Analysis of Player Statistics in Major League Baseball Players Before and After Achilles Tendon Repair

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Abstract *Background:* No currently available literature evaluates the effect of Achilles tendon repair on professional baseball players in the Major League Baseball (MLB). *Questions/Purposes:* The purpose of this study was to determine the impact of Achilles tendon rupture and repair on MLB players in terms of return to play and batting/fielding performance metrics. *Methods:* Achilles tendon rupture data were retrospectively collected using information from the MLB disabled list, injury reports, MLB game summaries, player profiles, and publicly available news articles. Four pair-matched control MLB position players were selected for each of the players who underwent advanced analysis. Baseline characteristics were compared between injured players and controls using Fisher's exact or Student's *t* test. *Results:* Overall, the incidence of Achilles tendon rupture reported in MLB has increased substantially since 1996. Rate of return to play in MLB after Achilles tendon rupture and repair is 62% for position players (non-pitchers) who suffer the injury. There was no association of injury with any player metric. Compared with injury to the non-power side, injury to the power side was associated with fewer plate

appearances, fewer triples, an increase in percentage of at-bats with strikeouts, and decreased speed score. *Conclusion:* The incidence of Achilles tendon rupture in MLB has increased substantially since 1996. While comparison suggests that overall Achilles tendon injury does not have an effect on MLB player statistics in the years following surgical repair, subset analysis of injury to the rear (power-generating) leg may lead to a decline in those statistics which denote a player's speed and running ability.

Keywords Achilles tendon · baseball · Major League Baseball · performance

Introduction

Achilles tendon rupture during professional or amateur sports participation is becoming more frequent, and can threaten to alter or even end one's career [12, 19]. The risk for Achilles tendon rupture is greater in those athletes that are older, atypical in size for their sport, who experience high tensile loads, leg dominance, or fatigue [19]. Historical studies have demonstrated significant declines in performance with low rates of return to competitive play for professional athletes after Achilles tendon repair [13], whereas some more recent authors have achieved excellent results in athletes who have undergone open or percutaneous repair of Achilles tendon ruptures with high rate of return to pre-injury level of sports and low complication rates [6, 12, 13, 16–18].

The incidence of Achilles tendon rupture is more common to certain high-level sports participants than others [15], with an association with aerial sports [19] or sports activity involving jumping, sprinting, and change of direction [8, 10]. As such, recent literature evaluating Achilles tendon rupture and repair in professional sports has had a predilection toward certain sports more than others. While multiple studies have investigated the impact of anterior

Level of Evidence: Therapeutic Study (Level III).

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cruciate ligament reconstruction (ACLR) [5], ulnar collateral ligament reconstruction (UCLR) [7], and revision UCLR [9, 11] on professional baseball players, no such currently available literature evaluates the effect of Achilles tendon repair on professional baseball players in the MLB.

MLB players must possess specific batting and fielding performance metrics that provide implications of the players' ability to successfully perform such tasks as running, cutting, planting, pivoting, and pushing-off of their lower extremities, all of which may be affected by the health of the Achilles tendon. Of particular interest may be the effect of Achilles tendon injury on batting and throwing performance metrics, and whether the ruptured Achilles tendon involved the rear (power-generating) batting/throwing leg or the front (lead) batting/throwing leg. The rear or power leg provides push-off and pivoting during both the swing of a baseball bat or throw of a baseball suggesting a key role of the Achilles tendon in this leg for this sport. Fabricant et al. [5] explored this latter concept in the setting of ACLR in MLB players, and given the biomechanical function of the Achilles tendon, it remains a pertinent question to evaluate in this injury pattern as well. We hypothesize that Achilles tendon rupture and repair would lead to universal decline in batting and fielding performance and significantly affect the rate of return to play. In addition, we suggest that involvement of the rear (power-generating) extremity would have a greater effect on post-injury batting and fielding statistics than with injury of its counterpart front (lead) leg.

The purpose of this study was to determine the impact of Achilles tendon rupture and repair on MLB players in terms of the following: (1) incidence of Achilles tendon rupture and rate of return to play, (2) specific batting and fielding performance metrics that are specific to Achilles tendon function, and (3) effect on batting performance metrics based on whether the ruptured Achilles tendon was on the rear (power-generating) batting/throwing leg or the front (lead) batting/throwing leg.

Patients and Methods

In this case-controlled study, Achilles tendon rupture data were retrospectively collected, using information from the MLB disabled list, injury reports, MLB game summaries, player profiles, and publicly available news articles. All of these aforementioned informational sources have been synthesized by Baseball Injury Consultants (www.baseballic.com), a privately owned entity monitoring medical updates among professional baseball players and the latest in baseball injury research.

Inclusion criteria for incidence identification were Achilles tendon rupture with reconstruction from any year from the inception of the MLB (the year 1876) until 2015. This yielded 26 players (both pitchers and position [non-pitchers] players) available for inclusion. In theory, our data collection methods surveyed 18,593 total players over the last 140 seasons with, again, the potential for likely limitations in reporting of Achilles tendon injuries in the early stages of

the MLB. Players who were injured during the 2015 season ($n = 2$) were excluded from return-to-play analysis as return to play data and postoperative statistics were unavailable. Due to the rarity of Achilles tendon ruptures in pitchers ($n = 2$), they were excluded from performance analysis to maintain a uniform cohort. One player was excluded because he underwent elbow surgery in the same year as his Achilles tendon repair, and thus, it provided a significant confounder to performance statistics in the player's postoperative years. The remaining players did not suffer any additional injuries leading to lost playing time during the years analyzed. Position players (non-pitchers) who played in the MLB the season prior to Achilles tendon rupture but who did not return to MLB play for at least 81 games (50% of a single season) were excluded from final performance metric comparison analyses as they were characterized as "did not return" ($n = 8$). In total, 13 position players were included in our analysis as the Achilles tendon rupture cohort.

When at least 81 games (50% of the season) were played in the year of injury, the position player statistics from that season were considered as the "year prior to injury." When less than 81 games were played, the season was not considered to have been competed in enough to allow for appropriate player statistics to be generated. Thus, the previous season was designated the "year prior to injury" for purposes of analysis. For example, if the patient ruptured his Achilles tendon during game 99 of the 2009 season, then the player's statistics from the 2009 season before injury were considered the "year prior to injury."

The following demographic data were recorded for the included players: age, throwing side (right versus left), batting side (right versus left), body mass index (BMI), fielding position(s), total years and games played professionally (including Minor League), and total years and games played in the MLB. Data were obtained from three separate, cohesive, publicly available databases (www.MLB.com, www.baseball-reference.com, and www.fangraph.com) by two of the resident authors (B.M.S., M.W.T.) and one medical student authors (D.T.), each with an in-depth knowledge and understanding of the MLB. All three were accessed for data and cross-referenced for accuracy. Players considered to have played a year in the MLB or Minor Leagues are defined by the leagues as being included in the active roster and playing at least one game during the regular season or postseason. Table 1 depicts the advanced metric batting statistics, fielding statistics, and MLB awards that were available to be recorded and analyzed, as well as their definitions and, where applicable, their means of calculation. Fielding statistics were only recorded for position players who played a single position in the field, as those who played multiple positions could not appropriately have their individual fielding statistics combined.

Position player batting and fielding statistics were gathered for the "year prior to injury," "two years prior to injury," and "three years prior to injury" in order to provide a trend of player statistics leading up to Achilles tendon rupture. Similarly, data were gathered for the "year after injury," "two years after injury," and "three years after injury" when available. For those position players where

Table 1 Advanced metric batting statistics, fielding statistics, and MLB awards available for analysis, including their definition and means of calculation

Statistic	Definition/calculation
Batting statistics	
Plate appearances [PA]	Number of times the player went up to the plate to bat [= “number of at-bats” + BB]
Hits [H]	(no further explanation)
Singles [1B]	(no further explanation)
Doubles [2B]	(no further explanation)
Triples [3B]	(no further explanation)
Home runs [HR]	(no further explanation)
Walks [BB]	(no further explanation)
Strikeouts [K]	(no further explanation)
Intentional walks [IBB]	A subset of walks [BB], when a pitcher intentionally throws four balls to the batter to issue a walk
Runs [R]	Runs scored by the player (number of times crossing home plate)
Runs batted in [RBI]	Number of players that the batter has brought across home plate
Ground into double plays [GDP]	Number of times the player made contact with the ball in which it resulted in said player and an additional base-runner being called out
Caught stealing [CS]	Number of times the player is called out on the base path when attempting to steal a base
Stolen bases [SB]	(no further explanation)
Ratio of walks:strikeouts [BB/K]	(no further explanation)
Percentage of at-bats with walks [BB%]	(no further explanation)
Percentage of at-bats with strikeouts [K%]	(no further explanation)
Isolated power [slugging average; ISO]	A power index of hitting that measures the difference between the slugging percentage and batting average [SLG–BAvg]
Batting average on balls in play [BABIP]	Measures how often non-home run batted balls (often called “balls in play”) fall for hits [(H–HR)/(“at-bats”–K–HR + “sacrifice fly balls”)]
Batting average [BAvg]	The percentage of “at-bats” which result in a Hit [H/(“at-bats”)]
On-base percentage [OBP]	Measures the percentage of “at-bats” which do not result in an out [= (H + BB + “hit-by-pitch”)/(“at-bats” + BB + “hit-by-pitch” + “sacrifice fly”)]
Slugging percentage [SLG]	Total number of bases reached per at bat [= (1 + 2*2B + 3*3B + 4*HR)/(“number of at-bats”)]
Runs per plate appearance [wRC+]	The wRC statistic, scaled to where 100 is average, both league and park adjusted, based on linear weighted on-base average. [= ((wRAA/PA + League R/PA) + (League R/PA–(Park factor × League R / PA)))/(American or National League wRC/PA excluding pitchers)*100]
Base running runs above average (including SB or CS) [BsR]	All-encompassing base running statistic that turns SB, CS, and other base running plays into runs above and below average [= wSB + UBR + wGDP]
Batting and base-running combined (above average) [Off]	Measures a player’s context neutral batting runs and base running runs above average. [= “batting runs” + “base running runs”]
Wins above replacement [WAR]	This attempts to estimate a player’s total value relative to a free available player, such as a Minor League free agent. [= (“batting runs” + “base running runs” + “fielding runs” + “positional adjustment” + “replacement runs”) / (“runs per win”)]
On base plus slugging percentage [OPS]	The sum of a player’s on-base percentage and their slugging percentage. [= (OBP + SLG)]
Speed score [Spd]	Rates a player on their speed and baserunning ability (consists of stolen base percentage, frequency of stolen base attempts, percentage of triples, and runs scored percentage)
Ultimate base running in runs above average (not including SB or CS) [UBR]	Means of accounting for the value a player adds to their team via base running, determined using linear weights, with each individual base running event receiving a specific run value
Ground into double play runs above average [wGDP]	Number of runs above or below average a player has accumulated based on their ability to stay out of double plays. (taken as the average rate of GDP in GDP opportunities and apply it to the number of opportunities the player had)
Stolen bases and caught stealing runs above average [wSB]	Estimates the number of runs a player contributes to his team by stealing bases, as compared to the average player [= (SB * runSB) + (CS * runCS)–(League wSB * (1B + BB + HBP + IBB))]
Runs Created based on Weighted On-Base Average [wRC]	Attempts to credit a player for the value of each outcome (1B, 2B, etc.) rather than treating all hits or times on base equally. [= (((wOBP–League wOBP)/(w OBA Scale) + (League R/PA)) * PA]
Runs above average based on weighted on-base average [wRAA]	Measures the number of offensive runs a player contributes to their team compared to the average player [= ((wOBA–League wOBA)/wOBA scale) * PA]
Weighted on-base average [wOBA]	Attempts to credit a hitter for the value of each outcome (1B, 2B, etc.) rather than treating all hits or times on base equally [= (0.69 * uBB + 0.72 * HBP + 0.89 * 1B + 1.27 * 2B + 1.62 * 3B + 2.10 * HR) / (“at-bats” + BB – IBB + “sacrifice flies” + HBP)]
Fielding statistics	
Innings of play [Inn]	(no further explanation)
Put-outs [PO]	(no further explanation)
Assists [assist]	(no further explanation)

Errors [error]	(no further explanation)
Defensive chances [Ch]	Number of opportunities to create an out, provide an assist, or create an error. [= (PO + assist + error)]
Fielding percentage [Fld%]	Percentage of successful fielding opportunities [= (PO + assists)/(PO + assists + errors)]
Total zone total fielding runs above average [Rtot]	The number of runs above or below average the player was worth based on the number of plays made
Defensive runs saved above average [Rdrs]	Indicates how many runs a player saved or hurt his team in the field compared to the average player at his position
Rtot per year (1200 innings) [Rtot/year]	The number of runs above or below average the player was worth based on the number of plays made, per year
Rdrs per year (1200 innings) [Rdrs/year]	Indicates how many runs a player saved or hurt his team in the field compared to the average player at his position, per year
Range factor per 9 innings [RF/9]	A fielding statistic combining putouts and assists in terms of innings played [= $9 * (PO + assist) / ("innings played")$]
Range factor per game [RF/G]	A fielding statistic combining putouts and assists in terms of games played [= $(PO + assist) / ("games played")$]
MLB awards	
Most valuable player award winner [MVP]	(no further explanation)
All-star game participant [AS]	(no further explanation)

MLB Major League Baseball

post-injury data were not available for 3 years after injury, the reason for stop in play was gathered to assess for whether or not further temporary or permanent discontinuation of play was attributable to the Achilles tendon rupture, personal decision, or other injury pattern.

Four pair-matched control MLB position players were selected for each of the 13 position players who underwent advanced analysis. These four control players were selected for each of the injured case players using an algorithm developed by Baseball-Reference.com [2] which uses a concept termed “similarity scores” that are generated to determine a player from current or historical play that most closely matches the player of interest in terms of career play statistics (two of the four controls) and/or age (the other two of the four controls). This control cohort was included to evaluate for reference changes in player statistics that may be attributable to variations seen each year from the toll of a professional baseball career rather than specifically due to the Achilles tendon rupture and repair. None of the position players in the control cohort had suffered an Achilles tendon rupture or other injury during the years analyzed. The year in the control player’s career which most closely matched in his career the time in the injured player’s career when the Achilles tendon rupture occurred was considered the “year of injury” to serve as the reference point for six total years of baseball statistics to be analyzed (as the 3 years before/after injury for the players with Achilles tendon injury). The same batting statistics, fielding statistics, and MLB award data seen in Table 1 were recorded for these players to allow comparison with the injured cohort.

Baseline characteristics were compared between injured position players and controls using Fisher’s exact (for categorical variables) or Student’s *t* test (for continuous variables). The change in player statistics from pre-injury to post-injury was calculated for control and injury players. The difference in the changes in position player statistics between control and injured players was calculated and considered the “effect” of the injury on players’ careers. For continuous player statistics, multivariate linear

regression was used to calculate 95% confidence intervals and *p* values for this effect. For binary player statistics, Poisson regression with robust error variance was used to calculate 95% confidence intervals and *p* values for this effect. For these regressions, the unit of analysis was year of a player’s career, the outcome was the player statistic, and predictor variables included control versus injury, pre-injury versus post-injury, and an interaction term between those two predictor variables. The coefficient (for linear regression) or relative risk (for Poisson regression with robust error variance) of the interaction term is the same as the “effect” calculated above; however, the regression enabled the significance of that effect to be described. Notably, the regression was adjusted for clustering around each of the individual players (6 years included in the regression per player).

These methods were then duplicated for stratified analyses, first among only position players with non-power-sided injuries, and second among position players with power-sided injuries. Finally, again using parallel methods, among only those who actually injured their Achilles tendons, player statistics for patients who injured their power side were compared to player statistics for patients who injured their non-power side to determine if injury to the power side resulted in a greater effect on position player statistics than injury to the non-power side.

Results

Overall, the incidence of Achilles tendon rupture by year for the total 26 players who incurred injury has increased substantially since 1996 in comparison to pre-1996 recordings (Fig. 1). While not all of these players were appropriate for final analysis per our inclusion criteria, each suffered an Achilles tendon rupture, and thus, their incidence is recorded here. Of the dates of injury, 18 of 26 total Achilles tendon ruptures (69%) occurred during the preseason or regular season, with five (19%) occurring during the preseason or

Fig. 1. This graph provides the incidence of Achilles tendon rupture in MLB by year.

in the first month of the regular season. Five (19%) occurred during the offseason, and the remaining three (12%) occurred during the Playoffs.

Thirteen of 21 position players (62%) returned to MLB play for at least 81 games after Achilles tendon repair. There were no differences between those players who returned to play and those who did not in terms of age at time of injury/surgery, BMI, power or non-power side involvement, years of MLB experience prior to injury, or number of MLB games played prior to injury. The thirteen position players who returned to play and were thus appropriate for inclusion in our analysis were a mean 31.6 ± 3.2 years of age at the time of rupture, at a median 9 years into their MLB careers. Mean BMI was 25.9 ± 1.6 kg/m². One player suffered Achilles tendon ruptures to both lower extremities at 3 years apart—each injury was included as a separate occurrence and analyzed independently. Baseline characteristics did not differ between players with and without (control cohort) Achilles tendon injuries ($p > 0.05$ for each: Table 2).

There was no association of Achilles tendon injury with any of the player statistics, suggesting that Achilles tendon injury does not have an effect on player statistics ($p > 0.05$ for each: Table 3). Dominant or non-dominant side of injury could not be determined in two of the 13 injured players: one player was a “switch hitter” and thus batted from both the right and left side of the plate, so his power and non-power sides are in theory interchangeable; the second player had a

well-documented Achilles tendon rupture and surgical repair in the 1970s, although no report is available which dictates the laterality of injury.

Of those in which sidedness could be determined, three (27%) occurred on the power (rear) side, while eight (73%) occurred on the non-power (front) side. Among only injuries to the non-power side and their controls, injury (to non-power side versus control patients) was associated with 1.14 greater triples ($p = 0.033$; Table 4). Among only injuries to the power side and their controls, injury (to power side versus control patients) was associated with 28.65 fewer total games ($p = 0.039$), 141.63 fewer plate appearances ($p = 0.010$), 1.44 lower speed scores ($p = 0.004$), and 0.76 fewer stolen bases and caught stealing runs above average ($p = 0.021$; Table 5). Finally, compared with injury to the non-power side, injury to the power side (versus non-power side) was associated with 199.37 fewer plate appearances ($p = 0.003$), 1.34 fewer triples ($p = 0.025$), an increase in the percentage of at-bats with strikeouts by 5% ($p = 0.005$), and a decrease in speed score by 1.58 ($p = 0.011$; Table 6).

Discussion

The purpose of this study was to determine the incidence and impact of Achilles tendon rupture and repair on MLB players in terms of return to play and batting/fielding

Table 2 Comparison of demographic characteristics between injured players and control players

	Control players ($N = 52$)	Injured players ($N = 13$)	p value
Age (years $\pm$ SD)	36.6 ± 13.8	31.6 ± 3.2	0.253
Height (inches $\pm$ SD)	73.0 ± 2.2	74.1 ± 2.3	0.118
Weight (kg $\pm$ SD)	197.1 ± 19.2	202.7 ± 5.9	0.245
BMI (kg/m ² $\pm$ SD)	26.0 ± 2.0	25.9 ± 1.6	0.693
Batting side (n , [%])			0.164
Both	1 (1.9%)	1 (7.7%)	
Left	23 (44.2%)	4 (30.8%)	
Right	28 (53.9%)	8 (61.5%)	
Injury side (n , [%])			—
Left	—	9 (69.2%)	
Right	—	3 (23.1%)	
Unknown	—	1 (7.7%)	

SD standard deviation

Table 3 Association of player statistics with Achilles tendon injury

	Control players (mean)			Injured players (mean)			Effect of injury		
	Before	After	Difference	Before	After	Difference	Coef. ^a	95% CI	p value
Total games	103.90	89.70	-14.20	111.83	86.59	-25.24	-11.04	-30.28 to 8.21	0.256
Plate appearances	401.00	325.40	-75.60	416.17	296.09	-120.08	-44.48	-142.95 to 53.99	0.370
Total hits	98.76	79.30	-19.46	106.74	76.24	-30.50	-11.04	-37.71 to 15.63	0.411
Singles	65.50	52.66	-12.84	67.94	49.42	-18.52	-5.68	-21.93 to 10.57	0.488
Doubles	18.18	14.94	-3.24	22.03	15.76	-6.27	-3.03	-9.27 to 3.22	0.337
Triples	2.58	1.70	-0.88	1.91	1.18	-0.73	0.15	-0.77 to 1.08	0.742
Walks	35.89	29.73	-6.16	38.83	29.21	-9.62	-3.46	-13.78 to 6.88	0.507
Strikeouts	58.02	49.58	-8.44	64.71	47.42	-17.29	-8.85	-24.15 to 6.44	0.252
Intentional walks	3.85	2.47	-1.38	5.26	2.79	-2.47	-1.09	-3.17 to 1.00	0.294
Ground into double plays	8.19	6.80	-1.39	9.26	6.82	-2.44	-1.05	-3.32 to 1.21	0.357
Caught stealing	2.77	1.93	-0.84	2.54	1.55	-0.99	-0.15	-1.30 to 0.98	0.780
Ratio of walks:strikeouts	0.69	0.83	0.14	0.73	0.73	0.00	-0.14	-0.46 to 0.19	0.397
Home runs	12.45	9.97	-2.48	14.85	9.88	-4.97	-2.49	-7.62 to 2.62	0.333
Runs	51.54	40.69	-10.85	58.80	38.24	-20.56	-9.71	-24.78 to 5.37	0.203
Runs batted in	51.35	41.80	-9.55	57.51	41.94	-15.57	-6.02	-23.79 to 11.74	0.501
Stolen bases	5.94	4.11	-1.83	8.91	4.39	-4.52	-2.69	-5.79 to 0.40	0.087
Percentage of at-bats with walks	1.95	3.38	1.43	0.09	0.09	0.00	-1.43	-4.37 to 1.51	0.335
Percentage of at-bats with strikeouts	4.82	3.99	-0.83	0.16	0.16	0.00	0.83	-1.14 to 2.77	0.407
Isolated power	0.16	0.15	-0.01	0.17	0.16	-0.01	0.00	-0.04 to 0.03	0.914
Batting average on balls in play	0.29	0.28	-0.01	0.30	0.28	-0.02	-0.01	-0.03 to 0.02	0.511
Batting average	0.26	0.25	-0.01	0.28	0.25	-0.03	-0.02	-0.03 to 0.01	0.305
On base percentage	0.34	0.32	-0.02	0.35	0.32	-0.03	-0.01	-0.03 to 0.01	0.244
Slugging percentage	0.42	0.39	-0.03	0.45	0.41	-0.04	-0.01	-0.06 to 0.04	0.696
Runs per plate appearance	103.1	93.8	-9.30	109.40	93.15	-16.25	-6.95	-23.67 to 9.77	0.409
Base running runs above average	-0.01	-0.14	-0.13	0.41	-0.22	-0.63	-0.50	-1.63 to 0.65	0.393
Batting and base-running combined	6.46	3.86	-2.60	11.04	6.82	-4.22	-1.62	-11.46 to 8.20	0.742
Defensive chances	-3.53	-3.28	0.25	-6.15	-4.85	1.30	1.05	-1.56 to 3.69	0.420
Wins above replacement	1.65	1.29	-0.36	1.83	0.81	-1.02	-0.66	-1.51 to 0.20	0.132
On base plus slugging percentage	0.76	0.70	-0.06	0.80	0.73	-0.07	-0.01	-0.08 to 0.06	0.772
Speed score	3.92	3.24	-0.68	4.19	3.13	-1.06	-0.38	-1.00 to 0.23	0.220
Ultimate base running in runs above average	0.19	-0.29	-0.48	-0.70	-0.79	-0.09	0.39	-1.44 to 2.21	0.669
Ground into double play runs above average	0.72	-0.22	-0.94	1.18	0.08	-1.10	-0.16	-2.85 to 2.53	0.905
Stolen bases and caught stealing runs above average	-0.05	0.02	0.07	0.61	0.13	-0.48	-0.55	-1.8 to 0.07	0.080
Runs created based on weighted on-base average	56.19	43.41	-12.78	62.83	42.27	-20.56	-7.78	-25.62 to 10.10	0.388
Runs above average based on weighted on-base average	8.17	5.07	-3.10	11.39	4.16	-7.23	-4.13	-12.04 to 3.76	0.299
Weighted on-base average	0.34	0.32	-0.02	0.35	0.32	-0.03	-0.01	-0.03 to 0.17	0.503

	Control players (proportion)			Injured players (proportion)			Effect of injury		
	Before	After	Difference	Before	After	Difference	RR ^b	95% CI	p value
MVP awards	0.10	0.05	-0.05	0.22	0.14	-0.08	1.33	0.46 to 3.84	0.591
All-star games	0.14	0.11	-0.03	0.35	0.24	-0.11	0.87	0.36 to 2.11	0.761

CI confidence interval, Coef. coefficient, RR relative risk

^aA statistically significant positive coefficient indicates that an Achilles tendon injury leads to an increase in player statistics following the injury, while a statistically significant negative coefficient indicates that an Achilles tendon injury leads to a decrease in player statistics following the injury^bA statistically significant relative risk above 1.00 indicates that Achilles tendon injury leads to an increase in player statistics following the injury, while a statistically significant relative risk below 1.00 indicates that an Achilles tendon injury leads to a decrease in player statistics following the injury

Table 4 Among only injuries to non-power side and their controls, association of player statistics with Achilles tendon injury

	Control players (mean)			Injured players (mean)			Effect of injury		
	Before	After	Difference	Before	After	Difference	Coef. ^a	95% CI	p value
	Before	After	Difference	Before	After	Difference	Coef. ^a	95% CI	p value
Total games	101.80	87.54	-14.26	105.10	94.79	-10.31	3.95	-21.75 to 29.64	0.758
Plate appearances	395.77	326.18	-69.59	366.35	352.95	-13.40	56.19	-49.36 to 161.73	0.288
Total hits	100.04	82.05	-17.99	101.30	90.95	-10.35	7.64	-22.36 to 37.62	0.609
Singles	69.63	56.29	-13.34	66.95	59.32	-7.63	5.71	-13.59 to 25.01	0.553
Doubles	18.27	15.58	-2.69	21.25	19.21	-2.04	0.65	-7.59 to 8.88	0.874
Triples	3.23	2.17	-1.06	1.50	1.58	0.08	1.14	0.09 to 2.18	0.033
Walks	32.30	27.29	-5.01	33.55	33.00	-0.55	4.46	-6.77 to 15.70	0.426
Strikeouts	48.97	43.57	-5.40	44.65	40.16	-4.49	0.91	-11.07 to 12.90	0.878
Intentional walks	3.17	2.03	-1.14	4.80	3.16	-1.64	-0.50	-3.21 to 2.19	0.705
Ground into double plays	8.31	6.62	-1.69	9.45	7.53	-1.92	-0.23	-2.76 to 2.90	0.959
Caught stealing	3.30	2.17	-1.13	2.60	2.21	-0.39	0.74	-0.69 to 2.16	0.302
Ratio of walks:strikeouts	0.77	0.98	0.21	0.90	0.91	0.01	-0.20	-0.76 to 0.36	0.479
Home runs	8.91	7.96	-0.95	11.60	10.84	-0.76	0.19	-4.54 to 4.92	0.935
Runs	51.00	42.28	-8.72	55.95	47.05	-8.90	-0.18	-17.15 to 16.81	0.984
Runs batted in	45.35	38.00	-7.35	48.90	47.00	-1.90	5.45	-10.90 to 21.81	0.504
Percentage of at-bats with walks	8.04	5.66	-2.38	11.85	7.42	-4.43	-2.05	-7.44 to 3.35	0.447
Percentage of at-bats with strikeouts	1.80	1.39	-0.41	0.09	0.09	0.00	0.41	-0.46 to 1.29	0.344
Isolated power	5.47	3.27	-2.20	0.13	0.13	0.00	2.20	-1.00 to 5.39	0.172
Batting average on balls in play	0.13	0.14	0.01	0.16	0.17	0.01	0.00	-0.03 to 0.05	0.598
Batting average	0.30	0.29	-0.01	0.31	0.29	-0.02	-0.01	-0.04 to 0.02	0.614
On base percentage	0.27	0.26	-0.01	0.29	0.27	-0.02	-0.01	-0.04 to 0.02	0.504
Slugging percentage	0.34	0.33	-0.01	0.36	0.34	-0.02	-0.01	-0.04 to 0.04	0.837
Runs per plate appearance	0.41	0.40	-0.01	0.45	0.45	0.00	0.01	-0.05 to 0.07	0.835
Base running runs above average	102.54	96.82	-5.72	112.20	106.95	-5.25	0.47	-22.23 to 23.16	0.967
Batting and base-running combined	0.20	0.03	-0.17	1.40	0.31	-1.09	-0.92	-2.05 to 0.22	0.111
Defensive chances	4.70	4.50	-0.20	13.49	14.17	0.69	0.89	-12.70 to 14.45	0.896
Wins above replacement	-1.15	-1.78	-0.63	-3.62	-3.65	-0.03	0.60	-2.97 to 4.15	0.738
On base plus slugging percentage	1.71	1.59	-0.12	2.13	1.53	-0.60	-0.48	-1.62 to 0.66	0.397
Speed score	0.75	0.72	-0.03	0.81	0.79	-0.02	0.01	-0.08 to 0.09	0.940
Ultimate base running in runs above average	4.26	3.75	-0.51	4.45	3.87	-0.58	-0.07	-0.92 to 0.79	0.876
Ground into double play runs above average	0.45	-0.13	-0.58	0.67	-0.33	-1.00	-0.42	-1.84 to 1.01	0.546
Stolen bases and caught stealing runs above average	-0.42	-0.28	0.14	-0.19	0.11	0.30	0.16	-0.88 to 1.19	0.751
Runs created based on weighted on-base average	0.17	0.16	-0.01	1.18	0.45	-0.73	-0.72	-1.67 to 0.22	0.130
Runs above average based on weighted on-base average	54.46	43.39	-11.07	58.85	51.89	-6.96	4.11	-16.12 to 24.34	0.683
Weighted on-base average	6.04	5.58	-0.46	12.24	8.12	-4.12	-3.66	-12.09 to 4.79	0.387
	0.33	0.32	-0.01	0.35	0.34	-0.01	0.00	-0.03 to 0.04	0.874

	Control players (proportion)			Injured players (proportion)			Effect of injury		
	Before	After	Difference	Before	After	Difference	RR ^b	95% CI	p value
	Before	After	Difference	Before	After	Difference	RR ^b	95% CI	p value
MVP award	0.08	0.07	-0.01	0.30	0.20	-0.10	0.76	0.25 to 2.35	0.638
All-star game	0.13	0.13	0.00	0.35	0.33	-0.02	0.98	0.53 to 1.81	0.952

Items in italics refer to those values which meet statistical significance

CI confidence interval, Coef. coefficient, RR relative risk

^a A statistically significant positive coefficient indicates that an Achilles tendon injury leads to an increase in player statistics following the injury, while a statistically significant negative coefficient indicates that an Achilles tendon injury leads to a decrease in player statistics following the injury

^b A statistically significant relative risk above 1.00 indicates that Achilles tendon injury leads to an increase in player statistics following the injury, while a statistically significant relative risk below 1.00 indicates that an Achilles tendon injury leads to a decrease in player statistics following the injury

Table 5 Among only injuries to power side and their controls, association of player statistics with Achilles tendon injury

	Control players (mean)			Injured players (mean)			Effect of injury		
	Before	After	Difference	Before	After	Difference	Coef. ^a	95% CI	p value
Total games	111.08	104.29	-6.79	118.33	82.89	-35.44	-28.65	-55.57 to -1.73	0.039
Plate appearances	441.92	370.77	-71.15	465.78	253.00	-212.78	-141.63	-243.38 to -39.88	0.010
Total hits	107.39	86.29	-21.10	108.44	71.63	-36.81	-15.71	-57.43 to 25.99	0.432
Singles	64.17	54.35	-9.82	62.56	44.13	-18.43	-8.61	-31.28 to 14.04	0.428
Doubles	20.63	15.38	-5.25	22.22	14.37	-7.85	-2.60	-11.54 to 6.35	0.544
Triples	1.61	1.13	-0.48	1.89	0.63	-1.26	-0.78	-1.61 to 0.046	0.062
Walks	45.89	39.03	-6.86	45.00	27.50	-17.50	-10.64	-30.34 to 9.05	0.266
Strikeouts	76.78	68.52	-8.26	101.00	78.88	-22.12	-13.86	-50.68 to 22.96	0.433
Intentional walks	5.42	3.42	-2.00	6.78	2.75	-4.03	-2.03	-6.33 to 2.27	0.329
Ground into double plays	9.22	8.71	-0.51	7.78	6.63	-1.15	-0.64	-4.12 to 2.84	0.699
Caught stealing	1.67	1.52	-0.15	1.11	0.13	-0.98	-0.83	-3.14 to 1.47	0.449
Ratio of walks:strikeouts	0.61	0.59	-0.02	0.46	0.37	-0.09	-0.07	-0.21 to 0.05	0.212
Home runs	20.81	15.42	-5.39	21.78	12.50	-9.28	-3.89	-16.36 to 8.58	0.514
Runs batted in	58.25	44.39	-13.86	60.67	35.00	-25.67	-11.81	-38.10 to 14.49	0.352
Stolen bases	69.67	55.74	-13.93	72.56	48.00	-24.56	-10.63	-49.80 to 28.54	0.570
Percentage of at-bats with walks	2.28	1.65	-0.63	4.56	0.13	-4.43	-3.80	-8.67 to 1.07	0.117
Percentage of at-bats with strikeouts	2.49	9.79	7.30	0.09	0.08	-0.01	-7.31	-19.96 to 5.35	0.236
Isolated power	3.69	6.19	2.50	0.21	0.26	0.05	-2.45	-5.57 to 0.68	0.115
Batting average	0.29	0.27	-0.02	0.30	0.29	-0.01	0.01	-0.07 to 0.07	0.982
Batting average on balls in play	0.27	0.24	-0.03	0.27	0.24	-0.03	0.00	-0.02 to 0.03	0.654
On base percentage	0.35	0.32	-0.03	0.35	0.31	-0.04	-0.01	-0.05 to 0.01	0.227
Slugging percentage	0.48	0.40	-0.08	0.48	0.41	-0.07	0.01	-0.08 to 0.10	0.828
Runs per plate appearance	114.06	96.61	-17.45	116.33	91.00	-25.33	-7.88	-36.10 to 20.31	0.558
Base running runs above average	-0.41	-0.48	-0.07	-1.02	-1.34	-0.32	-0.25	-4.05 to 3.57	0.894
Batting and base-running combined	14.04	3.90	-10.14	9.98	-0.95	-10.93	-0.79	-15.11 to 13.53	0.908
Defensive chances	-7.57	-6.72	0.85	-9.47	-6.73	2.74	1.89	-2.27 to 6.07	0.345
Wins above replacement	2.12	0.98	-1.14	1.62	0.21	-1.41	-0.27	-1.78 to 1.24	0.712
On base plus slugging percentage	0.82	0.68	-0.14	0.83	0.72	-0.11	0.03	-0.10 to 0.18	0.538
Speed score	2.93	2.24	-0.69	3.74	1.61	-2.13	-1.44	-2.35 to -0.53	0.004
Ultimate base running in runs above average	-0.38	-0.83	-0.45	-2.46	-1.50	0.96	1.41	-2.15 to 4.96	0.381
Ground into double play runs above average	2.61	-0.25	-2.86	2.54	0.04	-2.50	0.36	-6.61 to 7.30	0.911
Stolen bases and caught stealing runs above average	-0.40	-0.10	0.30	0.23	-0.23	-0.46	-0.76	-1.40 to -0.11	0.025
Runs created based on weighted on-base average	68.72	50.58	-18.14	68.22	39.00	-29.22	-11.08	-40.90 to 18.73	0.439
Runs above average based on weighted on-base average	17.22	5.47	-11.75	12.34	2.13	-10.21	1.54	-15.93 to 19.00	0.853
Weighted on-base average	0.36	0.32	-0.04	0.36	0.31	-0.05	-0.01	-0.05 to 0.04	0.774

	Control players (proportion)			Injured players (proportion)			Effect of injury		
	Before	After	Difference	Before	After	Difference	RR ^b	95% CI	p value
MVP awards	0.19	0.00	-0.19	0.00	0.00	0.00	N/A ^b	-	-
All-star games	0.22	0.11	-0.11	0.00	0.00	-0.33	N/A ^b	-	-

Items in italics refer to those values which meet statistical significance

CI confidence interval, Coef. coefficient, RR relative risk

^a A statistically significant positive coefficient indicates that an Achilles tendon injury leads to an increase in player statistics following the injury, while a statistically significant negative coefficient indicates that an Achilles tendon injury leads to a decrease in player statistics following the injury

^b Could not be calculated due to zero cells

Table 6 Association of player statistics with sidedness of Achilles tendon injury

	Front-sided injuries (mean)			Rear-sided injuries (mean)			Effect of rear versus front		
	Before	After	Difference	Before	After	Difference	Coef. ^a	95% CI	p value
	Before	After	Difference	Before	After	Difference	Coef. ^a	95% CI	p value
Total games	105.10	94.79	-10.31	118.33	82.89	-35.44	-25.13	-56.89 to 6.02	0.108
Plate appearances	366.35	352.94	-13.41	465.78	253.00	-212.78	-199.37	-322.45 to -76.30	0.003
Total hits	101.30	90.95	-10.35	108.44	71.63	-36.81	-26.46	-75.99 to 23.06	0.261
Singles	66.95	59.32	-7.63	62.56	44.12	-18.44	-10.81	-38.35 to 16.76	0.403
Doubles	21.25	19.21	-2.04	22.22	14.38	-7.84	-5.80	-17.78 to 6.17	0.305
Triples	1.50	1.58	0.08	1.89	0.63	-1.26	-1.34	-2.44 to -0.25	0.025
Walks	33.55	33.00	-0.55	45.00	27.50	-17.50	-16.95	-39.91 to 6.01	0.131
Strikeouts	44.65	40.16	-4.49	101.00	78.88	-22.12	-17.63	-55.81 to 20.54	0.328
Intentional walks	4.80	3.16	-1.64	6.78	2.75	-4.03	-2.39	-7.48 to 2.71	0.321
Ground into double plays	9.45	7.53	-1.92	7.78	6.63	-1.15	0.77	-3.34 to 4.88	0.685
Caught stealing	2.60	2.21	-0.39	1.11	0.12	-0.99	-0.60	-2.10 to 0.91	0.399
Ratio of walks:strikeouts	0.90	0.91	0.01	0.46	0.37	-0.09	-0.10	-0.39 to 0.18	0.437
Home runs	11.60	10.84	-0.76	21.78	12.50	-9.28	-8.52	-22.17 to 5.13	0.194
Runs	55.95	47.05	-8.90	60.67	35.00	-25.67	-16.77	-47.79 to 14.76	0.256
Runs batted in	48.90	47.00	-1.90	72.56	48.00	-24.56	-22.66	-66.02 to 20.71	0.271
Stolen bases	11.85	7.42	-4.43	4.56	0.12	-4.44	-0.01	-7.52 to 7.51	1.000
Percentage of at-bats with walks	0.09	0.09	0.00	0.09	0.08	-0.01	-0.01	-0.04 to 0.02	0.447
Percentage of at-bats with strikeouts	0.13	0.13	0.00	0.21	0.26	0.05	0.05	0.02 to 0.10	0.005
Isolated power	0.16	0.17	0.01	0.21	0.17	-0.04	-0.05	-0.14 to 0.02	0.144
Batting average on balls in play	0.31	0.29	-0.02	0.30	0.29	-0.01	0.01	-0.01 to 0.04	0.112
Batting average	0.29	0.27	-0.02	0.26	0.24	-0.02	0.00	-0.03 to 0.02	0.648
On base percentage	0.36	0.34	-0.02	0.35	0.31	-0.04	-0.02	-0.06 to 0.01	0.190
Slugging percentage	0.45	0.45	0.00	0.48	0.41	-0.07	-0.07	-0.17 to 0.04	0.198
Runs per plate appearance	112.20	106.95	-5.25	116.33	91.00	-25.33	-20.08	-50.85 to 10.68	0.177
Base running runs above average	1.40	0.31	-1.09	-1.02	-1.34	-0.32	0.77	-3.42 to 4.96	0.691
Batting and base-running combined	13.49	14.17	0.68	9.98	-9.95	-10.93	-11.61	-31.70 to 8.48	0.227
Defensive chances	-3.62	-3.65	-0.03	-9.47	-6.73	2.74	2.77	-1.50 to 7.05	0.179
Wins above replacement	2.13	1.53	-0.60	1.62	0.22	-1.40	-0.80	-2.46 to 0.84	0.299
On base plus slugging percentage	0.81	0.79	-0.02	0.83	0.72	-0.11	-0.09	-0.22 to 0.04	0.171
Speed score	4.44	3.89	-0.55	3.74	1.61	-2.13	-1.58	-2.66 to -0.45	0.011
Ultimate base running in runs above average	0.67	-0.33	-1.00	-2.46	-1.50	0.96	1.96	-1.69 to 5.6	0.246
Ground into double play runs above average	-0.19	0.11	0.30	2.54	0.04	-2.50	-2.80	-7.07 to 1.47	0.164
Stolen bases and caught stealing runs above average	1.18	0.45	-0.73	0.23	-0.22	-0.45	0.28	-0.86 to 1.4	0.603
Runs created based on weighted on-base average	58.85	51.89	-6.96	68.22	39.00	-29.22	-22.26	-58.15 to 13.61	0.197
Runs above average based on weighted on-base average	12.24	8.12	-4.12	12.34	2.13	-10.21	-6.09	-25.15 to 12.94	0.491
Weighted on-base average	0.35	0.34	-0.01	0.36	0.31	-0.05	-0.04	-0.078 to 0.01	0.144

	Front-sided injuries (proportion)			Rear-sided injuries (proportion)			Effect of rear versus front		
	Before	After	Difference	Before	After	Difference	RR	95% CI	p value
	Before	After	Difference	Before	After	Difference	RR	95% CI	p value
MVP awards	0.29	0.20	-0.09	0.00	0.00	0.00	N/A ^b	-	-
All-star games	0.35	0.33	-0.02	0.33	0.00	-0.33	N/A ^b	-	-

Items in italics refer to those values which meet statistical significance

CI confidence interval, *Coef.* coefficient, *RR* relative risk

^a A statistically significant positive coefficient indicates that a power-sided Achilles tendon injury leads to an increase in player statistics following the injury as compared to a non-power-sided injury, while a statistically significant negative coefficient indicates that a power-sided Achilles tendon injury leads to a decrease in player statistics following the injury as compared to a non-power sided injury

^b Could not be calculated due to zero cells

performance metrics. Overall, the incidence of Achilles tendon rupture reported in MLB has increased substantially since 1996. The rate of return to play in MLB after Achilles tendon rupture and repair is 62% for position players who suffer the injury. Our overall data demonstrates through comparison of injured players and four sets of matched controls (with statistically similar demographics) that there was no association of Achilles tendon injury with effect on any of the advanced player metrics, suggesting that Achilles tendon injury does not affect player statistics in those who return-to-play after surgery. However, laterality of the Achilles tendon rupture may have an effect on these players' performance. In comparison to players who injured the Achilles tendon of their front (non-power-generating) leg, those with Achilles tendon ruptures of the rear (power-generating) had significantly less plate appearances and increased at-bats with strikeouts. In addition, they had significantly fewer triples, which take subjectively high levels of speed and agility to attain in comparison to other hits, and a significant decrease in speed score (which is a statistic which attempts to measure a player's running ability) suggesting that the careers of those with Achilles tendon rupture to the power-generating rear leg are detrimentally affected. This similar finding held true in comparing power and non-power extremity injuries to their corresponding controls, which found that among only injuries to the non-power side and their controls, injury was associated with a greater number of triples, whereas those with injury to the rear leg had significantly fewer total games, less plate appearances, and lower speed scores and stolen bases. The increased number of triples for those with injuries to the non-power side in comparison to their controls is an inconsistent finding with the general trends of injured and non-injured patients throughout the rest of our analysis, and either represents an outlier finding, or a currently difficult to explain organic etiology that would require future study.

This study provides the first quantitative look at how Achilles tendon rupture and repair affects the return to play rate and quality of professional MLB players, but there are limitations to a study of this design. First, we are limited by the relatively low number of Achilles tendon ruptures that have been reported in MLB players ($n = 13$). This affects both the power and number of subgroup analyses that are available with our data calculations. Additionally, the reliance for accurate and precise data collection was on publicly available sources, and specifics on player metrics or concomitant injuries that could theoretically have went unpublished would be lost in our analysis and interpretation of the data. In particular, it is possible that record keeping has improved with time, and thus, there could be Achilles tendon ruptures from decades ago that went unrecorded in the available databases that we were unable to analyze. Information regarding the surgical technique utilized at the time of Achilles tendon repair (i.e., open versus percutaneous) and postoperative rehabilitation were unavailable, which limits this study from assessing stratifying MLB player return and performance metrics in terms of these important variables. The identification of pair-matched control groups was provided by an unpublished statistical algorithm [2]. As

has been referenced as a limitation in previous studies of similar design to this one [5], it was not possible to account for players' sport- or team-related confounders, including team style of play, team batting or base-stealing strategies, coaching staff, city and layout of ballpark played in, competition level of the players' team division, and other variables that influence individual player performance metrics [5]. Finally, it is possible that performance metrics which are not statistically significant may be of substantial effect to on-field play.

Parekh et al. [14] identified 31 National Football League (NFL) players between 1997 and 2002 who suffered Achilles tendon ruptures. They reported that 19% of injuries occurred during preseason play, while another 18% occurred in the first month of the official season. On average, they found that players experienced a greater than 50% reduction in their power ratings, and 32% of NFL players with an Achilles tendon rupture did not return to play in the NFL. Amin et al. [1] identified 18 professional National Basketball Association (NBA) players with Achilles tendon repair over a 23-year period (1988–2011); they reported that seven never returned to play an NBA game, and 11 returned to play at least one season with eight returning for 2+ seasons. Although the NBA and NFL have had representative studies reporting the incidence and outcomes after Achilles tendon rupture and repair, no such study exists for professional MLB players. Our study found comparable rates of injury during preseason or the first month of the regular season and very similar return to play for MLB position players as these aforementioned NFL and NBA players. However, unlike the NBA players from Amin et al. [1] who in comparison to controls demonstrated a significant decline in player efficiency rating in the first season after their return, the MLB players in our study overall did not significantly decline in performance. All MLB players with Achilles tendon rupture were managed operatively, coincident with data that would suggest that the re-rupture rate is lower with surgical intervention [4].

There is a relative scarcity of Achilles tendon ruptures in MLB players (just 26 total between 1972 and 2015) as compared to Achilles tendon injuries in other professional sports, or as compared to upper extremity injuries. However, the importance of reporting the findings from this injury is pertinent given the incidence of this injury seems to be increasing in recent decades, particularly in recent years: two Achilles tendon ruptures occurred in MLB players in 2015 and were thus too recent for inclusion in our analysis of postoperative play, and two Achilles tendon ruptures occurred in 2014 with these players ultimately retiring rather than returning to play after surgery. This recent increase in the last few decades is coincident with an era of steroid use in professional baseball, and given the potential association of systemic steroid use and Achilles tendon rupture [3], this injury may become more prevalent in the future. Other possible explanations would have to be evaluated with future study and analysis but may potentially include increasing emphasis on player size and muscle content in recent years/decades, greater emphasis on strength and weight training, changes in rehabilitation protocols, legal or illegal

supplement use, off-season workouts, or overall cumulative play (prior to professional play, including total time of play during age group, travel baseball, high school and collegiate competition). Unfortunately, due to low numbers of pitchers with Achilles tendon ruptures and of players who play only one position in the field, we were unable to analyze pitchers or the position players' fielding performance statistics. This will provide an avenue for future assessments when the relative number of players with such information available increases, as this temporal trend may have us believe it will.

Compliance with Ethical Standards

Conflict of Interest: Bryan M. Saltzman, MD receives personal fees from Nova Science Publishers and Postgraduate Institute for Medicine, outside the work. Bernard R. Bach, Jr., MD reports personal fees from SLACK Incorporated; other from Arthrex, Inc, CONMED Linvatec, DJ Orthopaedics, Ossur, Smith & Nephew, and Tornier; Board or committee member for American Orthopaedic Society for Sports Medicine, outside the work. Simon Lee, MD, reports personal fees from SLACK Incorporated, outside the work; and American Orthopaedic Foot and Ankle Society: Committee member; Foot and Ankle International: Board Membership. Matthew W. Tetreault, MD, Daniel D. Bohl, MD, Danielle Tetreault, BS, have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was waived from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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