$ compared with all other sports.

Game and Performance Outcomes After Surgery

After ACLR, athletes of all sports played significantly fewer games during postoperative season 1 ($P < .001$ to $P = .008$) (Figure 3). MLB and NFL athletes did return to preinjury levels of game participation by postoperative seasons 2 and 3 ($P = .11$ and $P = .16$, respectively). NBA and NHL athletes continued to participate in significantly fewer games at postoperative seasons 2 and 3 ($P < .001$ and $P < .001$, respectively).

Both NBA and NFL athletes had a significant decrease in performance for the season after surgery ($P < .001$ and $P < .001$, respectively). NBA athletes recovered to preinjury levels of performance in seasons 2 and 3 ($P = .22$), while NFL players continued to experience a significant decrease in performance ($P = .002$). MLB and NHL athletes experienced no significant change in performance in both the short- (postoperative season 1) and medium-term periods (postoperative seasons 2 and 3) after surgery ($P = .19$ and $P = .17$, respectively) (Figure 4).

Graft Ruptures and Contralateral ACL Tears

There were 12 identified cases (3.4%) of graft failure after surgery (7 NFL, 1 NBA, 3 MLB, and 1 NHL) that required

a revision ACLR procedure. The return-to-play rate after this second operative procedure ($n = 6$, 50.0%) was significantly lower compared with index ACLR ($P = .01$). Of note, 2 NFL athletes sustained a third ACL tear and underwent a third ACLR procedure. One was unable to return to sport, while the other has started 92% of games since his last injury, is about to enter postoperative season 5, and was selected to his first-team All-Pro in his fourth postoperative season. Additionally, 6 NFL and 1 NBA players (2.0%) underwent ACLR for a contralateral tear within the study period. The RTP rate (71.4%) for this subgroup was not significantly different ($P = .30$) than that of first-time ACLR.

DISCUSSION

Athletes undergo ACLR and subsequent rehabilitation with the goal of returning to full function afterward. While excellent outcomes have been previously reported after ACLR in professional athletes of individual sports,^{9,11,15,26} it is unknown how these differ across sports. Furthermore, because of the high level of performance that is required to return to play in a professional setting, athletes may not return to preinjury performance levels until years after surgical treatment. Previous studies in this arena have not attempted to detect these differences and quantify performance changes across short- and medium-term time points.

When compared with players in all sports, NFL athletes performed the worst after ACLR, with significantly shorter careers and a lower survival rate. Furthermore, these players experienced significant decreases in performance the season after returning that persisted through seasons 2 and 3. While recent media reports may have skewed the public perception of recovery from this injury by highlighting cases of high-profile athletes who return to elite (and sometimes better) levels of performance after surgery, our data suggest that those cases may be exceptions to the norm. The explanation for these outcomes is likely

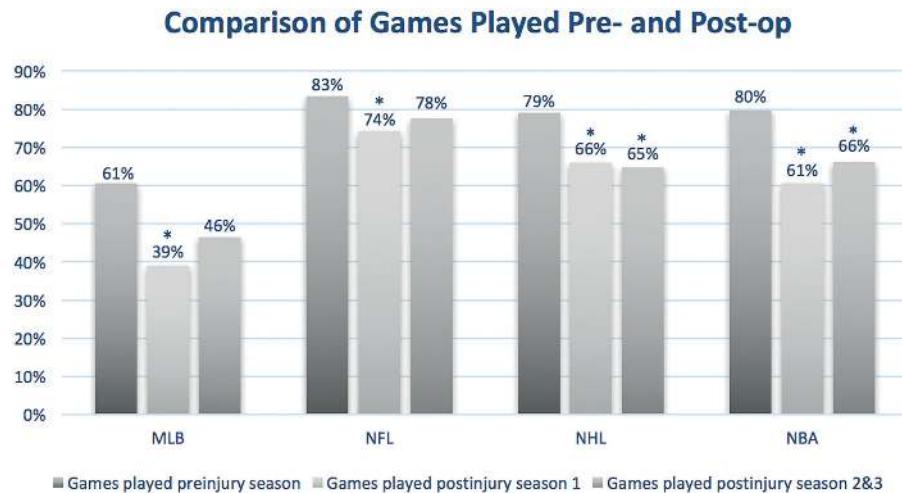


Figure 3. Standardized comparison of games played in the preinjury season, postoperative season 1, and postoperative seasons 2 and 3. Games played were standardized based on the typical regular-season length and expressed as a fraction of a full regular season. All cohorts participated in fewer games in postoperative season 1. In seasons 2 and 3, National Basketball Association (NBA) and National Hockey League (NHL) athletes continued to participate in fewer games, while Major League Baseball (MLB) and National Football League (NFL) athletes returned to baseline participation.

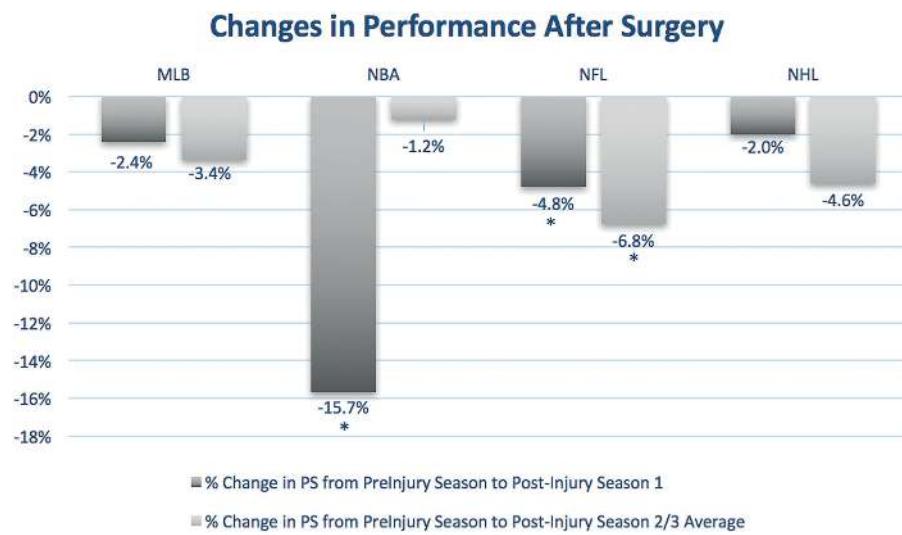


Figure 4. Standardized comparison of changes in performance after anterior cruciate ligament reconstruction (ACLR) compared with the preinjury season. National Basketball Association (NBA) and National Football League (NFL) athletes experienced significant decreases in performance in postoperative season 1. Only NFL athletes experienced a persistent decrease in performance 3 seasons after ACLR. * $P < .05$. PS, performance score.

multifactorial. First, position may play a role in outcomes, as Brophy et al⁴ demonstrated that defensive linemen, linebackers, and offensive linemen were less likely to play in the NFL after undergoing ACLR before the NFL draft compared with players of other positions ($P = .04-.05$). These positions accounted for 41.0% ($n = 84$) of our NFL cohort and may have contributed to the worse outcomes observed. Second, BMI was found to be an independent negative predictor of postoperative career length, and NFL athletes had significantly higher values than athletes of the other sports.

This characteristic may place more physical demands on a reconstructed ligament and can also be associated with a higher incidence of additional intra-articular injuries at the time of the ACL injury.¹ While this increased stress on the knee may not necessarily lead to ruptures, it may affect an athlete's medium-term performance by decreasing survivorship and on-field statistics.

Conversely, the data in this study suggest that NHL athletes have the most favorable prognosis after ACLR. NHL athletes had significantly higher rates of RTP, the

shortest time to return after surgery, no changes in performance after surgery, and the highest survival rate. The contrast of the physical demands imposed by both hockey and American football may explain these substantial differences. Skating as opposed to running with cleats may induce less stress on the knee after RTP. The forces placed upon a surgically reconstructed knee can be more significant with running and cutting maneuvers, which can lead to increased anterior tibial shear forces, increased valgus strain, and increased strain on the ACL.⁷ NHL athletes may be spared of these forces and consequently have less physical demands placed on the knee after ACLR. Furthermore, differences in the personal traits of athletes, coaching philosophy, and availability of suitable replacements may also influence RTP and performance statistics.

Furthermore, it is important to recognize that NBA athletes after ACLR require the longest recovery time and have the worst statistical performance the first postoperative season but then return to baseline levels after 3 seasons. These differences in player behavior after surgery highlight the varied physical demands that each sport requires. It is possible that the repetitive and quick-burst jumping, landing, and pivoting motions unique to professional basketball may entail an extended period of rehabilitation, but after stability is achieved, baseline performance can be expected. Similarly, the same surgical procedure in American football players may result in a quicker recovery period but cause trauma to decrease medium-term statistical performance. The relative differences in outcomes between these sports warrant further study to delineate the reasons for these findings.

This study, as well as other similar publications from our research group, is associated with several well-recognized limitations. Details regarding injury diagnosis and management, including imaging reports, injury severity, exact pathology, unreported concomitant pathologies such as chondral defects, exact medical clearance date to return, and graft type were not available for all players. Because players were identified via information on public record, the possibility of reporting errors, selection bias, and omissions exists. While ACL ruptures are somewhat understood and published by the media, associated pathologies such as a concomitant meniscus injury may not be reported as reliably. Without operative reports, it is unclear which surgeries involved meniscectomy or chondral repair or which graft type at the time of ACLR. While we controlled for this by corroborating multiple sources and eliminating players with conflicting reports, there remains the possibility for inaccurate data. The recent advances in ACLR suggest potential differences in outcomes based on the year of surgery; however, our cohort consisted of relatively few cases before the year 2000. The methodology of this study may not be appropriate to assess these differences based on time intervals.

Furthermore, there are many reasons unrelated to performance of why an athlete may choose to retire (eg, contract negotiations, personal reasons) that were not accounted for because of limitations in the information available. Although, for the purposes of this study, the first game on an active roster defined successful RTP, it is important to consider that this may not define the exact

length of recovery. Medical clearance to return to sport may predate returning to the field if during the offseason. However, when analyzing the data based on the time of injury, no significant differences in the RTP rate, time to return, career after surgery, or performance were observed. Further, well-known methods to use injury reports to influence the opponent's game strategy and preparation, such as that in the NFL and NHL, may also have affected reporting with these cohorts. Finally, there remains the possibility of selection bias in our cohorts in which only successful or "newsworthy" players were included. However, the wide range of preoperative experience, games played, and performance scores demonstrate that athletes of all calibers were included.

CONCLUSION

ACLR leads to excellent outcomes for professional athletes of the 4 major sports. However, the intricacies of each sport place significantly different physical demands on the reconstructed ligament and lead to differences in outcomes. The data in this study suggest that NFL athletes have the worst prognosis after ACLR, with the lowest survival rate, shortest career length after surgery, and sustained decreases in performance. Conversely, NHL athletes have the best prognosis after ACLR, with the highest rates of RTP, highest survival rates, longest career length after surgery, and no significant changes in performance.

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