Performance and Return to Sport After Anterior Cruciate Ligament Reconstruction in Professional Baseball Players

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Background: Anterior cruciate ligament reconstruction (ACLR) is the gold standard treatment for ACL tears to allow baseball players to return to sport (RTS). The optimal graft type and femoral tunnel drilling technique are currently unknown.

Hypothesis: There is a high rate of RTS in professional baseball players after ACLR, with no significant difference in RTS rates or performance between cases and controls or between graft types or femoral drilling techniques.

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

Methods: All professional baseball players who underwent ACLR between 2010 and 2015 were included. Demographic and performance data (pre- and postoperative) for each player were recorded. Performance metrics were then compared between cases and matched controls.

Results: A total of 124 players (mean age, 23.7 ± 4.1 years; 83% minor league players) underwent ACLR. Of these, 80% returned to sport (73% to the same or higher level) at a mean 310 ± 109 days overall and 333 ± 126 days at the same or higher level. The most common graft type was an ipsilateral bone–patellar tendon–bone (BTB) autograft (n = 87; 70%). A total of 91 players underwent concomitant meniscal debridement or repair. No significant difference in any of the primary performance metrics existed from before to after ACLR. Compared with matched controls, no significant difference existed in RTS rates or any performance metrics after ACLR. No significant difference existed in RTS rates or primary performance outcome measures between graft types or femoral drilling techniques.

Conclusion: The RTS rate for professional baseball players after ACLR was 80%. No significant difference in performance metrics existed between BTB and hamstring autografts or between femoral drilling techniques. Furthermore, no significant difference in performance or RTS rates existed between cases and matched controls. Femoral drilling technique and graft type did not affect performance and RTS rates in professional baseball players after ACLR.

Keywords: Major League Baseball (MLB); anterior cruciate ligament reconstruction (ACLR); knee; graft type; surgery; return to sport (RTS)

Anterior cruciate ligament (ACL) injuries have been increasing in frequency in both recreational and professional athletes over the past 10 years.[22,24] The gold standard treatment for athletes who sustain an ACL tear and wish to return to sport is ACL reconstruction (ACLR). Results after ACLR in professional athletes have been reasonable, with return-to-sport (RTS) rates generally cited at >75%.[9-11,14,15,18,26] However, the majority of studies available regarding RTS rates and performance upon RTS have been limited to publicly available data.[9,24]

There are several surgical techniques for drilling the femoral tunnel and graft types that are available when performing ACLR. Commonly used femoral drilling techniques include anteromedial drilling, transtibial drilling, and outside-in drilling, although studies to date have failed to demonstrate that one technique is superior to the others.[1,6,12] While there are countless graft types available for ACLR, including bone–patellar tendon–bone (BTB), hamstring, quadriceps, tibialis anterior, and others, grafts can be grossly broken down into autografts and allografts.[5,17,19,20]

Therefore, the purposes of this study were to determine the following among professional baseball players who underwent ACLR: (1) the rate of RTS after ACLR, (2) the difference in performance between before surgery and after RTS, (3) the difference in RTS rates and performance between players who underwent ACLR and matched controls without a history of ACLR, and (4) the difference in RTS rates and performance based on the femoral drilling technique and graft type in players who underwent ACLR.

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We hypothesized that there is a high rate of RTS in professional baseball players after ACLR with no significant difference in RTS rates or performance, specifically regarding the primary performance variables of earned run average (ERA), walks plus hits per inning pitched (WHIP), fielding independent pitching (FIP), and wins above replacement (WAR), between cases (ACLR) and controls (no ACLR). Furthermore, we hypothesized that no difference in RTS rates or performance would exist between graft types or femoral drilling techniques.

METHODS

This study was performed with the approval of the Major League Baseball Players Association (MLBPA) and the MLB Research Committee. All professional baseball players who underwent ACLR between 2010 and 2015 were eligible for inclusion. Study data from the MLB Health and Injury Tracking System (HITS) database were analyzed. The HITS database is a centralized electronic medical record that contains deidentified player information and was developed as a leaguewide surveillance system in 2010 to record player injuries and disability time.[28] This database was agreed upon by the MLB and MLBPA as a more efficient way to track medical histories and the injury history of a player throughout all major and minor league affiliates. Data are entered/uploaded into the HITS system by trainers and include injury reports, imaging studies, and operative reports, among others. The HITS system has been used in several prior studies and has been found to be a reliable source of information.[3,4] One author (B.J.E.) reviewed all operative reports for each player to confirm that the player underwent ACLR. Surgical variables including graft type, femoral drilling technique, concomitant injuries, and others were recorded for each player. All players identified were included in this study if data related to the RTS rate were provided. A player was deemed to have returned to sport if he played in any professional game after surgery. Players who underwent ACLR with a minimum 18-month follow-up were included in the study. Participant inclusion criteria were any male professional baseball player (after being drafted or at least 1 game played in professional baseball before ACLR). Participant exclusion criteria were collegiate (National Collegiate Athletic Association [NCAA]) players and players who never played in professional baseball.

Players who returned to professional baseball and had played in at least 1 game were included in the preinjury and postinjury in-game performance statistical analysis (Tables 1-4). In-game performance variables were analyzed as an average over the pre-ACLR and post-ACLR course of the player's career. A control group was selected to compare the data with the case (ACLR) group. Controls were matched to cases based on sex, age, years of experience in professional baseball, level of play (Fall Ball, Rookie, A-, A, AA, AAA, MLB), and performance metrics (Appendix Tables A1 and A2). An "index year" was designated for controls, analogous to the ACLR year in cases. In other words, the controls played the same number of years before the index year as the cases played before the injury. The same demographic and in-game performance data were collected and analyzed as a total before and after the index year.

Statistical Analysis

Descriptive statistics were calculated. Data were analyzed for normality using the Kolmogorov-Smirnov test, and parametric and nonparametric tests were used as appropriate. Performance outcomes were averaged before the injury and postoperatively/after the injury. To do so, performance data were categorized as either $\geq$1 year before the injury or $\geq$1 year postoperatively. Performance data within the year of surgery were felt to be too influenced by variations in rehabilitation to allow comparisons across participants. Patients who underwent revision procedures or concomitant reconstruction or repair of another knee ligament were excluded from further analyses. If they underwent index ACLR as a professional, they were included for this surgery, but the data after their revision procedure were not included as a separate entity.

Performance data are reported as both raw counts and percentages. For those performance data available as counts, we determined the number of available years before the injury and postoperatively/after the injury and divided the sum of each count by the number of available years to determine the number per year. For those performance data available as percentages, we calculated averages weighted by the number of games played per year.

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Ethical approval for this study was obtained from the institutional review board at the University of Utah (No. 00114699) and approved by the Major League Baseball Players Association.

TABLE 1
Demographic and Operative Data (N = 124)[a]

	No. or n (%)
Level of play	
Minor league	103 (83)
Major league	21 (17)
Side of injury	
Right	70 (56)
Left	54 (44)
ACLR	
Primary	118 (95)
Revision	6 (5)
Graft type	
BTB autograft (ipsilateral)	87 (70)
Hamstring autograft (4-strand)	23 (19)
Quadriceps autograft	1 (1)
BTB allograft	6 (5)
Achilles allograft	5 (4)
Hamstring allograft	1 (1)
Tibialis anterior allograft	1 (1)
Drilling technique	
Anteromedial	71 (57)
Transtibial	47 (38)
Outside-in	6 (5)
Concomitant abnormality and treatment	
Meniscal tear (91 players)	
Medial	56
Debridement	23
Repair	27
Lateral	64
Debridement	47
Repair	9
Chondral damage	24
Medial femoral condyle	9
Lateral femoral condyle	9
Patella	8
Medial tibial plateau	4
Lateral tibial plateau	3
Microfracture	4
Chondroplasty	20
Posterolateral corner reconstruction	3
Posterior cruciate ligament repair	2
Medial collateral ligament repair	2
Lateral collateral ligament repair	1
Medial patellofemoral ligament repair	1

[a]ACLR, anterior cruciate ligament reconstruction; BTB, bone–patellar tendon–bone.

Preinjury and postinjury/postoperative performance data were then compared using the paired Student *t* test and related-samples Wilcoxon signed-rank test as appropriate based on data normality. For each player, the maximum preoperative and postoperative level of play was calculated, with the 9 levels arranged from highest to lowest as MLB, AAA, AA, A+, A, A-, Rookie, Foreign, and Fall Ball. Based on the preinjury and postinjury/postoperative maximum level, each player could then be categorized as not having returned to play, having returned but to a lower level, or having returned to the same or a higher level. We then compared preoperative and postoperative data between operative cases and matched controls. We also conducted subgroup analyses to compare (1) 4-strand hamstring autografts and ipsilateral BTB autografts and (2) anteromedial and transtibial femoral drilling techniques. Other graft types and drilling techniques were not compared, as the numbers did not support subgroup analyses.

TABLE 2
Positions Played by Each Player

Position	No.
First baseman	7
Second baseman	7
Shortstop	17
Third baseman	7
Catcher	18
Center fielder	6
Infielder	4
Left fielder	1
Right fielder	0
Left-handed reliever	4
Left-handed starter	9
Outfielder	13
Right-handed reliever	15
Right-handed starter	16

RESULTS

Overall, 124 professional baseball players underwent ACLR between 2010 and 2015 (Table 2). A total of 57 different surgeons performed these procedures. Of these, 80% of players were able to return to sport (73% of all players returned at the same or higher level). No difference existed in RTS rates between major and minor league players. On average, it took players 310 ± 109 days to return to sport overall and 333 ± 126 days to return to the same or higher level of play. The majority of ACLR procedures were performed in minor league players (n = 103; 83%), and the most common graft type was an ipsilateral BTB autograft (n = 87; 70%) (Table 1). Of the 13 players (10.5%) who underwent ACLR using an allograft, 10 of these were for primary ACLR, and only 3 were in the setting of revision ACLR. When evaluating predictors of surgical technique, no significant difference existed in age between players who underwent ACLR with a BTB or hamstring graft (P = .470). Players were no more likely to undergo accessory anteromedial femoral drilling than transtibial femoral drilling if the graft type was a hamstring (P = .966), and the graft type was not different between the landing (lead) leg and drive (trail) leg in pitchers (P = .659).

Overall, 91 individual players sustained a concomitant medial, lateral, or both medial and lateral meniscal tears. When evaluating medial and lateral meniscal tears, 48% of the medial meniscal tears were repaired, while only 14% of all lateral meniscal tears were repaired. Between 2010 and 2015, there was 1 player who underwent primary ACLR followed by contralateral ACLR (425 days apart), while 3 players underwent ACLR followed by revision ACLR. These patients were excluded from subsequent analyses. The primary grafts in these 3 players were a BTB autograft

TABLE 3
Performance Metrics of Players Using Varying Graft Types and Drilling Techniques[a]

	ERA		WHIP		RTS (%)		
	Preoperative	Postoperative	Preoperative	Postoperative	Same/Higher Level	Lower Level	None
Graft type							
BTB autograft	5.23 ± 6.20	7.01 ± 9.80	1.36 ± 0.30	1.44 ± 0.30	74.50	3.60	21.80
Hamstring autograft	5.24 ± 3.80	3.94 ± 1.10	1.63 ± 0.60	1.36 ± 0.30	72.70	0.00	27.30
P value	.614	.970	.327	.902	.769		
Drilling technique							
Anteromedial	3.72 ± 2.10	3.91 ± 1.30	1.38 ± 0.30	1.35 ± 0.20	65.90	6.80	27.30
Transtibial	8.02 ± 9.30	10.20 ± 13.30	1.46 ± 0.40	1.54 ± 0.40	81.80	3.00	15.20
P value	.258	.201	.902	.653	.296		

[a]BTB, bone–patellar tendon–bone; ERA, earned run average; RTS, return to sport; WHIP, walks plus hits per inning pitched.

TABLE 4
Graft Type by Position[a]

Graft	Infielders	Outfielders	Pitchers	Catchers
BTB autograft	31 (73.8)	15 (75.0)	34 (77.3)	7 (38.9)
Hamstring autograft	4 (9.5)	3 (15.0)	8 (18.2)	8 (44.4)
Quadriceps autograft	1 (2.4)	0 (0.0)	0 (0.0)	0 (0.0)
BTB allograft	4 (9.5)	1 (5.0)	0 (0.0)	1 (5.6)
Achilles allograft	2 (4.8)	1 (5.0)	1 (2.3)	1 (5.6)
Hamstring allograft	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.6)
Tibialis anterior allograft	0 (0.0)	0 (0.0)	1 (2.3)	0 (0.0)

[a]Data are shown as n (%). BTB, bone–patellar tendon–bone.

(n = 1), BTB allograft (n = 1), and hamstring autograft (n = 1), and 2 utilized anteromedial drilling and 1 transtibial drilling. The mean time from primary ACLR to revision ACLR was 553 ± 372 days.

Players with a history of ACLR were matched to controls with no history of ACLR based on demographic and performance data (Appendix Table A1). The only difference preoperatively between groups was that controls averaged more hits per at bat than cases (0.27 vs 0.24, respectively; $P = .011$). When comparing postoperative performance metrics in cases to performance after the index year in controls, no significant difference existed in any of the performance metrics between cases and controls (Appendix Table A2). Furthermore, no significant difference existed between cases and controls with regard to the overall RTS rate, progression to a higher level, or level at which cases or controls returned to sport ($P = .684$).

The performance metrics for players with a history of ACLR were then compared from before their ACL tear to after ACLR. No significant difference in any of the primary outcomes existed between preoperative and postoperative performance (Appendix Table A3). There were 2 secondary performance metrics (home runs per year by pitchers [declined] and number of triples per year by batters [improved]) that differed after surgery.

When the most common graft types (BTB and hamstring) and drilling techniques (anteromedial and transtibial) were compared, no significant difference existed in RTS rates or primary performance outcome measures between these players (Table 3). Graft types were then compared among players based on position (Table 4). Compared with all other positions, catchers were significantly more likely to undergo ACLR with a hamstring autograft ($P = .023$) and significantly less likely to undergo ACLR using a BTB autograft ($P = .008$).

DISCUSSION

Although not as common in professional baseball players as injuries to the ulnar collateral ligament, ACL tears, and subsequently ACLR, have become more frequent among these elite athletes.[9,24] Our hypotheses were confirmed, as the RTS rate after ACLR was 80%, with no significant difference in RTS rates or performance upon RTS in the primary outcome performance variables of ERA, WHIP, FIP, and WAR between cases and controls. Furthermore, no difference in RTS rates or performance upon RTS existed between graft types or femoral drilling techniques.

ACLR has become the gold standard treatment for ACL tears in athletes who wish to return to sport at a high level.[8,13] The RTS rate in this study was 80%, which is consistent with a prior study by Mai et al[24] that reported an RTS rate of 80% for MLB players undergoing ACLR. The study by Mai et al reported an RTS rate of 95.8% in National Hockey League (NHL), 82.4% in National Basketball Association (NBA), and 85.5% in National Football

League (NFL) athletes after ACLR.[24] While some other sports involve more consistent cutting and pivoting, there is a significant amount of rotational force placed on the athlete's knees while hitting in baseball as well as a quick change in direction needed when running the bases and at times when playing the field. The 80% RTS rate in this study is slightly lower than that in a prior study that looked at ACLR in professional baseball players over a 13-year period using publicly available data.[15] That prior study included 26 MLB position players who had undergone ACLR, while the current study included 124 players (both pitchers and position players in both minor and major leagues) and separated the results based on pitching and batting performance metrics. It is possible that the other study had a higher RTS rate because it only included MLB athletes who are presumably more skilled and have a greater financial incentive to return. Similar to the prior study, this study found no significant change in performance after ACLR in professional baseball players. Furthermore, when matched to control players, there was no difference in performance metrics in the current study. Hence, while players may decline with age, there does not appear to be a faster decline in players' performance after ACLR compared with those who have not undergone ACLR.

One finding that deserves attention is the difference in graft types when performing ACLR in catchers compared to all other positions. The most common graft in catchers was a hamstring autograft, while a BTB autograft was by far the most common graft among all other positions (>70% for all other positions). A recent review found a higher rate of anterior knee pain and kneeling pain in patients who underwent ACLR with BTB autograft compared with hamstring autograft.[27] As such, given the demands on the knees of catchers and the need to pop up from a squatting position to throw runners out, it is intuitive that the graft of choice in catchers is a hamstring rather than a BTB.

Of late, there has been significant debate regarding femoral drilling techniques in ACLR. The current study found that 57% of players underwent ACLR using the anteromedial technique, while 38% underwent ACLR using the transtibial technique. Proponents of the anteromedial drilling technique often argue that the transtibial technique adequately restores anteroposterior translation of the knee but does not properly restore rotational control because the graft cannot be placed low enough on the wall.[16] Conversely, surgeons who drill transtibially cite recent studies that have shown higher rerupture rates when the graft is placed too low on the wall.[29] While studies can be found to support either technique, recent prospective randomized studies have found no difference in clinical outcomes between anteromedial and transtibial femoral drilling techniques.[23] This was echoed by the present study, as no difference in RTS rates or performance upon RTS was seen between transtibial and anteromedial drilling techniques. Hence, surgeons performing ACLR in these athletes should use the technique with which they are most familiar and technically comfortable, as the ability to technically execute ACLR well seems to be more important than the actual femoral drilling technique. Certainly, ACLR within professional baseball players may not represent the results of these drilling techniques within a community setting.

One interesting finding from this study is that RTS rates, as well as performance upon RTS, did not differ between specific graft types (BTB autograft vs hamstring autograft). There have been many studies evaluating the difference in failure rates and RTS rates, among others, based on graft type in ACLR, but no study has definitively found one graft type to be superior to all others.[2,7,25] However, there have been several studies to date that have shown an increased failure rate, increased knee laxity, and a heightened immune response in allografts compared with autografts.[21,30-32] It is therefore interesting that 10 professional baseball players in this study underwent primary ACLR using allografts. Notably, 1 of these 10 players underwent revision ACLR during this study period, while only 2 of 114 players who underwent primary ACLR using an autograft underwent revision ACLR during the study period. While these numbers are too small to compare, it is our recommendation that in the setting of primary ACLR, an autograft should be the graft of choice in professional baseball players.

Limitations

This study did not use public data but rather used the MLB HITS database to ensure the accuracy of these patients' data. Furthermore, all operative reports were reviewed to remove any possibility of including a player who did not undergo ACLR. While the HITS database was used, there is the possibility that some players who underwent ACLR were not entered into the database and were therefore missed. Furthermore, the exact timing of the injury was unknown so the risk of ACL tears in game situations could not be analyzed. The cases were matched best as possible to a group of controls, but differences between the groups could still exist. There was a lack of specific information regarding patients with meniscal or chondral damage that was addressed at the time of their ACLR to make a meaningful comparison between these players and those without concomitant injuries.

CONCLUSION

The RTS rate for professional baseball players after ACLR was 80%. No significant difference in performance metrics existed between BTB and hamstring autografts or between femoral drilling techniques. Furthermore, no significant difference in performance or RTS rates existed between cases and matched controls.

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APPENDIX

TABLE A1
Preoperative (Before Index Year for Controls) Demographic and Performance Metrics[a]

	Cases	Controls	*P*
Demographic information			
Age, y	23.70 ± 4.10	24.10 ± 4.40	.454
Experience in professional baseball, y	4.14 ± 4.10	4.17 ± 4.50	.814
Position, %			
Infielder	26.90	27.40	.929
Outfielder	17.60	9.50	.929
Catcher	14.80	19.10	.929
Starting pitcher	23.10	23.80	.929
Relief pitcher	17.60	20.20	.929
Throws right-handed, %	85.20	86.90	.734
Bats right-handed, %	61.10	66.70	.165
Preoperative pitching-specific statistics			
Win-loss percentage	12.50 ± 48.70	0.57 ± 0.17	.958
ERA	5.11 ± 5.70	3.81 ± 1.10	.653
Average runs	7.38 ± 11.80	5.43 ± 1.10	.888
WHIP	1.41 ± 0.39	1.34 ± 0.15	.914
Hits per 9 innings	8.60 ± 2.20	8.62 ± 1.20	.985
Home runs per 9 innings	0.57 ± 0.41	0.51 ± 0.34	.835
Walks allowed per 9 innings	4.06 ± 2.10	3.42 ± 1.20	.379
Strikeouts per 9 innings	8.56 ± 2.03	8.18 ± 1.60	.610
Strikeouts per walk	2.94 ± 1.50	2.90 ± 1.10	.667
Wins per year	6.73 ± 12.80	3.74 ± 1.90	.923
Losses per year	15.30 ± 50.50	3.43 ± 2.50	.939
Games per year	20.30 ± 11.90	21.80 ± 8.90	.383
Games started per year	6.65 ± 7.60	7.71 ± 7.10	.400
Games finished per year	7.37 ± 10.90	5.55 ± 5.10	.364
Complete games per year	1.47 ± 6.1 0	0.12 ± 0.20	.813
Shutouts per year	0.11 ± 0.40	0.05 ± 0.10	.909
Saves per year	3.08 ± 6.30	1.11 ± 1.40	.942
Innings pitched per year	53.70 ± 36.20	61.60 ± 35.60	.251
Hits per year	52.70 ± 36.40	61.10 ± 35.60	.270
Runs per year	25.10 ± 18.90	31.70 ± 17.90	.084
Earned runs per year	21.20 ± 17.40	27.20 ± 16.10	.084
Home runs per year	3.45 ± 3.30	4.39 ± 3.90	.444
Walks allowed per year	19.60 ± 13.40	21.50 ± 10.60	.383
Intentional walks per year	4.82 ± 17.90	0.60 ± 0.69	.666
Shutouts per year	46.30 ± 28.70	53.40 ± 26.40	.305
Hit batters per year	3.49 ± 2.20	4.16 ± 2.40	.261
Balks per year	0.26 ± 0.30	0.37 ± 0.50	.870
Wild pitches per year	4.59 ± 3.30	5.02 ± 3.50	.705
Batters faced per year	226.20 ± 159.00	265.90 ± 137.10	.270
WAR (pitchers)	1.21 ± 1.30	0.44 ± 0.60	.272
FIP	4.18 ± 1.10	5.56 ± 2.40	.224
Preoperative batting-specific statistics			
Games per year	67.10 ± 31.20	73.60 ± 32.20	.454
Plate appearances per year	266.80 ± 136.40	291.50 ± 141.30	.507
At bats per year	235.20 ± 122.40	256.01 ± 127.90	.553
Runs per year	33.40 ± 19.40	35.70 ± 18.40	.598
Hits per year	63.20 ± 36.30	68.60 ± 36.90	.601
Doubles per year	12.10 ± 8.10	13.90 ± 8.40	.407
Triples per year	1.98 ± 1.50	1.78 ± 1.70	.377
Home runs per year	4.38 ± 5.10	4.71 ± 4.10	.392
Runs batted in per year	26.90 ± 19.30	31.90 ± 16.80	.540
Stolen bases per year	7.51 ± 7.60	6.23 ± 5.90	.655
Caught stealing per year	3.64 ± 3.10	3.28 ± 2.80	.687
Walks per year	23.30 ± 14.70	26.30 ± 14.80	.358
Strikeouts per year	48.40 ± 25.40	48.90 ± 22.80	>.999
Total bases per year	101.20 ± 6.96	102.70 ± 66.50	.684
Double plays grounded into per year	5.33 ± 4.10	5.39 ± 3.90	.748
Hit by pitch per year	2.93 ± 2.00	3.37 ± 3.10	.888
Sacrifice hits per year	1.87 ± 1.60	2.33 ± 1.80	.264
Sacrifice flies per year	1.99 ± 1.56	2.10 ± 1.40	.552
Intentional walks per year	1.32 ± 1.58	1.05 ± 1.10	.669
Hits per at bat	**0.24 ± 0.10**	**0.27 ± 0.10**	**.011**
On-base percentage	0.33 ± 0.10	0.34 ± 0.10	.296
Slugging percentage	0.35 ± 0.10	0.38 ± 0.10	.188
On-base plus slugging percentage	0.68 ± 0.10	0.73 ± 0.10	.164
WAR (batters)	0.69 ± 1.40	0.33 ± 0.80	.863

[a]Data are shown as mean ± SD unless otherwise indicated. Bolded values indicate statistical significance ($P < .05$). ERA, earned run average; FIP, fielding independent pitching; WAR, wins above replacement; WHIP, walks plus hits per inning pitched.

TABLE A2
Postoperative (After Index Year for Controls) Demographic and Performance Metrics[a]

	Cases	Controls	*P*
Postoperative pitching-specific statistics			
Win-loss percentage	20.80 ± 74.90	20.48 ± 0.20	.917
ERA	6.35 ± 8.60	5.07 ± 4.10	.434
Average runs	9.51 ± 18.20	5.61 ± 4.00	.233
WHIP	1.42 ± 0.30	1.47 ± 0.40	.925

TABLE A2 (continued)

	Cases	Controls	*P*
Hits per 9 innings	9.26 ± 1.60	9.49 ± 3.10	.450
Home runs per 9 innings	0.76 ± 0.50	0.79 ± 0.40	.450
Walks allowed per 9 innings	3.53 ± 2.10	3.80 ± 1.70	.792
Strikeouts per 9 innings	7.61 ± 1.50	7.92 ± 1.60	.365
Strikeouts per walk	3.17 ± 2.90	2.45 ± 1.10	.592
Wins per year	9.36 ± 24.00	9.59 ± 2.40	.901
Losses per year	6.40 ± 88.20	3.44 ± 2.60	.492
Games per year	25.20 ± 14.70	26.00 ± 12.50	.663
Games started per year	4.95 ± 8.10	6.46 ± 8.30	.257
Games finished per year	9.34 ± 12.10	7.63 ± 6.70	.957
Complete games per year	2.77 ± 12.50	0.09 ± 0.23	.498
Shutouts per year	0.12 ± 0.58	0.01 ± 0.03	.505
Saves per year	3.02 ± 8.50	1.49 ± 2.70	.424
Innings pitched per year	54.80 ± 39.30	61.30 ± 40.50	.593
Hits per year	62.90 ± 45.30	52.20 ± 44.90	.722
Runs per year	29.10 ± 22.40	31.30 ± 20.50	.682
Earned runs per year	25.10 ± 19.80	27.60 ± 19.00	.729
Home runs per year	4.47 ± 4.20	5.79 ± 5.90	.454
Walks allowed per year	18.40 ± 12.90	21.90 ± 12.90	.408
Intentional walks per year	9.24 ± 37.90	0.54 ± 0.50	.533
Shutouts per year	44.40 ± 31.70	51.90 ± 36.40	.551
Hit batters per year	2.72 ± 2.50	3.25 ± 2.70	.335
Balks per year	0.43 ± 0.80	0.31 ± 0.30	.546
Wild pitches per year	3.75 ± 2.40	4.39 ± 4.10	.643
Batters faced per year	232.60 ± 175.10	266.10 ± 174.30	.569
WAR (pitchers)	0.69 ± 1.30	0.19 ± 0.80	.299
FIP	5.39 ± 3.00	5.53 ± 3.30	.918
Postoperative batting-specific statistics			
Games per year	76.80 ± 42.30	69.40 ± 31.20	.443
Plate appearances per year	295.40 ± 172.70	258.50 ± 123.20	.315
At bats per year	263.90 ± 153.90	227.70 ± 108.50	.273
Runs per year	33.40 ± 22.40	28.40 ± 15.30	.412
Hits per year	69.00 ± 44.00	57.40 ± 30.20	.205
Doubles per year	13.30 ± 10.20	11.30 ± 6.60	.526
Triples per year	1.42 ± 1.50	1.22 ± 1.20	.664
Home runs per year	5.56 ± 6.20	4.39 ± 3.80	.894
Runs batted in per year	29.90 ± 19.20	26.40 ± 13.90	.706
Stolen bases per year	5.28 ± 8.10	3.48 ± 4.30	.503
Caught stealing per year	2.62 ± 3.00	1.69 ± 1.90	.121
Walks per year	24.90 ± 18.80	24.20 ± 16.50	.966
Strikeouts per year	54.00 ± 32.20	50.10 ± 30.20	.659
Total bases per year	114.20 ± 74.30	135.20 ± 100.90	.297
Double plays grounded into per year	6.39 ± 4.80	7.83 ± 5.80	.280
Hit by pitch per year	4.35 ± 5.00	4.01 ± 2.70	.558
Sacrifice hits per year	2.31 ± 1.90	2.34 ± 2.40	.712
Sacrifice flies per year	2.52 ± 1.30	2.99 ± 2.60	.737
Intentional walks per year	1.20 ± 1.90	1.46 ± 1.50	.168
Hits per at bat	0.26 ± 0.03	0.25 ± 0.03	.628
On-base percentage	0.33 ± 0.10	0.31 ± 0.10	.133
Slugging percentage	0.38 ± 0.10	0.36 ± 0.10	.325
On-base plus slugging percentage	0.72 ± 0.10	0.68 ± 0.10	.247
WAR (batters)	0.46 ± 0.90	0.21 ± 0.70	.418

[a]Data are shown as mean ± SD. ERA, earned run average; FIP, fielding independent pitching; WAR, wins above replacement; WHIP, walks plus hits per inning pitched.

TABLE A3
Performance Metrics Before and After Surgery[a]

	Mean Difference (Pre- – Postoperative)	*P*
Pitching statistics		
Win-loss percentage	–4.60	.425
ERA	–0.95	.221
Average runs	–1.52	.284
WHIP	–0.05	.603
Hits per 9 innings	–1.02	.081
Home runs per 9 innings	–0.18	.059
Walks allowed per 9 innings	0.54	.328
Strikeouts per 9 innings	0.81	.060
Strikeouts per walk	–0.11	.836
Wins per year	–2.17	.421
Losses per year	–8.46	.324
Games per year	–4.12	.113
Games started per year	1.10	.402
Games finished per year	–0.78	.711
Complete games per year	–0.99	.477
Shutouts per year	0.01	.620
Saves per year	0.99	.475
Innings pitched per year	–5.14	.458
Hits per year	–15.41	.055
Runs per year	–7.67	.059
Earned runs per year	–6.81	.060
Home runs per year	**–1.73**	**.011**
Walks allowed per year	–0.44	.867
Intentional walks per year	–3.64	.413
Shutouts per year	–0.39	.936
Hit batters per year	0.52	.457
Balks per year	–0.19	.335
Wild pitches per year	0.23	.735
Batters faced per year	–27.17	.362
WAR (pitchers)	0.01	.996
FIP	–0.02	.966

TABLE A3 (continued)

	Mean Difference (Pre- – Postoperative)	*P*
Batting statistics		
Games per year	–5.29	.464
Plate appearances per year	–8.77	.763
At bats per year	–11.41	.659
Runs per year	2.52	.528
Hits per year	–1.69	.812
Doubles per year	–0.05	.970
Triples per year	**0.77**	**.046**
Home runs per year	–1.22	.217
Runs batted in per year	1.22	.701
Stolen bases per year	**3.72**	**.016**
Caught stealing per year	**1.41**	**.013**
Walks per year	0.18	.949
Strikeouts per year	–2.05	.714
Total bases per year	–10.08	.548
Double plays grounded into per year	–0.62	.536
Hit by pitch per year	–1.03	.319
Sacrifice hits per year	–0.26	.587
Sacrifice flies per year	–0.60	.136
Intentional walks per year	–0.13	.648
Hits per at bat	–0.01	.293
On-base percentage	–0.01	.573
Slugging percentage	–0.03	.125
On-base plus slugging percentage	–0.04	.166
WAR (batters)	0.19	.603

[a]Bolded values indicate statistical significance ($P < .05$). ERA, earned run average; FIP, fielding independent pitching; WAR, wins above replacement; WHIP, walks plus hits per inning pitched.