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# Performance Metrics in Professional Baseball Pitchers before and after Surgical Treatment for Neurogenic Thoracic Outlet Syndrome

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**Background:** High-performance throwing athletes may be susceptible to the development of neurogenic thoracic outlet syndrome (NTOS). This condition can be career-threatening but the outcomes of treatment for NTOS in elite athletes have not been well characterized. The purpose of this study was to utilize objective performance metrics to evaluate the impact of surgical treatment for NTOS in Major League Baseball (MLB) pitchers.

**Methods:** Thirteen established MLB pitchers underwent operations for NTOS between July 2001 and July 2014. For those returning to MLB, traditional and advanced (PitchF/x) MLB performance metrics were acquired from public databases for various time-period scenarios before and after surgery, with comparisons made using paired *t*-tests, Wilcoxon matched-pair signed-rank tests, and Kruskal–Wallis analysis of variance.

**Results:** Ten of 13 pitchers (77%) achieved a sustained return to MLB, with a mean age of  $30.2 \pm 1.4$  years at the time of surgery and  $10.8 \pm 1.5$  months of postoperative rehabilitation before the return to MLB. Pre- and postoperative career data revealed no significant differences for 15 traditional pitching metrics, including earned run average (ERA), fielding independent pitching, walks plus hits per inning pitched (WHIP), walks per 9 innings, and strikeouts to walk ratio (SO/BB). There were also no significant differences between the 3 years before and the 3 years after surgical treatment. Using PitchF/x data for 72 advanced metrics and 25 different time-period scenarios, the highest number of significant relationships ( $n = 18$ ) was observed for the 8 weeks before/12 weeks after scenario. In this analysis, 54 (75%) measures were unchanged (including ERA, WHIP, and SO/BB) and 14 (19%) were significantly improved, while only 4 (6%) were significantly decreased (including hard pitch maximal velocity  $93.1 \pm 1.0$  vs.  $92.5 \pm 0.9$  miles/hr,  $P = 0.047$ ). Six pitchers remained active in MLB during the study period, while the other 4 had retired due to factors or injuries unrelated to NTOS.

**Conclusions:** Objective performance metrics demonstrate that pitchers returning to MLB after surgery for NTOS have had capabilities equivalent to or better than before treatment. Thoracic outlet decompression coupled with an ample period of postoperative rehabilitation can provide effective treatment for professional baseball pitchers with career-threatening NTOS.

Conflicts of interest: None.

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## INTRODUCTION

Neurogenic thoracic outlet syndrome (NTOS) is a rare and potentially disabling condition caused by dynamic compression of the brachial plexus.<sup>1</sup> It is thought to be caused by predisposing variations in anatomy combined with scalene and/or pectoralis minor muscle hypertrophy or injury, resulting in muscle fibrosis and excessive, sustained, muscle spasm.<sup>1</sup> Compression and irritation of the adjacent brachial plexus is reflected by tenderness over the scalene triangle and/or subcoracoid space, along with exacerbation of upper extremity pain, numbness, and paresthesia during arm elevation.<sup>2,3</sup> Because there are no laboratory testing approaches, electrophysiological tests, or imaging procedures that are sufficiently accurate to establish or dismiss NTOS, the diagnosis is based largely on the exclusion of other conditions and a recognition of stereotypical clinical patterns.<sup>3</sup> The initial treatment of NTOS is almost always centered on pain management, physical therapy, and workplace ergonomic modifications, but surgical management is recommended when there are disabling symptoms, a sound clinical diagnosis, and a lack of satisfactory improvement following conservative approaches.<sup>1,4</sup>

Recent studies indicate that there have been improvements in the outcome of surgical treatment for NTOS, along with increasing evidence for enhanced quality-of-life in surgical patients.<sup>4–7</sup> The outcomes of surgery for NTOS are usually measured in conventional terms (postoperative complications, hospital length of stay, etc.), as well as self-assessment symptom surveys, validated measurement instruments, and rates of return to work.<sup>4–7</sup> However, such approaches may provide incomplete assessment of results, given that patients recovered from surgical treatment may still have intermittent or activity-related symptoms. It is important to continue developing new approaches to more accurately assess the functional outcomes of surgical treatment for NTOS.

High-performance throwing athletes may be susceptible to the development of NTOS as a manifestation of repetitive strain injury and this condition has been occasionally identified in collegiate and professional baseball players.<sup>8–12</sup> In elite athletes, NTOS can be a career-threatening condition and surgical treatment may often be recommended. While excellent outcomes of surgical treatment have been described for elite overhead athletes undergoing surgical treatment for venous TOS (subclavian vein effort thrombosis) and forms of arterial TOS,<sup>10,13–15</sup> the outcomes of treatment for NTOS in this unique population have not been well characterized.

With the advent of comprehensive pitch-by-pitch assessment, application of complex statistical analytics, and the availability of large public databases, a wealth of detailed information is currently available regarding baseball pitching performance at the professional level.<sup>16–21</sup> This information has been used to evaluate the success rates and outcomes of treatment for other conditions, such as reconstruction of the medial ulnar collateral ligament, yielding new insights into the value, and limitations of surgical treatment.<sup>22–26</sup> The purpose of this study was to utilize objective performance metrics for Major League Baseball (MLB) pitchers who have undergone surgical treatment for NTOS, to determine the effects of treatment on postoperative athletic performance.

## METHODS

### Study Group

Professional MLB pitchers who underwent surgical treatment for NTOS between July 2001 and July 2014 were identified from publicly available media and MLB team injury reports. Position players with NTOS were excluded from analysis, as were pitchers who had undergone surgical treatment for either arterial or venous forms of TOS. Of 13 MLB pitchers meeting these criteria, 3 individuals did not achieve a sustained return to play at the MLB level after surgical treatment for NTOS. The study group thereby consisted of 10 individuals meeting the inclusion criteria and achieving a sustained return to MLB before October 2015. The study was determined to be exempt from full Institutional Review Board (IRB) review by the Washington University School of Medicine Human Research Subjects Committee.

### Sources of Data

For each study subject, individual game logs for MLB regular season games were compared from 2 independent sources to ensure data accuracy, FanGraphs (<http://www.fangraphs.com>) and Brooks Baseball (Pitch Info LLC, Chicago, IL; <http://www.brooksbaseball.net>), with additional data obtained from Baseball Reference (<http://www.baseball-reference.com>).

### Traditional Pitching Metrics

Fifteen traditional pitching metrics thought to be potentially affected by NTOS were selected for inclusion in the study, including win–loss percentage, strikeouts per 9 innings, walks per 9 innings (BB/9), strikeouts per walks (SO/BB), home runs per 9

**Table I.** MLB pitchers with NTOS, careers before surgical treatment

Pitcher	Side	Age at debut	Career in MLB before surgery			
			Days	Games	Innings	Pitches
1	Left	24	4485	587	2242	31,039
2	Left	22	381	26	147	2439
3	Right	23	103	9	52	841
4	Right	25	3075	358	363	5818
5	Right	25	3213	159	890	13,473
6	Right	21	4327	315	1937	29,344
7	Right	23	2869	188	994	15,294
8	Right	24	2611	308	333	4862
9	Left	24	2028	147	771	12,248
10	Left	21	2191	106	594	9449
Mean $\pm$ SEM		23 $\pm$ 1	2528 $\pm$ 457	220 $\pm$ 55	832 $\pm$ 232	12,481 $\pm$ 3309
Median		23.5	2740	174	683	10,849

SEM, standard error of the mean.

innings, walks per batter faced, line drives per batter faced, walks plus hits per inning pitched (WHIP), strikeouts per batter faced, home runs per batter faced, home runs per flyballs plus line drives, ground ball per batter faced, fly balls per batter faced, earned run average (ERA), fielding independent pitching (FIP), ball percentage (B%), and strike percentage (Str%).

### Advanced Pitching Metrics

Beginning in 2006, the PitchF/x system (Sportvision, Chicago, IL) has tracked velocity, movement, spin rate, spin direction, and other parameters on all pitches at the MLB level. Pitch classifications within the PitchF/x system are based on a real-time automated neural network algorithm, but automated classifiers can have difficulty with certain pitch types and pitches within a player's skill set. Brooks Baseball reports pitch classification data that Pitch Info LLC manually reviews for each pitcher and are confirmed by other sources including video analysis and on-field personnel. Pitch classifications used in this analysis included grouped pitch types (hard, off-speed, and breaking) and individual pitch types (fourseam fastball, sinker, changeup, curveball, cutter, and split-finger). The PitchF/x metrics used for analysis in this study included average pitch velocity (AvgV), maximum pitch velocity (MaxV), horizontal movement, vertical movement, vertical movement plus gravity effects, grooved pitch percentage, whiff percentage, opponents isolated percentage, swing percent, whiffs per swing, line drives per ball in play, ground balls per ball in play, fly balls per

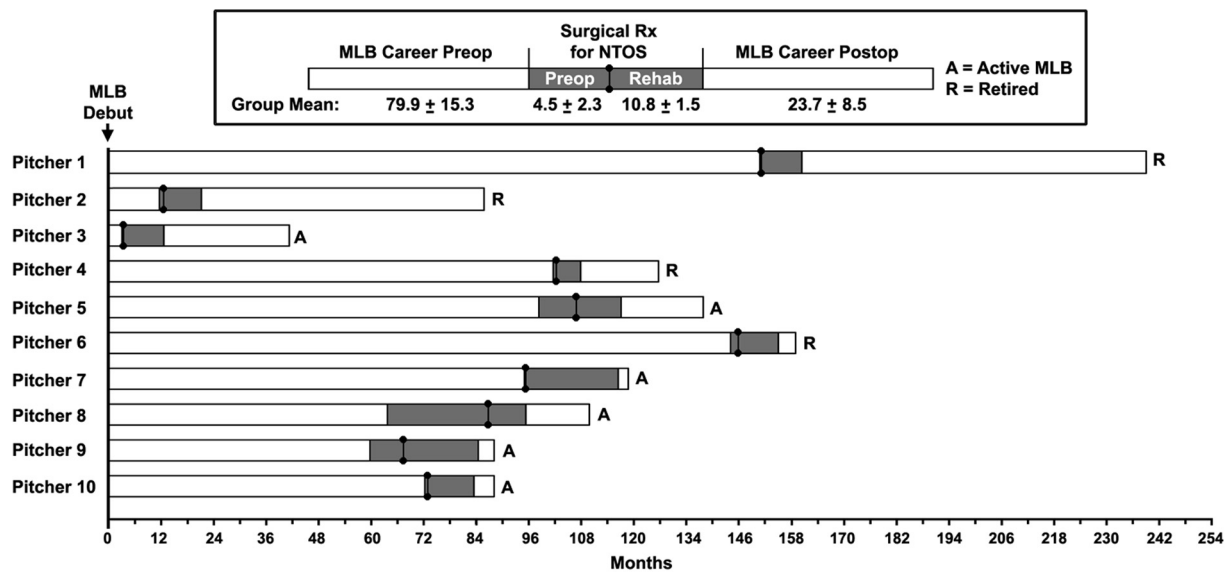
ball in play, opponent batting average, and opponent slugging percentage.

### Time-Period Scenarios for Analysis

For each study subject, individual career data for traditional pitching metrics were initially compared from before and after the time of surgical treatment. As NTOS presents over shorter periods of time that may not be reflected by career data, we next examined traditional and advanced pitching metrics for the 3 years surrounding the index (surgical treatment) year. For more detailed analysis closer to the time of surgery, we then examined traditional and advanced pitching metrics to compare 5 different time periods before the last game played prior to surgery (4 weeks, 8 weeks, 12 weeks, 6 months, and 12 months) and the same 5 different time periods after the first game back to pitching in an official MLB game.

### Statistical Methods

All statistical analyses were performed using SPSS version 22 (IBM Corporation, Armonk, NY) or Prism 6.0 (GraphPad Software, Inc., La Jolla, CA). For before-and-after surgery comparisons, paired average performance data were analyzed by paired *t*-tests for normally distributed data and by Wilcoxon matched-pairs signed-rank tests for data that were not normally distributed. Unpaired data were analyzed using the nonparametric Mann–Whitney *U*-test. Multiple-group analyses were performed using the nonparametric Kruskal–Wallis analysis of variance test. For all tests, a *P* value



**Fig. 1.** Career timelines related to surgery for NTOS. Career timelines are shown as *horizontal bars* for 10 MLB pitchers in relation to surgical treatment for NTOS, from the first MLB appearance (debut) to the end of 2015. The surgical treatment interval is divided into the “preop” period (the interval between the last MLB game appearance and surgical treatment) and the

“rehab” period (the interval between surgical treatment and the first MLB game appearance following surgery). Mean  $\pm$  SEM values (months) are shown for each interval in the key (*bordered inset*). Current MLB playing status as of October 2015 for each pitcher is designated as retired (R) or active (A). SEM, standard error of the mean.

**Table II.** MLB pitchers with NTOS, careers after surgical treatment

Pitcher	Age at surgery	Rehab days	Career after return to MLB				Current status
			Days	Games	Innings	Pitches	
1	36	246	2357	206	1253	19,940	Retired
2	23	260	1934	109	521	8860	Retired
3	23	281	862	72	446	7118	MLB
4	34	167	533	50	43	717	Retired
5	34	306	562	64	288	4865	MLB
6	33	273	116	20	115	1895	Retired
7	31	636	66	7	35	551	MLB
8	31	258	436	79	70	1107	MLB
9	30	509	109	23	42	671	MLB
10	27	315	141	20	129	1796	MLB
Mean $\pm$ SEM		30 $\pm$ 1	325 $\pm$ 44	712 $\pm$ 254	65 $\pm$ 19	294 $\pm$ 120	4752 $\pm$ 1926
Median		31.0	277	485	57	122	1846

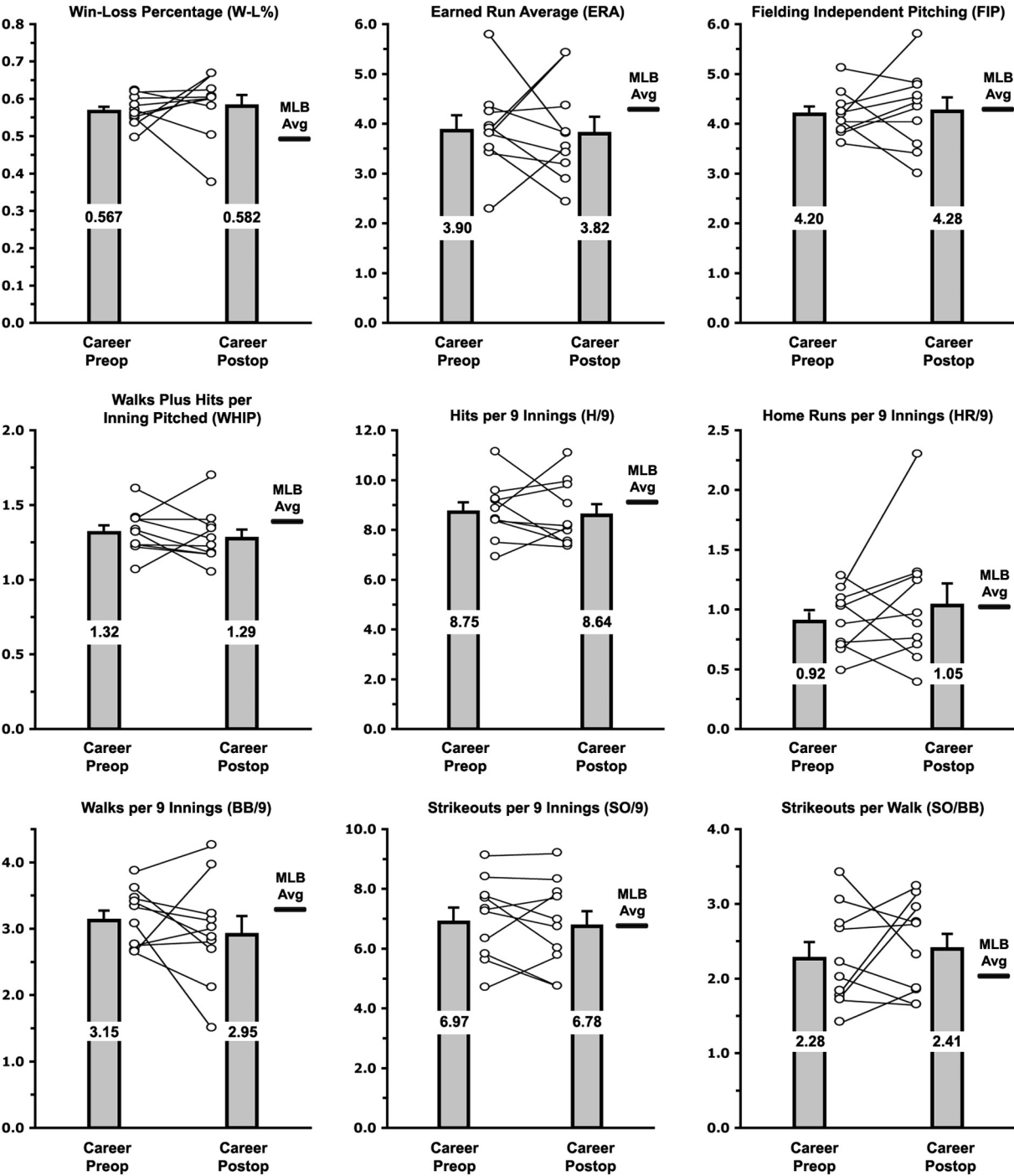
SEM, standard error of the mean.

$<0.05$  was considered to indicate a statistically significant difference.

## RESULTS

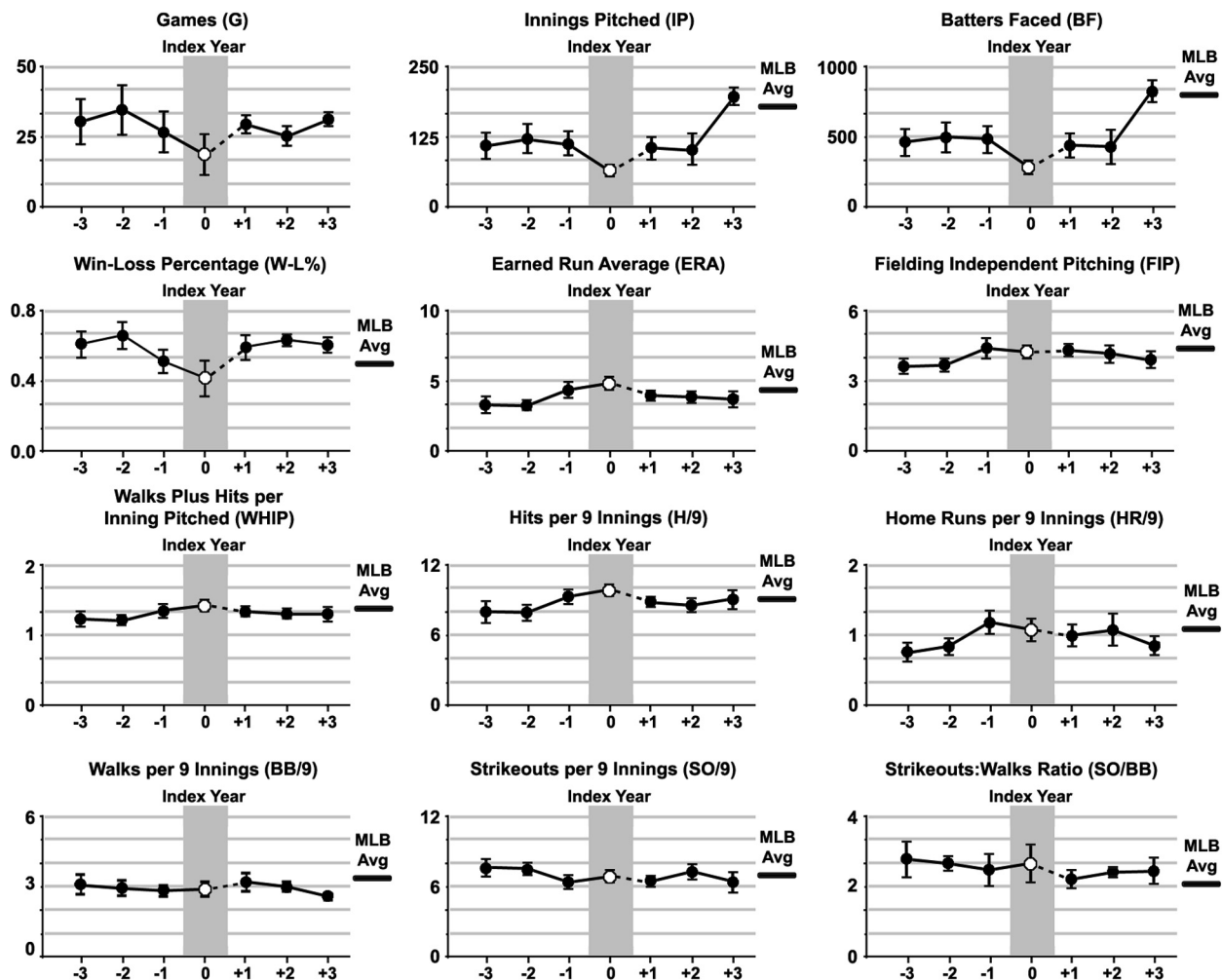
The 10 pitchers included in the study had a mean age of  $23.2 \pm 0.5$  years at first MLB appearance

and  $6.9 \pm 1.3$  years of playing time before treatment for NTOS, which occurred at a mean age of  $30.2 \pm 1.4$  years (Table I). Figure 1 illustrates the overall career timelines for this cohort in relation to the time of surgery for NTOS, demonstrating a mean interval between the last MLB appearance and surgical treatment of  $4.5 \pm 2.3$  months and a mean period of postoperative rehabilitation to the



**Fig. 2.** Traditional pitching metrics, career. Nine relevant traditional pitching performance metrics for 10 MLB pitchers, comparing careers before and after surgical treatment for NTOS. Data shown illustrate the individual pitchers (open circles and line graphs) and group mean  $\pm$  SEM (shaded bar graphs with mean values

indicated). Solid horizontal lines to the right of each panel indicate the 20-year MLB average for each metric (based on 180 innings pitched per year). There were no significant differences for any of the preop versus postop comparisons shown (Wilcoxon matched-pairs signed-rank tests). SEM, standard error of the mean.



**Fig. 3.** Traditional pitching metrics, 3 years surrounding index year. Twelve relevant traditional pitching performance metrics for 10 MLB pitchers, comparing the 3 years before and after the index (surgical treatment) year for NTOS. Data shown illustrate the mean  $\pm$  SEM for the group at each year surrounding the index year. For each year, the number of evaluable individuals was

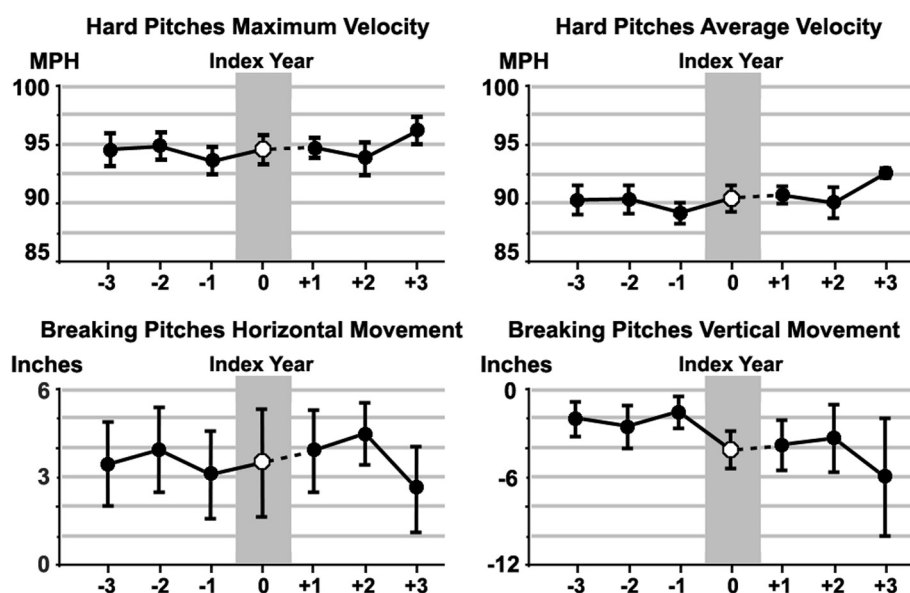
8 (Index - 3), 8 (Index - 2), 8 (Index - 1), 7 (Index), 9 (Index + 1), 7 (Index + 2), and 3 (Index + 3). Solid horizontal lines to the right of each panel indicate the 20-year MLB average for each metric (based on 180 innings pitched per year). There were no significant differences for any of the comparisons shown (Kruskal-Wallis analysis of variance tests). SEM, standard error of the mean.

first MLB reappearance of  $10.8 \pm 1.5$  months. Following the return after surgical treatment, the pitchers in this cohort continued to play at the major league level for a mean of  $2.0 \pm 0.7$  years, with 6 remaining active in MLB at the close of the study period and the other 4 individuals having retired due to factors or injuries unrelated to NTOS. (Table II).

Analysis of pitching performance metrics was conducted in 3 separate stages. First, data were compared between the preoperative and postoperative career periods for the cohort of pitchers returning to MLB after surgery for NTOS. As

illustrated in Figure 2, this revealed no significant differences with regard to 15 traditional pitching metrics, including ERA, FIP, WHIP, BB/9, and SO/BB.

In the second stage of analysis, data were examined for the 3 years before and the 3 years after the return to MLB from surgical treatment. This also revealed that there were no significant differences in traditional pitching metrics when compared with the 2 time periods (Fig. 3). A complete summary of traditional and advanced pitching metrics for the 10 individual pitchers, for the 3 years surrounding the index (surgical treatment) year, is



**Fig. 4.** Pitch velocity and movement metrics, 3 years surrounding index year. Four relevant PitchF/x advanced pitch metrics for 9 MLB pitchers, comparing the 3 years before and after the index (surgical treatment) year for NTOS. Data shown illustrate the mean  $\pm$  SEM for the group at each year surrounding the index year. For

each year, the number of evaluable individuals was 7 (Index - 3), 7 (Index - 2), 7 (Index - 1), 6 (Index), 8 (Index + 1), 6 (Index + 2), and 2 (Index + 3). There were no significant differences for any of the comparisons shown (Kruskal–Wallis analysis of variance tests). SEM, standard error of the mean.

presented in the [Appendix](#). [Figure 4](#) presents data for 4 relevant PitchF/x advanced pitch metrics, for which there were no significant differences.

In the third stage of analysis, performance data were examined for 25 different time-period scenarios surrounding the time of surgical treatment to compare 72 advanced performance metrics (in total, approximately 1800 time-period scenarios and performance metrics were used as variables for analysis). By using paired *t*-tests and Wilcoxon matched-pairs signed-rank tests, there were a total of 247 significant relationships detected among the permutations analyzed. The data shown in [Table III](#) indicate the number of significant relationships detected for different time-period scenarios, with the 8- to 12-week scenario having the highest number (18, 25% of the 72 metrics analyzed). In assessing the specific performance metrics for the 8- to 12-week time-period scenario, 54 of the 72 metrics (75%) analyzed were unchanged (including ERA, WHIP, and SO/BB). Fourteen metrics (19%) with a significant difference represented an improvement in pitching performance after the return from surgical treatment and 4 of the 18 metrics (6%) represented a decline in pitching performance ([Table IV](#)). One of these metrics that might be particularly relevant to pitching performance was hard pitch maximum velocity, where direct analysis of the 8- to 12-wk time-

period scenario revealed a decline from  $93.1 \pm 1.0$  miles/hr before surgery to  $92.5 \pm 0.9$  miles/hr after surgery ( $P = 0.047$ , Wilcoxon matched-pairs signed-rank test). Data shown in [Figure 5](#) illustrate that these before–after differences were considered significant for only 3 of the 9 pitchers (3, 4, and 8), whereas the comparisons for pitchers 2, 5, 6, 7, 9, and 10 were not significantly different (Mann–Whitney *U*-tests).

## DISCUSSION

In this study, we utilized analysis of traditional and advanced pitching performance metrics for a series of professional baseball pitchers returning to MLB after surgery for NTOS. The results demonstrate that this cohort exhibited postoperative pitching performance capabilities largely equivalent to or better than those exhibited before surgical treatment. This provides the first such evidence that thoracic outlet decompression, along with an ample period of postoperative rehabilitation, can provide effective treatment for professional baseball pitchers with career-threatening NTOS.

While this study represents the first analysis of professional baseball pitchers that have returned to MLB after treatment for NTOS, it remains limited

**Table III.** Summary results for advanced pitching performance metrics, other time-period scenarios

Time period before leave for surgery	Time period after return from surgery	Abbreviation used	Number of significant relationships observed
12 months	4 weeks	12 months to 4 weeks	4
12 months	8 weeks	12 months to 8 weeks	7
12 months	12 weeks	12 months to 12 weeks	11
12 months	6 months	12 months to 6 months	9
12 months	12 months	12 months to 12 months	9
6 months	4 weeks	6 months to 4 weeks	8
6 months	8 weeks	6 months to 8 weeks	11
6 months	12 weeks	6 months to 12 weeks	14
6 months	6 months	6 months to 6 months	8
6 months	12 months	6 months to 12 months	8
12 weeks	4 weeks	12 weeks to 4 weeks	10
12 weeks	8 weeks	12 weeks to 8 weeks	17
12 weeks	12 weeks	12 weeks to 12 weeks	16
12 weeks	6 months	12 weeks to 6 months	12
12 weeks	12 months	12 weeks to 12 months	11
8 weeks	4 weeks	8 weeks to 4 weeks	10
8 weeks	8 weeks	8 weeks to 8 weeks	14
8 weeks	12 weeks	8 weeks to 12 weeks	18
8 weeks	6 months	8 weeks to 6 months	10
8 weeks	12 months	8 weeks to 12 months	10
4 weeks	4 weeks	4 weeks to 4 weeks	6
4 weeks	8 weeks	4 weeks to 8 weeks	5
4 weeks	12 weeks	4 weeks to 12 weeks	6
4 weeks	6 months	4 weeks to 6 months	6
4 weeks	12 months	4 weeks to 12 months	6

Twenty-five different time-period scenarios were selected for detailed analysis of before–after surgery comparisons of 72 advanced performance metrics for 9 MLB pitchers undergoing surgical treatment for NTOS (in total, approximately 1800 time-period scenarios and performance metrics were used as variables for analysis). By paired *t*-tests and Wilcoxon matched-pairs signed-rank tests, there were a total of 247 significant relationships detected among the permutations analyzed. The data shown indicate the number of significant relationships detected for different time-period scenarios, with the 8- to 12-week scenario having the highest number (18, 25% of the 72 metrics analyzed).

by the small number of subjects available for analysis. Only 10 of the 13 pitchers (77%) who have undergone surgical treatment for NTOS exhibited a successful return to play at the MLB level for which there were appropriate data available, so the study group was necessarily biased toward those with successful outcomes from surgery. It is not known why other individuals did not achieve a return to MLB, or if this was related to NTOS or other factors. In addition, it is not entirely clear why the individuals who retired during the study period chose to end their MLB careers despite an apparently successful return from surgery for NTOS. Another limitation is the lack of information on additional injuries that might have affected individual pitchers and thereby influenced their performance, beyond any limitations that might be attributed to NTOS.

The small number of pitchers described in this study undoubtedly reflects the relatively rare

occurrence of NTOS compared with other conditions more frequently affecting MLB pitchers, such as shoulder or ulnar collateral ligament injuries, as well as the difficulty in diagnosis and possible reluctance to consider surgical treatment for NTOS in elite athletes. The majority of the individuals in this study (8 of 10) underwent surgical treatment after 2010, suggesting that there has been increasing recognition of NTOS and appreciation for the potential benefits of surgical treatment. It remains unclear if this might also reflect an actual increase in the prevalence of NTOS in elite athletes, but this is possible given the rigor of contemporary sports training, high performance expectations, and the frequency of upper extremity injury.

This study is unique with regard to the approach used to assess surgical outcomes. Measures used to evaluate results of treatment for NTOS are usually semiquantitative patient-reported assessments of

**Table IV.** Significant relationships for the 8- to 12-week time-period scenario

Pitch type	Pitching variable	Eight weeks before (mean $\pm$ SEM)	Twelve weeks after (mean $\pm$ SEM)	Eight week to twelve week difference	P value
All	FB/BF	0.25 $\pm$ 0.02	0.23 $\pm$ 0.03	0.03 $\pm$ 0.01	0.047 <sup>a</sup>
All	GB/BF	0.32 $\pm$ 0.03	0.36 $\pm$ 0.03	-0.03 $\pm$ 0.01	0.040 <sup>a</sup>
Hard	MaxV	93.12 $\pm$ 1.03	92.50 $\pm$ 0.93	0.62 $\pm$ 0.23	0.025 <sup>b</sup>
Hard	OBA	0.303 $\pm$ 0.014	0.265 $\pm$ 0.021	0.04 $\pm$ 0.01	0.007 <sup>a</sup>
Breaking	FB/BIP	23.29 $\pm$ 3.81	10.42 $\pm$ 3.22	12.87 $\pm$ 3.69	0.008 <sup>a</sup>
Breaking	GB/BIP	33.26 $\pm$ 5.73	43.09 $\pm$ 6.96	-9.83 $\pm$ 2.88	0.009 <sup>a</sup>
Breaking	HorzM	3.41 $\pm$ 1.26	4.08 $\pm$ 1.25	-0.67 $\pm$ 0.21	0.015 <sup>a</sup>
Breaking	OBA	0.226 $\pm$ 0.028	0.167 $\pm$ 0.019	0.06 $\pm$ 0.02	0.023 <sup>a</sup>
Breaking	OSLG	0.343 $\pm$ 0.047	0.229 $\pm$ 0.029	0.11 $\pm$ 0.03	0.002 <sup>a</sup>
Sinker	Wf/Sw	5.08 $\pm$ 0.28	3.57 $\pm$ 0.45	3.64 $\pm$ 1.40	0.040 <sup>b</sup>
Sinker	MaxV	92.93 $\pm$ 0.99	92.31 $\pm$ 0.97	0.62 $\pm$ 0.17	0.011 <sup>b</sup>
Sinker	FB/BIP	18.83 $\pm$ 1.80	11.57 $\pm$ 2.84	7.27 $\pm$ 2.07	0.013 <sup>b</sup>
Sinker	OBA	0.336 $\pm$ 0.040	0.228 $\pm$ 0.036	0.11 $\pm$ 0.03	0.012 <sup>a</sup>
Sinker	OSLG	0.521 $\pm$ 0.035	0.347 $\pm$ 0.045	0.11 $\pm$ 0.03	0.012 <sup>a</sup>
Curveball	GB/BIP	27.95 $\pm$ 8.01	41.09 $\pm$ 7.15	-13.15 $\pm$ 5.15	0.038 <sup>a</sup>
Curveball	HorzM	2.39 $\pm$ 1.36	3.10 $\pm$ 1.44	-0.71 $\pm$ 0.29	0.042 <sup>a</sup>
Curveball	OBA	0.192 $\pm$ 0.041	0.123 $\pm$ 0.034	0.07 $\pm$ 0.02	0.014 <sup>a</sup>
Slider	VertM + G	-39.27 $\pm$ 2.04	-36.36 $\pm$ 2.17	-2.91 $\pm$ 0.44	0.022 <sup>a</sup>

Specific advanced performance metrics exhibiting significant differences in analysis of the 8- to 12-week time-period scenario for 9 MLB pitchers undergoing surgical treatment for NTOS. Fifty-four of 72 metrics (75%) analyzed were unchanged (not shown, including ERA, WHIP, and SO/BB). Fourteen metrics (19%) with a significant difference represented an improvement in pitching performance after the return from surgical treatment for NTOS. Four of the 18 metrics (6%) with a significant difference represented a decline in pitching performance.

FB/BF, flyball per batter faced; FB/BIP, flyball per ball in play; GB/BF, groundball per batter faced; GB/BIP, groundball per ball in play; HorzM, horizontal movement (inches); MaxV, maximum velocity (miles/hr); OBA, opponent batting average; OSLG, opponent slugging percentage; SEM, standard error of the mean; VertM + G, vertical movement plus gravity (inches); Wf/Sw, whiff per swing.

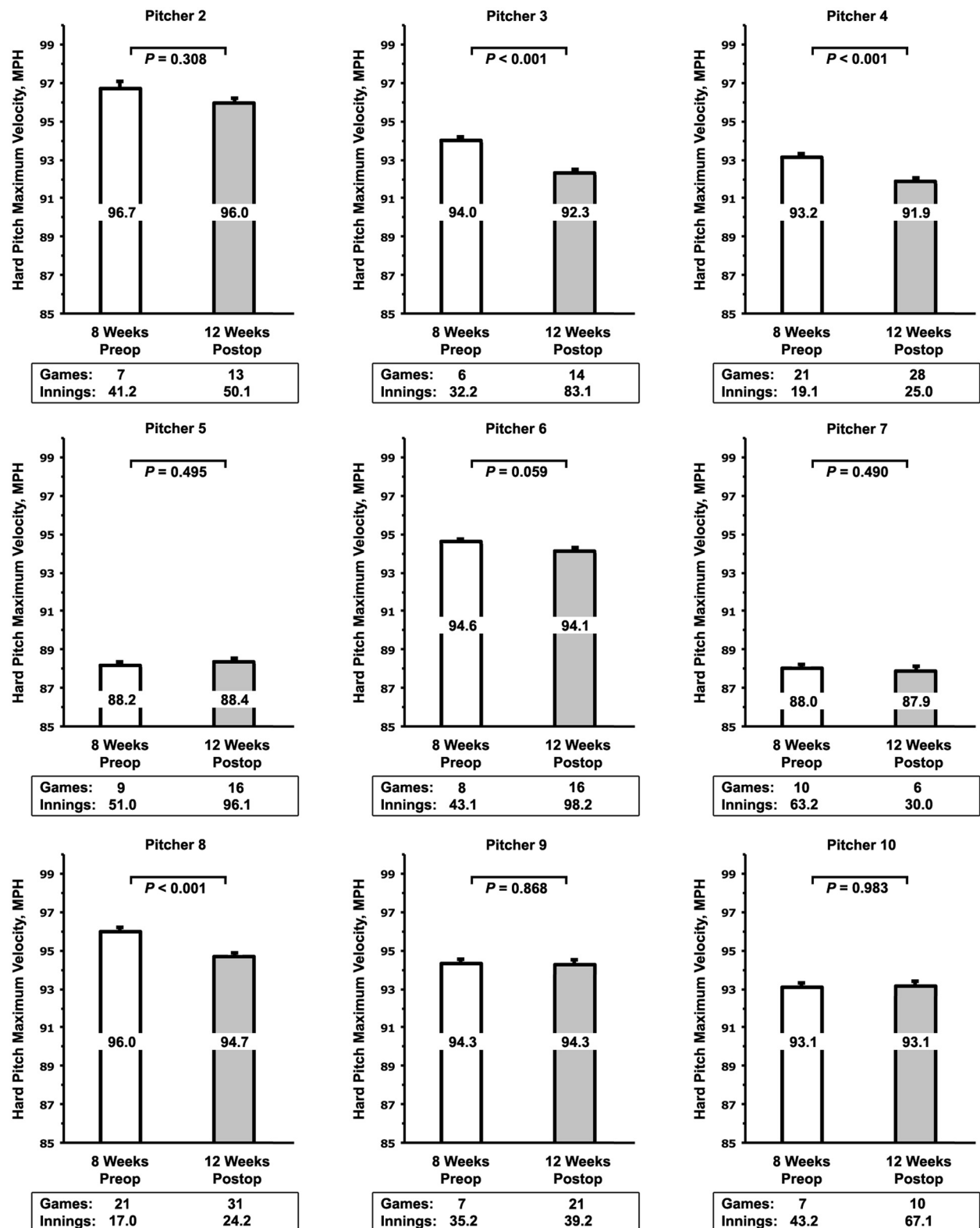
<sup>a</sup>Difference designates improved pitching performance.

<sup>b</sup>Difference designates diminished pitching performance.

pain and functional disability, which can be relatively subjective as well as highly variable.<sup>4-6</sup> The abundance of objective performance measures available in professional baseball thereby allows an opportunity to assess the sport-specific outcomes of surgery for NTOS in a manner independent of subjective symptoms. Professional baseball pitchers are certainly not typical of patients with NTOS, without having had the magnitude or duration of disability often exhibited by those with this condition, and the outcomes in professional baseball pitchers cannot be extrapolated to other populations of patients. Nonetheless, NTOS in an MLB pitcher is a career-threatening development as it prevents satisfactory performance and does not respond well to conservative therapy. Thus, an important conclusion from this study is that successful outcomes can still be achieved with surgical treatment for NTOS, even in a patient population with particularly demanding occupational requirements.

It is valuable in considering the findings of this study to distinguish between the various statistical metrics and how they might reflect different aspects of baseball pitching performance following surgical

treatment. For example, "counting" metrics (e.g., G, IP) largely reflect playing opportunity and pitcher durability and "aggregate" metrics (e.g., HR) depend on opponent performance, whereas "descriptive" metrics (e.g., AvgV, MaxV) most directly reflect health and level of performance and "rate" metrics (e.g., SO%, WHIP) more closely reflect pitching skill and effectiveness. Metrics that depend on opponent hits or runs are thereby unsatisfactory in evaluating pitching recovery and performance, and it is more valuable to emphasize metrics that are under the more direct control of the pitcher. Pitching performance metrics may also be separated into those that assess throwing strength (pitch velocity) and those that assess fine neurological motor function (pitch control), because velocity and control may return at different phases of recovery from surgery. Furthermore, some of the metrics assessed here predominantly reflect the style of an individual pitcher rather than talent or performance. For example, the proportion of fly balls versus ground balls reveals the general tendencies of hitters against a given pitcher, based on the types of pitches thrown and different game situations, and



**Fig. 5.** Individual comparisons of hard pitch maximum velocity for the 8- to 12-week time-period scenario. Hard pitch maximum velocity (PitchF/x advanced pitch metrics) for 9 MLB pitchers, in direct analysis of the 8- to 12-week time-period scenario. Data shown illustrate the mean  $\pm$  SEM maximum velocity for each pitcher along with the number of games played and

innings pitched during each interval. The before–after differences were considered significant for 3 of the 9 pitchers (3, 4, and 8), whereas comparisons for the remaining pitchers (2, 5, 6, 7, 9, and 10) were not significantly different (Mann–Whitney *U*-tests). SEM, standard error of the mean.

may not provide insight into the level of skill or pitching performance. Indeed, pitcher style may change over time and some may choose to change their pitching repertoire during the course of their careers. Finally, baseball organizations often use aging curves to predict the decline or rise of player performance over time. While pitching performance is expected to diminish with age, players who have been able to return to the same level of performance after a long period of recovery from surgery may actually be considered to be improved given their concomitant increase in age. These factors will all be useful considerations for future research.

One of the most valuable insights from this study is the apparent importance of gradual recovery and postoperative rehabilitation, with most pitchers requiring close to a year after surgery to return to game-ready MLB performance. This is similar to the recovery period expected for MLB pitchers undergoing ulnar collateral ligament reconstruction, where attempts to recover more rapidly can be predicted to have less successful outcomes and a higher rate of recurrent injury.<sup>22–26</sup> Many of the individuals in this study appear likely to have had some degree of NTOS symptoms for one or more seasons before diagnosis, along with multiple forms of treatment and previous operations, without addressing the underlying source of disability. These pitchers may have tried to play through considerable symptoms without success, with surgery for NTOS undertaken only as a “last resort” before considering retirement. While the inciting cause of chronic brachial plexus compression injury may be alleviated by thoracic outlet decompression, neural healing is an extremely slow process that may only begin once decompression is accomplished. Furthermore, patients with longstanding NTOS develop compensatory alterations in posture and shoulder girdle mechanics to minimize brachial plexus nerve irritation. These adaptations may cause additional secondary symptoms, such as sustained spasm in the rhomboid, trapezius, and posterior neck muscles. Because surgical treatment for NTOS does not necessarily alter chronic neural injury or compensatory alterations, physical therapy remains a crucial part of recovery to retrain associated muscle groups and to improve shoulder girdle biomechanics. This is likely another major reason that recovery from surgery for NTOS can take much longer than might be expected, a factor likely to be magnified in MLB pitchers.

This study suggests a number of directions for future research. While there have been similar studies on MLB pitchers examining return to play and performance metrics after ulnar collateral ligament repair, investigators have also begun to

examine specific alterations in pitching biomechanics in pitchers who have undergone such operations.<sup>27,28</sup> It would therefore be of interest to examine if pitchers recovered from surgery for NTOS have any consistent or sustained alterations in shoulder girdle or throwing biomechanics. There have also been attempts to identify sabermetric parameters or profiles associated with subsequent injury or time on the disabled list due to shoulder or elbow injuries, raising the possibility that there might be similar sabermetric profiles of pitchers at risk for developing NTOS.<sup>29–31</sup> Finally, it is notable that the subjects of this study typically underwent surgery for NTOS after a period of declining performance and a protracted search for diagnosis, which may have adversely affected recovery from surgery. It remains possible that with earlier diagnosis and prompt surgical treatment, more rapid recovery and rehabilitation may be feasible than observed in the present cohort. Efforts to provide earlier diagnosis of NTOS, such as with exercise-enhanced scalene muscle anesthetic blocks,<sup>32,33</sup> may help improve results from physical therapy, use of alternative approaches (e.g., scalene muscle injections with botulinum toxin),<sup>34,35</sup> or different forms of surgical treatment.<sup>36</sup>

## CONCLUSIONS

Based on the analysis of traditional and advanced pitching metrics, the performance of professional baseball pitchers who returned to MLB after surgery for NTOS was similar to their performance before treatment. Thoracic outlet decompression and postoperative rehabilitation can provide effective treatment for professional baseball pitchers with career-threatening NTOS.

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## SUPPLEMENTARY DATA

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.avsg.2016.05.103>.

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