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To cite this article: Michael J. Gutman, Brian S. Gutman, Christopher D. Joyce, Jacob M. Kirsch, Matthew B. Sherman & Surena Namdari (2022) Performance in major league baseball pitchers after surgical treatment of thoracic outlet syndrome, *The Physician and Sportsmedicine*, 50:2, 141-146, DOI: [10.1080/00913847.2021.1880251](https://doi.org/10.1080/00913847.2021.1880251)

To link to this article: <https://doi.org/10.1080/00913847.2021.1880251>



Published online: 21 Mar 2021.



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ORIGINAL RESEARCH



Performance in major league baseball pitchers after surgical treatment of thoracic outlet syndrome

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ABSTRACT

Introduction: Thoracic outlet syndrome (TOS) can be a career-threatening injury for Major League Baseball (MLB) pitchers, often requiring surgical management. The purpose of this study is to determine the efficacy of surgical management for TOS as a function of return to play and quantitative pitching metrics.

Methods: 27 MLB pitchers underwent surgical treatment for TOS between January 2001 and December 2017. Analysis of pre and postoperative pitching metrics were used to assess the effect of surgery on 20 pitchers who returned to pitch in MLB. All pitching metrics were compared via assessing performance two years prior to surgery and two years after surgery. For 20 pitchers who returned to pitch, MLB pitching metrics of earned run average (ERA), walks plus hits per innings pitched (WHIP), wins above replacement (WAR), and average fastball velocity were used to assess a pitcher's ability to return to preoperative performance level.

Results: Of the 27 pitchers, 20 pitchers were diagnosed with neurogenic thoracic outlet syndrome (NTOS) and seven with venous thoracic outlet syndrome (VTOS). The average age of onset of TOS was 28.6 years. There was no significant difference between the age of onset between the NTOS and VTOS populations ($p = 0.272$). Of the 27 pitchers, 20 (74.1%) were able to return to MLB play at a mean of 297 days (range, 105–638 days) after surgery. Pitching metrics demonstrated that pitcher ERA remained inferior postoperatively compared to baseline preoperative performance (3.66 vs 4.50, $p = 0.03$). Fastball velocity ($p = 0.94$) and strike percentage ($p = 0.50$) were equivalent to pre-injury performance.

Conclusion: 74% of professional pitchers who undergo surgical intervention for TOS are able to return to play at the MLB level. With regards to performance, the majority of metrics were unchanged from prior to surgery, indicating return at a similar functional level.

ARTICLE HISTORY

Received 31 July 2020

Accepted 19 January 2021

KEYWORDS

Neurogenic thoracic outlet syndrome; brachial plexus; baseball; shoulder; return to play; venous thoracic outlet syndrome

Introduction

Thoracic outlet syndrome (TOS) is a rare condition that occurs when there is compression of the subclavian artery, subclavian vein, or the brachial plexus [1–4]. Though multiple compressive structures are implicated in TOS, hypertrophic scalene or pectoralis minor muscles are most commonly seen in overhead athletes [1,5–8]. TOS can further be subdivided based on the compromised neurovascular structures such as arterial, venous, or neurogenic. Most cases of TOS are neurogenic, composing 95% of the cases, followed by venous thoracic outlet obstruction (VTOS) comprising 4% of the cases [2]. The C8 and T1 nerve roots are most commonly affected in neurogenic thoracic outlet syndrome (NTOS), causing paresthesia, weakness, and pain commonly involving multiple fingers. Symptoms in NTOS are typically worse with arm elevation [9]. These abnormal findings are not necessarily in a standard dermatomal pattern but rather to a region, such as the arm, hands, or fingers [3,10]. VTOS may

present as either acute thrombosis or chronic intermittent obstruction [6,7].

In the general population, the most common method of treatment for NTOS is physical therapy to relieve pain and dysfunction [11–15]. For patients who are unsuccessfully treated via physical therapy, surgical management can be considered [7,12,16]. Surgical management of NTOS involves reducing compression on the nerves. This can be done by either directly releasing the scalene or pectoralis minor muscles or indirectly by excising the first rib [16–19]. Surgical management of VTOS is comprised of thrombolysis of the acute clot and embolectomy [7].

For the professional pitcher, TOS can be a career ending injury. Moreover, the definition of surgical success in the general population is different than that in the professional athlete. There has been an increase in media coverage of TOS due to several major league baseball pitchers undergoing surgery

over the last few years. The purpose of this study is to determine the outcome of surgical treatment of TOS in Major League Baseball (MLB) pitchers using return to play and objective performance metrics.

Methods

This retrospective study was exempt from institutional review board (IRB) approval since all patient information used is publicly available. The cohort consisted of Major League Baseball (MLB) pitchers who underwent surgical treatment for TOS between January 2001 and October 2017. These pitchers were identified for injury via press releases and team injury reports, in accordance with the Major League Baseball Players Association's collective bargaining agreement. The sources used to confirm the pitchers injuries were Fan-Graphs (<http://www.fangraphs.com>), Pro Sports Transactions (<http://www.prosportstransactions.com>) and Major League Baseball (MLB.com) injury reports. Position players were excluded for the purposes of this study. For each pitcher, articles written before and after surgery were reviewed to classify the cause of the TOS as either neurogenic or venous. Patients who underwent surgery due to 'blood clots' were classified as VTOS [9].

For each patient, pre and postoperative baseball statistics were confirmed via two independent sources. The primary sources of pitching metrics were ESPN (<https://www.espn.com/>), Major League Baseball (<https://www.mlb.com/>), Brooks Baseball (<http://www.brooksbaseball.net/>), Fan-Graphs (<http://www.fangraphs.com>), and Baseball Reference (<http://www.baseballreference.com>).

Preoperative statistical analysis was run on all players to determine risk factors for TOS development. The following preoperative information was collected: age at MLB debut, total years of pitching in the MLB, total games pitched in the MLB, total innings pitched in MLB prior to injury, total pitches thrown prior to injury, and total complete games pitched before injury.

Postoperative baseball statistics were analyzed for pitchers who successfully returned to play. All categories were compared from the pitchers' baseline statistics two years prior to surgery through two years after surgery. The pitching metrics compared were earned runs average (ERA), walks plus hits per inning pitched (WHIP), wins above replacement (WAR), strikeouts per 9 innings (K/9), average fastball velocity, and strike percentage. Pitching statistics that reflect team performance such as wins and losses were excluded from the analysis. The time from surgery to return to play was calculated for each pitcher.

Statistics

T-tests were used to calculate the p values for continuous data and Chi Square testing or Fisher's Exact tests were used for categorical testing to calculate p values. After univariate analysis, a set of t-tests were performed comparing the difference in performance metrics two years before and two years after the injury. Correlational analysis was performed to evaluate pitching performance over time. All

values <0.05 were deemed to be significant. All statistical analyses were conducted using R Studio (Version 3.6.1, Vienna, Austria).

Results

Twenty-seven major league pitchers underwent surgical treatment of TOS between 2001 and 2017. Twenty pitchers were diagnosed with NTOS and 7 with VTOS. The mean age of onset of TOS was 28.6 ± 3.9 years (range, 23 to 37 years). The average age of NTOS and VTOS was 29.1 ± 3.7 , (range, 23 to 37 years) and 27.0 ± 4.2 , (range, 23 to 36 years) respectively ($p = 0.272$). Twenty-one (77.8%) of the pitchers were starters and six (22.2%) were relief pitchers. There was not a significant difference between the NTOS and VTOS cohorts in the development of TOS in relation to preoperative workload (pitches thrown, innings pitched, number of games pitched, years in the MLB, complete games thrown) (Table 1). In addition, there were no differences in the ability to return to play in the NTOS population compared to the VTOS population ($p = 1.00$).

For pitched included in our return to play analysis, 20 pitchers (74.1%, $n = 27$) returned to play at the major league level postoperatively of which 14 were NTOS and 6 were VTOS. Of the 7 pitched considered unable to return to play, 6 never returned to the MLB, and one did return for 5 innings before returning to the disabled list and never playing thereafter. The mean and median time from surgery to return to play was 297 and 274 days, respectively. There was no statistically significant difference between the time to return to play between the NTOS (mean 313; range, 135 to 638 days) and VTOS (mean 260; range, 105 to 456 days) groups ($p = 0.265$). In pitchers who returned to play, there was no difference between postoperative pitching performance in the NTOS and VTOS populations (Table 2).

To assess the success of surgical outcomes among the 20 pitchers who returned to pitching at the major league level, pitching metrics were compared from two years preoperatively to two years postoperatively (Table 3). Of the 20 pitchers that returned to play, 18 pitchers played a minimum of 2 years in the MLB after surgery. ERA (3.66 vs 4.50, $p = 0.03$) was significantly worse after surgery. There was no statistically significant difference in preoperative and postoperative WHIP (1.29 ± 0.19 vs 1.41 ± 0.24 , $p = 0.096$) and WAR (1.69 ± 1.67 vs 0.98 ± 1.56 , $p = 0.215$). Average fastball velocity (91.7 vs 91.8 , $p = 0.941$), strike percentage (63% vs. 63%, $p = 0.500$), and K/9 (7.32 vs. 7.23 , $p = 0.878$) were unchanged postoperatively.

Analysis was performed to evaluate if pitching performance declined from two years prior to surgery to year of surgery. During this time period, there was a decrease in pitching performance in both the NTOS and VTOS cohorts. In the NTOS population, ERA (Spearman's rho = 0.407, $p = 0.004$), WHIP (Spearman's rho = 0.310, $p = 0.032$), and WAR (Spearman's rho = -0.471, $p = 0.001$) performance continuously declined. In the VTOS population, ERA (Spearman's rho = 0.596, $p = 0.007$), WHIP (Spearman's rho = 0.486, $p = 0.035$) performance declined.

Two pitchers (33.3%) with VTOS had recurrence at two years and six years respectively after the initial operation.

Table 1. Comparison of pre-operative pitching metrics in neurogenic thoracic outlet obstruction (NTOS) versus venous thoracic outlet obstruction (VTOS).

	TOS (n = 27)	NTOS (n = 20)	VTOS (n = 7)	P Value
Return to MLB	21 (77.8%)	15 (75.0%)	6 (85.7%)	1.000
Age at Surgery	28.6 (3.85)	29.1 (3.65)	27.0 (4.24)	0.272
Starter vs Relief				1.000
Relief	6 (22.2%)	5 (25.0%)	1 (14.3%)	
Starter	21 (77.8%)	15 (75.0%)	6 (85.7%)	
Age of MLB Debut	23.1 (1.46)	23.4 (1.57)	22.6 (0.98)	0.144
Years in MLB Before Surgery	5.52 (3.79)	5.75 (3.85)	4.86 (3.80)	0.605
Games in MLB Before Surgery	146 (120)	136 (96.0)	176 (180)	0.589
Innings Pitched in MLB Before Surgery	622 (553)	598 (505)	690 (714)	0.760
Number of Pitches Before Surgery	9755 (8331)	9339 (7519)	10945 (10933)	0.728
Career Complete Games Prior to Surgery	3.30 (6.50)	3.50 (7.42)	2.71 (2.81)	0.694
Innings Pitched				
2 Years Prior	101 (80.9)	97.7 (82.9)	111 (82.1)	0.735
1 Year Prior	110 (72.9)	99.6 (72.0)	143 (71.6)	0.235
# Complete Games				
2 Years Prior	0.55 (1.14)	0.44 (0.63)	0.83 (2.04)	0.659
1 Year Prior	0.54 (0.93)	0.44 (0.98)	0.83 (0.75)	0.334
Year of Surgery	0.23 (0.53)	0.27 (0.59)	0.14 (0.38)	0.562
ERA				0.742
2 Years Prior	3.66 (1.19)	3.61 (1.18)	3.82 (1.31)	0.054
1 Year Prior	4.36 (1.29)	4.15 (1.39)	5.01 (0.65)	0.963
Year of Surgery	5.50 (1.97)	5.49 (2.32)	5.52 (0.98)	
WHIP			1.30 (0.27)	
2 Years Prior			1.52 (0.16)	0.782
1 Year Prior	1.28 (0.23)	1.27 (0.23)	1.55 (0.22)	0.062
Year of Surgery	1.39 (0.23)	1.55 (0.49)		0.999
	1.55 (0.41)	1.67 (1.64)		
WAR				
2 Years Prior	1.64 (1.49)	1.67 (1.64)	1.57 (1.09)	0.869
1 Year Prior	1.64 (1.49)	1.67 (1.64)	1.57 (1.09)	0.869
Year of Surgery	0.12 (0.77)	0.05 (0.57)	0.29 (1.12)	0.610
K/9				
2 Years Prior	7.32 (2.90)	6.84 (2.01)	8.60 (4.53)	0.397
1 Year Prior	6.51 (2.34)	6.49 (2.37)	6.56 (2.44)	0.951
Year of Surgery	6.51 (2.24)	6.85 (2.39)	5.78 (1.83)	0.267
Pitching Velocity				
2 Years Prior	92.4 (3.61)	91.7 (3.28)	97.0 (2.47)	0.145
1 Year Prior	92.2 (3.37)	91.6 (3.22)	95.3 (2.79)	0.133
Year of Surgery	93.1 (2.24)	92.8 (2.35)	93.9 (1.76)	0.366
Strike Percentage				
2 Years Prior	0.63 (0.07)	0.62 (0.08)	0.63 (0.04)	0.728
1 Year Prior	0.62 (0.06)	0.63 (0.07)	0.63 (0.02)	0.701
Year of Surgery	0.62 (0.06)	0.63 (0.07)	0.62 (0.03)	0.765

One pitcher (7.1%) with NTOS developed recurrence of NTOS one year after the initial operation. In addition, one pitcher with NTOS developed TOS in his non-dominant pitching arm four years later. All pitchers with TOS recurrence were successfully able to return to play after surgical treatment.

Outcomes between demographics and preoperative metrics were compared between the 20 patients that returned to pitching at the major league level after surgery and the 7 that did not. There were no statistically significant differences in preoperative demographics or pitching metrics (Table 4).

Discussion

Over the last several years, there has been an increase in surgery in Major League Baseball pitchers to treat TOS.

Between 2001–2010 there were only seven cases of pitchers undergoing surgery for TOS. Of those seven pitchers, four players experienced VTOS and three experienced NTOS. However, between 2011–2017, 20 pitchers underwent surgery for TOS, with 3 for VTOS and 17 for NTOS. It is unknown if the increase in surgical management and diagnosis of TOS in MLB pitchers is due to external factors such as exercise regimen or simply improved recognition of the condition.

TOS is potentially a career threatening injury for major league pitchers. This study shows a relatively high rate of return to play and maintenance of most performance measures in pitchers with NTOS and VTOS. Thompson et al. demonstrated that in the NTOS population, 10 of 13 (76.9%) patients were able to return to play after thoracic outlet decompression and the postoperative pitching performance was largely equivalent to preoperative performance [20].

Table 2. Comparison of post-operative pitching metrics in neurogenic thoracic outlet obstruction (NTOS) versus venous thoracic outlet obstruction (VTOS).

	TOS (n = 20)	NTOS (n = 14)	VTOS (n = 6)	P Value
Time from Surgery to Return to Play	297 (126.53)	313 (130.50)	260 (119.10)	0.265
ERA				
Year of Surgery	5.51 (1.94)	5.60 (2.36)	5.35 (0.95)	0.759
1 Year After	5.26 (2.17)	5.29 (2.36)	5.18 (1.88)	0.914
2 Years After	4.50 (1.07)	4.23 (1.14)	5.04 (0.72)	0.086
WHIP				
Year of Surgery	1.55 (0.21)	1.51 (0.23)	1.62 (0.12)	0.193
1 Year After	1.48 (0.29)	1.44 (0.24)	1.55 (0.39)	0.526
2 Years After	1.41 (0.24)	1.37 (0.26)	1.49 (0.17)	0.245
WAR				
Year of Surgery	0.08 (0.85)	0.06 (0.59)	0.35 (1.22)	0.462
1 Year After	0.71 (1.66)	0.45 (1.37)	1.27 (2.21)	0.430
2 Year After	0.98 (1.56)	1.00 (1.49)	0.95 (1.85)	0.955
K/9				
Year of Surgery	6.56 (1.67)	6.92 (1.45)	5.89 (1.98)	0.294
1 Year After	6.42 (1.66)	6.59 (1.00)	6.04 (2.70)	0.652
2 Years After	7.23 (1.71)	7.43 (1.47)	6.83 (2.22)	0.561
Pitching Velocity				
Year of Surgery	92.9 (2.50)	92.5 (2.59)	94.1 (2.10)	0.353
1 Year After	92.1 (2.65)	91.6 (2.62)	93.7 (2.38)	0.192
2 Year After	91.8 (2.70)	91.3 (2.71)	93.3 (2.35)	0.205
Strike Percentage				
Year of Surgery	0.63 (0.03)	0.64 (0.03)	0.62 (0.03)	0.238
1 Year Prior	0.63 (0.04)	0.63 (0.05)	0.63 (0.03)	0.723
2 Years Prior	0.63 (0.03)	0.63 (0.02)	0.62 (0.04)	0.477

Similarly, Shutze et al. demonstrated that in competitive athletes with NTOS, 70% of patients returned to sports at the same level and 50% were able to return to sports within 1 year of surgery [19].

The results of surgery in the 20 pitchers included in our analysis showed similar results. While, ERA demonstrated a significant decrease in performance ($p = 0.03$), other metrics such as average fastball velocity, strike percentage, and K/9 demonstrated nearly identical performance two years after surgery.

It is believed that 'descriptive' metrics such as fastball velocity or strike percentage are reflective of the pitcher's overall health status, while 'rate' metrics such as WHIP, ERA, or WAR are reflective of the pitcher's individual performance [20]. Based on the results, in the pitchers who returned to play, the mean pitching velocity and strike percentage 2 years post-operatively were nearly identical to their performance baseline two years prior to surgery. Pitching velocity can be used as a surrogate to assess pitcher strength, while strike percentage can be used as a surrogate to assess fine motor function and control. The rate metrics are likely to be influenced by both the pitcher's health status as well as the success of the team on which the pitcher plays.

We were unable to identify any preoperative indicators to predict which pitchers will return to the MLB after surgical intervention. There were no observable preoperative differences between the NTOS and VTOS populations and furthermore, there were no preoperative differences between the 20 pitchers who were able to return to pitching after TOS surgery and the 7 pitchers that did not return to pitching. External factors including rehabilitation time may also explain why some pitchers do not return to pitching, including the reluctance of MLB teams to offer a contract to pitchers after TOS.

A decline in pitching performance was observed in both the NTOS and VTOS cohorts between the two years prior to surgery and the time of surgery. This decline likely indicates that many pitchers tried to continue to pitch through the TOS symptoms for at least one or more seasons. This can be explained by the difficulty involving the diagnosis of NTOS. NTOS is often a diagnosis of exclusion due to unremarkable objective diagnostic data [4,14,21–23]. Therefore, pitchers were less likely to undergo immediate surgery for TOS. Interestingly, although patients with VTOS often underwent emergency surgery due to blood clots, similar to the NTOS cohort, they too encountered a decline in performance from two years preoperatively until the time of surgery. This

Table 3. Comparison of pitching metrics 2 years prior to surgery to 2 years postoperatively in pitchers that returned to play.

	2 years Prior to Surgery (n = 16)	Year of Surgery (n = 17)	2 years Post Operatively (n = 18)	Difference (2 years postop – 2 years prior)	P-Value of Difference
ERA	3.66 (1.06)	5.51 (1.94)	4.50 (1.07)	0.84	0.03
WHIP	1.29 (0.19)	1.55 (0.20)	1.41 (0.24)	0.13	0.096
K/9	7.32 (1.73)	6.56 (1.67)	7.23 (1.71)	-0.09	0.878
WAR	1.69 (1.67)	0.082 (0.85)	0.98 (1.56)	-0.71	0.215
Strike Percentage	0.63 (0.04)	0.63 (0.3)	0.63 (0.03)	0.0	0.500
Pitching Velocity	91.7 (3.02)	92.88 (2.5)	91.8 (2.70)	0.1	0.941

Table 4. Comparison of preoperative pitching metrics in pitchers that returned to play versus pitchers unable to return to play.

	Returned to play (n = 20)	Unable to return to play (n = 7)	P-Value
Type:			0.633
NTOS	14 (70.0%)	6 (85.7%)	
Venous	6 (30.0%)	1 (14.3%)	
Age at Surgery	28.1 (3.91)	29.9 (3.63)	0.302
Starter vs Relief			0.290
Relief	3 (15.0%)	3 (42.9%)	
Starter	17 (85.0%)	4 (57.1%)	
Age of MLB Debut	22.9 (1.17)	23.9 (2.04)	0.275
Years in MLB Before Injury	5.25 (3.64)	6.29 (4.39)	0.589
Games in MLB Before Injury	148 (133)	142 (82.8)	0.891
Innings Pitched in MLB Before Injury	676 (608)	467 (343)	0.281
Number of Pitches Before Injury	10540 (9145)	7514 (5291)	0.304
Career CG Prior to Injury	2.35 (2.81)	6.00 (12.1)	0.458
Innings Pitchers			
2 Years Prior	99.1 (81.1)	108 (87.8)	0.842
1 Year Prior	114 (70.9)	99.0 (84.5)	0.702
ERA			
2 Years Prior	3.66 (1.06)	3.66 (1.58)	1.000
1 Year Prior	4.27 (1.36)	4.64 (1.10)	0.523
WHIP			
2 Years Prior	1.29 (0.19)	1.26 (0.35)	0.866
1 Year Prior	1.36 (0.23)	1.46 (0.25)	0.413
WAR			
2 Years Prior	1.69 (1.67)	1.52 (0.95)	0.767
1 Year Prior	1.24 (1.58)	0.65 (1.55)	0.440
K/9			
2 Years Prior	7.32 (1.73)	7.33 (5.12)	0.999
1 Year Prior	6.53 (2.12)	6.43 (3.14)	0.943
Pitching Velocity			
2 Years Prior	91.7 (3.02)	93.8 (4.75)	0.407
1 Year Prior	92.3 (3.47)	91.9 (3.42)	0.808
Strike Percentage			
2 Years Prior	0.64 (0.04)	0.60 (0.11)	0.469
1 Year Prior	0.64 (0.03)	0.58 (0.10)	0.244

phenomenon can be attributed to nerve compression seen in some patients with VTOS.

Pitching performance continually improved in the NTOS cohort from time of surgery through two years after in ERA, WHIP, and WAR. The continued improvement over time indicates that following surgery, pitchers continue to improve even after returning to the major league pitching level. In the NTOS cohort, although surgical decompression of the nerve alleviates the constant compression on the brachial plexus, relieving the obstruction alone does not lead to immediate recovery since nerve damage heals very slowly [24]. Although surgery corrects the anatomic issues causing TOS, many of the pitchers in this study likely developed compensatory alterations to pitching mechanics including changes in posture to minimize pain preoperatively and minimize brachial plexus nerve irritation prior to diagnosis [20]. These long-standing changes in pitching mechanics prior to surgery may have negatively impacted pitcher performance after initial return to play.

Limitations

There are several limitations to this study. One major limitation is the scarcity of information on additional

injuries that may have influenced pitchers' performance. Although injury reports and press releases for every pitcher were comprehensively reviewed, it is possible that misreported information resulted in either excluding patients that underwent TOS or wrongly categorizing a pitcher as NTOS versus VTOS. Our study does not allow for analysis on pitcher satisfaction from surgery or patient perceived outcomes. Additionally, severity of presentation based on clinical exam and preoperative physical exam findings was not known, which could affect the ability to return to play and could not be accounted for. Furthermore, specific details of each surgical case (surgical technique, postoperative rehabilitation) were unknown and may not have been uniform for all pitchers. The postoperative clinical exam findings were not known, which may have affected pitchers ability to return to play. Therefore, we are unable to make any recommendations regarding specific technique resulting in superior outcomes. Although ERA, WHIP, WAR, K/9, strike percentage, and average fastball velocity were metrics used to analyze pitching performance, it is possible that there were other aspects of pitching performance not assessed by these metrics. While preoperative factors such as preoperative pitching load were analyzed to determine the effect of preoperative workload on the development of TOS, our study only looked at pitching load at the major league

level. Our study did not factor in pitching workload experienced in high school, college, and in minor league baseball or take into consideration the type of rehabilitation performed.

Conclusion

Surgical treatment for TOS was able to return over 74% of pitchers back to play at a major league level. Performance appears to be restored to pre-injury levels at two years after surgery. Further study will be needed to determine whether earlier surgical intervention would help to avoid the performance decline seen prior to surgery and improve the rate of return to play.

Acknowledgements

The authors thank Jeffrey Gutman, Marshall Meyers, and Nachum Meyers for their assistance with analysis of baseball performance metrics.

Declaration of interest

No potential conflict of interest was reported by the authors.

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