

# Performance and Return to Play After Surgery for Thoracic Outlet Syndrome in Professional Baseball Players

## A Matched Cohort Analysis

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**Background:** Thoracic outlet syndrome (TOS) remains a rare diagnosis but is being recognized as a cause of upper extremity dysfunction in professional baseball players.

**Purpose/Hypothesis:** The purpose was to determine performance and return-to-play (RTP) outcomes in professional baseball players after surgical treatment of TOS. The hypothesis was that there would be a high RTP rate in professional baseball players after TOS surgery with no statistical differences in performance between pitchers who had TOS surgery and matched controls.

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

**Methods:** All professional baseball players who underwent surgical treatment of TOS between 2010 and 2017 were identified using the Major League Baseball Health and Injury Tracking System database. Demographic and performance data (before and after surgery) for each player were recorded. Performance variables were then compared between players who underwent TOS surgery and matched controls. The matching criteria were no history of previous surgeries on affected arm, age at time of surgery, throwing side, level of play (Major or Minor League Baseball), and years of experience playing professional baseball.

**Results:** Overall, 52 players underwent surgery for TOS, of whom 46 (88%) were pitchers. The type of TOS was neurogenic in 69% and venous in 29%. One player had arterial TOS. After TOS surgery, 79% of players returned to play at the same or higher level (RTSP) by 9.5 months and played  $\geq 3$  years after surgery. No differences were found in RTSP rate based on the type of TOS. No statistical difference was found in RTP rates between major and minor league players. Pitchers had a 76% RTSP, which was similar to the natural attrition for control pitchers ( $P = .874$ ). After TOS surgery, pitchers saw a decline in several performance metrics, but these declines were not different from those of control pitchers, indicating that the decline in performance after TOS surgery was no faster than is seen in healthy professional pitchers as they age.

**Conclusion:** The rate of RTSP after surgery for TOS in professional baseball players was 79%. There was no difference in RTP based on the type of TOS. Pitchers who underwent surgery for TOS had no significant differences in pitching performance metrics after surgery compared with matched controls.

**Keywords:** thoracic outlet syndrome; baseball; surgery; return to sport; neurogenic; venous; arterial; performance

Thoracic outlet syndrome (TOS) is a group of uncommon upper extremity neurovascular conditions characterized by compression of either the brachial plexus (neurogenic; NTOS), the subclavian vein (venous; VTOS), or the subclavian artery (arterial; ATOS). Neurovascular compression in TOS can occur from the level of the scalene triangle in

the lower anterior neck to the subcoracoid (pectoralis minor) space in the axilla and can be caused by soft tissue or bony abnormalities. All 3 forms of TOS tend to arise in young, physically active individuals, including competitive athletes, in whom the symptoms can be career-threatening and the treatment can be challenging.<sup>5,19,21</sup>

The initial presentation of NTOS can be vague, and it often has an insidious course over time. It has classically been referred to as a diagnosis of exclusion, given its variable clinical presentation and the lack of a single gold standard testing modality.<sup>18</sup> A standardized definition has been proposed for NTOS based on fulfilling 3 of 4 criteria:

pain around the thoracic outlet, nerve compression symptoms, workup that rules out any other pathology, and a positive scalene injection test.<sup>15</sup>

Players who have NTOS typically have chronic pain over the shoulder girdle and chest wall with repetitive overhead throwing. They also report activity-related fatigue including decreasing pitch velocity, distal upper extremity numbness, paresthesia, and weakness. Garrison et al<sup>14</sup> reported that adolescent baseball players with a diagnosis of NTOS had significantly less external rotation of the affected shoulder compared with healthy matched controls.

Players with VTOS typically have upper extremity edema, venous stasis symptoms, or episodic coolness. A subset of VTOS, commonly referred to as Paget-Schroetter syndrome, is characterized by an “effort” thrombosis of the axillary-subclavian vein induced by repetitive, strenuous overhead stress to the throwing arm.<sup>16,23,24</sup> Players with ATOS have more significant symptoms of arterial occlusion, including pain, pulselessness, coolness, and even symptoms of acute ischemia.<sup>8,22</sup>

Once TOS is diagnosed in a baseball player, a period of nonoperative treatment is initiated unless the player has significant vascular compromise requiring an acute intervention. In those players who do not respond to nonoperative treatment, operative intervention aimed at correcting the compression (eg, first-rib resection, anterior scalenectomy, thrombectomy) is performed. Because of the short career window of many players, surgery is almost always performed after failed nonoperative treatment. However, the results after surgical intervention for TOS in professional baseball players are not well understood, and few data are available for this player population.<sup>20</sup>

The purpose of this study was to determine the performance and return-to-play (RTP) outcomes in professional baseball players after TOS surgery and compare these outcomes with those of a group of matched controls with no history of TOS surgery. We hypothesized there would be a high

RTP rate in professional baseball players after TOS surgery and with no significant decline in performance. Furthermore, we hypothesized that there would be no significant difference in performance between players who underwent TOS surgery and matched controls.

## METHODS

This study was performed with the approval of the Major League Baseball (MLB) Research Committee. Study data were analyzed from the MLB Health and Injury Tracking System (HITS). MLB HITS is a centralized electronic medical record that contains deidentified player information and was developed as a leaguewide surveillance system in 2010 to record player injuries and injured list time.<sup>17</sup> Players who were evaluated for this study were any MLB or Minor League Baseball (MiLB) player diagnosed with and surgically treated for TOS (neurogenic or vascular) between 2010 and 2017. One author (A.C.) reviewed all of the included players' preoperative documentation and intraoperative reports to confirm the diagnosis and classify the type of TOS.

NTOS was assigned to players who underwent surgery without any evidence of vascular lesions identified preoperatively or intraoperatively. VTOS or ATOS was assigned to players who underwent surgery for a history of known vascular lesions corresponding to the vessel identified by preoperative imaging and treatment. Players were further characterized as having Paget-Schroetter syndrome based on their preoperative history, clinical examination, and imaging consistent with a thrombosis of the axillary-subclavian vein associated with strenuous activity (effort thrombosis). All of the players with Paget-Schroetter syndrome had typical findings of a thrombus within the axillary-subclavian vein segment that failed anticoagulation, angioplasty, or other nonoperative treatment measures. All surgeries were performed by 1 of 2 vascular surgeons at 2 different

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institutions (R.T., G.J.P.). Because the purpose of the study was to evaluate RTP rates for players who underwent surgery for TOS, we did not perform comparative analyses between players treated nonoperatively with a diagnosis of TOS and the surgical cohort evaluated in the study's time frame.

Multiple variables were collected including ability to return to throwing (RTT), RTP at any level, and return to the same or higher level of play before surgery (RTSP). Multiple performance variables were collected only for pitchers in this study as described in previous studies.<sup>3,4,6,7,9-12</sup> Pitchers were then matched 1:1 with a control set of professional baseball players with no history of previous surgeries on the throwing arm or treatment of TOS. These pitchers were matched based on age at time of surgery, throwing side, level of play (MLB or MiLB), and years of experience playing professional baseball, as described in previous studies.<sup>6,7,9-12</sup> The same performance metrics were used as above and an index year was used for controls that corresponded to the surgical year so that appropriate statistical comparisons could be made.<sup>10</sup> Players who were unable to RTP were excluded from performance and RTP analyses. A single player who underwent revision TOS surgery was excluded from the matched analysis because his performance data between primary and revision surgery could not be clearly characterized. A single pitcher who had ATOS was not included in the comparison based on type of TOS.

### Statistical Analysis

All analyses were performed in SPSS 27 (IBM) and Excel 16 (Microsoft). No a priori power analysis was conducted because this is an uncommon surgery in a specific patient population and we included all available patients. We calculated descriptive statistics. We analyzed distribution for all data, and parametric and nonparametric tests were used as appropriate for Gaussian and non-Gaussian distributions as determined using the Kolmogorov-Smirnov test. All pitching performance data were divided into preoperative and postoperative data, and any data from the season of surgery were discarded because of interpatient differences in rehabilitation and recovery. All performance data were analyzed as previously described.<sup>9-12</sup> RTP and pre- and postoperative data were compared using Student *t* tests and Wilcoxon signed-rank tests depending on data normality. Maximum pre- and postoperative levels of play were determined for each player, and these levels were used to determine whether players had returned to the same or a better level of play, had returned but to a lower level of play, or had not returned to professional play.

## RESULTS

A total of 52 players were identified as having had surgery for TOS between 2010 and 2017 and were included in the analysis. Baseline patient characteristics and overall RTP statistics are listed in Table 1. The procedures were performed on the left side in 15% and right side in 85%

TABLE 1  
Patient Information and Return-to-Play Statistics  
for All of the Players With Thoracic Outlet  
Syndrome (N = 52)<sup>a</sup>

	Value
Age, y	26 ± 4
Body mass index	25 ± 2
Pitchers	46 (88)
Major League Baseball	23 (44)
Minor League Baseball	29 (56)
RTT	50 (96)
Months to RTT	3.0 ± 1.6
Weeks to RTT	13.0 ± 6.8
RTP	45 (87)
Months to RTP	7.4 ± 2.9
Weeks to RTP	32.1 ± 12.4
RTSP	41 (79)
Months to RTSP	9.5 ± 4.0
Weeks to RTSP	41.0 ± 17.2
Not active/retired	15 (29)
Career length after surgery, y	3.1 ± 2.3

<sup>a</sup>Values are expressed as mean ± SD or n (%) of players. RTP, return to any level of play; RTSP, return to same or higher level of play; RTT, return to throwing.

of players. These players included 1 first-baseman, 1 second-baseman, 1 third-baseman, 2 outfielders, 1 shortstop, and 46 (88%) pitchers. Of the pitchers, 9 of 46 (20%) were left-handed and 37 of 46 (80%) were right-handed; 29 of 46 (63%) were starters and 17 of 46 (37%) were relievers. Twenty players were identified by MLB HITS as being treated nonoperatively without any surgical intervention between 2010 and 2017. Of these 20 players, 14 (70%) returned to play at the same level at a mean of 108 days (15.4 weeks), and 2 players underwent surgery outside the study time frame. Four players retired or were unable to RTP at any level.

### Intraoperative Findings

When the TOS was subtyped, 36 of the 52 players (69%) were found to have NTOS and 15 of 52 (29%) had VTOS. One player had ATOS. In players with NTOS, the majority had typical intraoperative findings associated with NTOS and underwent scalenectomy, first-rib resection, and neurolysis. A pectoralis minor tenotomy was performed in 11 of the 36 (31%) NTOS players. A first-rib fracture non-union was found in 2 of the 36 (6%) NTOS players.

All of the players with VTOS were considered to have Paget-Schroetter syndrome as previously described. One player had chronic axillary artery thrombosis that was treated with an axillary artery thrombectomy and vein reconstruction. All VTOS and ATOS players underwent scalenectomy, first-rib resection, and neurolysis in addition to evaluation and treatment of the affected vessel as necessitated by the type of vascular lesion. All 15 patients with Paget-Schroetter syndrome received attempts at preoperative thrombolysis with anticoagulation or angioplasty. A

**TABLE 2**  
Return-to-Play Statistics for Players  
With VTOS or NTOS<sup>a</sup>

	VTOS (n = 15)	NTOS (n = 36)
Paget-Schroetter syndrome	15 (100)	NA
Pitchers <sup>b</sup>	12 (80)	33 (92)
Position	3 (20)	3 (8)
Major League Baseball	3 (20)	19 (53)
Minor League Baseball	12 (80)	17 (47)
Body mass index	25 ± 2	26 ± 2
RTT	15 (100)	34 (94)
Months to RTT	3.2 ± 1.5	3.0 ± 1.4
Weeks to RTT	13.7 ± 6.6	12.8 ± 6.0
RTP	14 (93)	30 (83)
Months to RTP	7.1 ± 2.3	7.6 ± 3.2
Weeks to RTP	30.6 ± 10	32.8 ± 13.7
RTSP	12 (80)	28 (78)
Months to RTSP	8.4 ± 1.8	10.0 ± 4
Weeks to RTSP	36.3 ± 8.0	43.2 ± 17.2
Not active/retired	7 (47)	10 (28)
Career length after surgery, y	3.3 ± 2.7	2.7 ± 2.3

<sup>a</sup>Values are expressed as mean ± SD or n (%) of players. NA, not applicable; NTOS, neurogenic thoracic outlet syndrome; RTP, return to any level of play; RTSP, return to same or higher level of play; RTT, return to throwing; VTOS, venous thoracic outlet syndrome.

<sup>b</sup>Single pitcher with ATOS excluded from this table.

vein reconstruction was performed in 4 of the 15 (27%) players who had Paget-Schroetter syndrome.

**Outcomes Based on Type of TOS**

Overall, players who had surgery for TOS had a 79% RTSP and played ≥3 years after surgery (Table 1). Further analysis by type of TOS (Table 2) was performed and did not reveal any significant differences in RTT, RTP, or RTSP between NTOS and VTOS that were surgically treated. At the time of this study, the single player with ATOS is currently active at the MLB level as a starting pitcher and has been playing for 10 years after surgery (Table 2).

**Outcomes Based on Type of League Status**

No significant differences were found in RTT, RTP, and RTSP between groups (Table 3).

**Outcomes Based on Position**

No significant differences were found in RTT, RTP, and RTSP between groups on the basis of position. All position players achieved RTSP (Table 4).

**Performance Metrics and Matched Controls**

No significant difference was found between the rate of return to the same or higher level of play in the included pitchers (n = 45) after TOS surgery (34/45; 76%) and the natural performance attrition that occurred in the control

**TABLE 3**  
Return-to-Play Statistics for MLB and MiLB Players<sup>a</sup>

	MLB Players (n = 23)	MiLB Players (n = 29)
Arterial TOS	1 (4)	0 (0)
Venous TOS	3 (13)	12 (41)
Neurogenic TOS	19 (83)	17 (59)
Pitchers	23 (100)	23 (79)
Body mass index	26 ± 2	25 ± 2
RTT	23 (100)	27 (93)
Months to RTT	2.7 ± 1.4	3.3 ± 1.4
Weeks to RTT	11.8 ± 6.0	14.2 ± 6.0
RTP	22 (96)	23 (79)
Months to RTP	7.0 ± 3.2	7.8 ± 3.2
Weeks to RTP	30.3 ± 13.8	33.6 ± 13.8
RTSP	21 (91)	20 (69)
Months to RTSP	8.9 ± 4.0	10.1 ± 4.0
Weeks to RTSP	38.5 ± 17.4	43.7 ± 17.4
Not active/retired	5 (22)	12 (41)
Career length after surgery, y	3.7 ± 2.7	2.4 ± 223.3

<sup>a</sup>Values are expressed as mean ± SD or n (%) of players. MiLB, Minor League Baseball; MLB, Major League Baseball; RTP, return to any level of play; RTSP, return to same or higher level of play; RTT, return to throwing; TOS, thoracic outlet syndrome.

**TABLE 4**  
Outcomes After TOS Surgery in Position  
Players and Pitchers<sup>a</sup>

	Position Players (n = 6)	Pitchers (n = 46)
Major League Baseball		23 (50)
Minor League Baseball	6 (100)	
Neurogenic TOS	3 (50)	33 (72)
Venous TOS	3 (50)	12 (26)
Arterial TOS	0 (0)	1 (2)
Body mass index	25 ± 2	25 ± 2
RTT	6 (100)	44 (96)
Months to RTT	3.6 ± 1.6	3 ± 1.4
Weeks to RTT	15.4 ± 6.8	12.8 ± 6
RTP	6 (100)	39 (85)
Months to RTP	6.4 ± 2.9	7.5 ± 3.2
Weeks to RTP	27.9 ± 12.4	32.6 ± 13.8
RTSP	6 (100)	35 (76)
Months to RTSP	8.1 ± 4.0	9.7 ± 4.0
Weeks to RTSP	35.2 ± 17.2	42.0 ± 17.2
Not active/retired	3 (50)	14 (30)
Career length after surgery, y	N/A	3.3 ± 2.7

<sup>a</sup>Values are expressed as mean ± SD or n (%) of players. RTP, return to any level of play; RTSP, return to same or higher level of play; RTT, return to throwing; TOS, thoracic outlet syndrome.

group, which had 33 of 45 (73%) players returning at the same or a higher level after the index year (*P* = .874). Several areas of pitching performance declined (walks and hits per inning pitched, *P* = .005; home runs per 9 innings, *P* < .00001; balls batted per 9 innings, *P* = .004; wins above

TABLE 5  
Performance Statistics for Pitchers Who Underwent Surgery for Thoracic Outlet Syndrome<sup>a</sup>

Variable	Before Surgery	After Surgery	<i>P</i>
Win percentage	0.55 ± 0.15	0.48 ± 0.11	.064
WHIP	1.25 ± 0.19	1.51 ± 0.45	<b>.005</b>
Hits per 9 innings	8.21 ± 1.77	9.39 ± 2.71	.051
Home runs per 9 innings	0.63 ± 0.27	1.04 ± 0.51	<b>.00001</b>
Balls batted per 9 innings	3.07 ± 1.2	4.23 ± 2.7	<b>.004</b>
Strikeouts per 9 innings	8.43 ± 1.94	8.24 ± 1.75	.588
Strikeouts per balls batted	3.13 ± 1.58	2.61 ± 1.13	.144
Wins above replacement pitcher	1.59 ± 1.33	0.44 ± 0.63	<b>.018</b>
Fielding independent pitching	3.83 ± 0.59	4.6 ± 0.7	<b>.018</b>
Earned run average	3.56 ± 1.19	4.81 ± 1.94	<b>.003</b>
Wins per year	4.77 ± 2.91	3.76 ± 2.69	.121
Losses per year	4.04 ± 2.3	3.8 ± 2.54	.616
Games per year	24.41 ± 10.47	26.85 ± 11.33	.393
Games started per year	10.94 ± 8.74	8.03 ± 8.7	<b>.034</b>
Games finished per year	5.03 ± 5.52	5.62 ± 5.67	.575
Shutouts per year	0.13 ± 0.24	0.05 ± 0.19	.094
Saves per year	1.57 ± 2.03	1.25 ± 1.94	.445
Innings pitched per year	78.61 ± 41.74	64.71 ± 40.43	.116
Hits per year	67.88 ± 37.59	63.27 ± 39.65	.551
Runs per year	34.97 ± 19.6	32.83 ± 20.24	.632
Earned runs per year	30.97 ± 18.33	29.97 ± 18.89	.812
Home runs per year	6.15 ± 4.73	7.46 ± 6.24	.211
Balls batted per year	26.51 ± 15.15	24.49 ± 13.46	.503
Intentional balls per year	2.2 ± 2.63	1.82 ± 3	.588
Strikeouts per year	70.66 ± 39.22	57.68 ± 34.86	.123
Hit-by-pitch per year	3.39 ± 2.44	2.76 ± 2.01	.128
Balks per year	0.53 ± 0.7	0.25 ± 0.37	<b>.024</b>
Wild pitches per year	4.36 ± 2.87	3.21 ± 2.12	<b>.028</b>
At bats per year	294.45 ± 156.74	246.55 ± 154.47	.152
Plate appearances per year	329.47 ± 174.24	277.69 ± 169.52	.161

<sup>a</sup>Values are expressed as mean ± SD. WHIP, walks and hits per inning pitched. *P* value < 0.05 is in boldface.

replacement pitcher, *P* = .018; fielding independent of pitching, *P* = .018; and earned run average, *P* = .003) (Table 5).

No differences were found between injured players and controls in any preoperative or postoperative performance variables, suggesting that this decline in performance was consistent with average performance attrition with age (Table 6).

## DISCUSSION

TOS can be challenging to diagnose because there is no pathognomonic constellation of symptoms. If nonoperative treatment fails, surgical intervention targeted at correcting the specific cause of TOS is undertaken. The purpose of this study was to critically evaluate the outcomes after surgery for TOS across all levels of professional baseball. Our hypotheses were confirmed, as we found a high rate of RTP at the same level after TOS surgery in professional baseball players and no difference in performance between pitchers who underwent TOS surgery and matched controls without a diagnosis of TOS.

TOS has become an increasingly recognized cause of pain and dysfunction in professional baseball players, although

arriving at the diagnosis can be challenging.<sup>5,18-21</sup> Given the constellation of symptoms and other more common conditions found in baseball players, TOS is not commonly considered in early evaluation. A thorough examination with appropriate diagnostic imaging or studies can help narrow the differential down to TOS. In NTOS, patients can have lower cord (C8-T1) conduction changes on an electromyogram with nonradicular or abnormal sensory disturbances related to activity. Ultrasound-guided injections within the anterior scalene and pectoralis minor muscles have been shown to be both diagnostic and therapeutic for NTOS in professional baseball players.<sup>2</sup> In VTOS, diagnosis can be confirmed more readily with vascular studies that show axillary-subclavian abnormalities. In elite overhead throwers, more vigilance has been paid to recognizing TOS as a cause of chronic decline in throwing performance.

The pathophysiology of TOS as it applies to elite overhead throwers can be multifactorial. Typically, TOS occurs in the dominant or throwing side. The repetitive traction and strenuous force generated from the position of the throwing arm in a hyperabducted, externally rotated position can predispose throwers to this condition. The scalene muscles can have hypertrophy, leading to compression of the brachial plexus. Similarly, chronic compression of the

TABLE 6  
Findings for Control Participants Before and After the Index Year of Matching With Comparison to Pre- and Postinjury for the TOS Surgery Group<sup>a</sup>

Variable	Pre	Post	P for Pre-Injury vs Pre-Control	P for Post-Injury vs Post-Control
Win percentage	0.49 ± 0.15	0.49 ± 0.03	.11	.713
WHIP	1.36 ± 0.26	1.42 ± 0.05	.42	.304
Hits per 9 innings	8.81 ± 1.82	9.23 ± 0.43	.133	.953
Home runs per 9 innings	0.67 ± 0.36	1.11 ± 0.11	.114	.415
Balls batted per 9 innings	3.42 ± 1.39	3.59 ± 0.28	.912	.141
Strikeouts per 9 innings	8.05 ± 1.69	8.5 ± 0.38	.47	.534
Strikeouts per balls batted	2.83 ± 1.02	2.63 ± 0.21	.447	.736
Wins above replacement pitcher	1.12 ± 0.91	0.38 ± 0.21	.296	.772
Fielding independent pitching	4.14 ± 0.64	5.1 ± 0.33	.871	.176
Earned run average	3.98 ± 1.36	4.34 ± 0.3	.153	.561
Wins per year	4.53 ± 3.28	3.14 ± 0.41	.646	.442
Losses per year	4.21 ± 2.74	3.36 ± 0.5	.227	.607
Games per year	22.85 ± 10.56	24.85 ± 2.53	.558	.714
Games started per year	10.8 ± 8.98	7.32 ± 1.48	.607	.729
Games finished per year	5.51 ± 8.47	6.4 ± 1.31	.395	.506
Shutouts per year	0.12 ± 0.23	0.04 ± 0.02	.824	.82
Saves per year	1.68 ± 4.28	1.19 ± 0.33	.514	.976
Innings pitched per year	75 ± 45.22	59.72 ± 7.11	.533	.733
Hits per year	70.73 ± 42.9	60.9 ± 7.51	.243	.951
Runs per year	36.9 ± 21.76	32.72 ± 3.99	.199	.862
Earned runs per year	31.78 ± 19.55	29.66 ± 3.7	.286	.866
Home runs per year	6.11 ± 5.51	7.34 ± 1.02	.462	.759
Balls batted per year	25.7 ± 14.57	21.12 ± 2.37	.422	.3
Intentional balls per year	2.58 ± 3.76	0.9 ± 0.26	.264	.182
Strikeouts per year	63.99 ± 35.95	53.28 ± 6.53	.784	.741
Hit-by-pitch per year	3.09 ± 2.17	2.76 ± 0.34	0.986	.76
Balks per year	0.37 ± 0.47	0.31 ± 0.1	.558	.836
Wild pitches per year	4.66 ± 3.89	3.06 ± 0.42	.255	.667
At bats per year	285.9 ± 172.37	230.89 ± 27.51	.456	.807
Plate appearances per year	319.35 ± 189.18	258.21 ± 30.22	.455	.758

<sup>a</sup>Values are expressed as mean ± SD. Pre, before the index year of matching; Post, after the index year of matching; WHIP, walks and hits per inning pitched.

subclavian vessels leads to intrinsic structural changes such as stenosis, aneurysm, or thrombosis.<sup>19,21</sup> Reports are available of first-rib stress fractures leading to TOS in overhead athletes. In a study of 23 overhead athletes with first-rib stress fractures, 3 athletes needed surgery for TOS because of failed nonoperative treatment.<sup>13</sup>

Initial imaging modalities such as radiography, computed tomography, and magnetic resonance imaging can identify anatomic abnormalities or space-occupying lesions. Multiple diagnostic modalities, including electromyography and nerve conduction studies for NTOS, can show changes of chronic compression. In cases of VTOS or ATOS, Doppler ultrasound or angiography can identify vascular lesions.

Nonoperative treatment options such as pain management, physical therapy, and activity modification are used to initially treat TOS. In ATOS or VTOS, anticoagulation can be used to initially treat the chronic thrombosis. Surgical treatment is indicated for players in whom nonoperative treatment has failed. The urgency to proceed with surgery is certainly higher in patients with ATOS or

VTOS who have reached limb-threatening ischemia. The surgical procedures are guided by the type of TOS.

In NTOS, an anterior scalenectomy with first-rib resection and neurolysis of the brachial plexus is typically performed. A pectoralis minor tenotomy can also be performed if the patient has preoperative symptoms concerning for compression or symptoms at that level. In VTOS, if anticoagulation therapy has failed, additional procedures ranging from angioplasty to open thrombectomy with vein or artery grafting may be necessary to address the diseased vascular segment. In ATOS, depending on the severity of symptoms, urgent intervention may be needed. In this study, the majority of players (69%) had NTOS and underwent scalenectomy, first-rib resection, and neurolysis. A pectoralis minor tenotomy was performed in 31% of the NTOS players. In VTOS, all players had a first-rib resection, scalenectomy, and neurolysis of the brachial plexus at that level and underwent variable management of the vascular lesion based on preoperative findings. One player in the VTOS cohort had a pectoralis minor tenotomy.

Surgery for TOS has been shown to be effective in both the athlete and the nonathlete populations.<sup>1</sup> However, the rate of RTP after surgery for TOS in professional baseball players has been limited to a few studies using media reports, single institutional databases, or a mixed population of athletes at different levels.<sup>1,5,16,18,20</sup> Thompson et al<sup>20</sup> evaluated the efficacy of surgical decompression for NTOS in 13 professional baseball players and found that 10 (77%) returned to play at the MLB level around 11 months after surgery, which was similar to our results. In their study, pre- and postoperative pitching performance metrics were relatively unchanged with no significant differences for those who returned to play.<sup>20</sup> Chandra et al<sup>5</sup> reported outcomes after TOS surgery in 41 competitive athletes, 13 (4 NTOS, 9 VTOS) of whom were baseball or softball players. Overall, 85% (82% for NTOS, 93% for VTOS) of athletes achieved RTSP at a mean of 4.6 months after surgery. Shutze et al<sup>18</sup> presented results from a midterm survey follow-up of 67 overhead throwing athletes who had undergone surgery for NTOS; the investigators reported an overall 70% rate of RTP or RTSP. Melby et al<sup>16</sup> evaluated 32 overhead athletes with Paget-Schroetter syndrome who were surgically managed, including 6 professional and 5 college baseball players. The investigators found that the mean RTP was 3.5 months, but overall ranged between 2 and 10 months. A subanalysis of the 6 professional baseball players in their study showed a mean RTP of 6 months, which is similar to our findings in this study.<sup>16</sup>

Our study included a single player with ATOS who underwent surgery and at the time of the study was currently active in the league 10 years after TOS surgery. However, outcomes of ATOS in elite overhead athletes have been typically limited to small case studies or case reports with a high RTSP.<sup>8,24</sup>

### Limitations

This study has multiple limitations, including that it is a retrospective review of an actively managed health tracking database. Although an inherent rarity of TOS is seen among MLB players, a potential limitation of this study is the smaller sample size we obtained over the study period compared with other more common conditions seen in professional baseball players. For patients with NTOS, initial symptoms are often vague, insidious, and commonly treated without the diagnosis of TOS in mind. Only after exhaustive workup or failed nonoperative therapy is NTOS considered, properly evaluated, and treated. Therefore, a limitation of this study is that the pre-surgical performance statistics of players could have been diminished enough to cause bias toward worse performance statistics than our matched controls. The MLB HITS database is a comprehensive and actively managed surveillance database on the health of professional baseball players. It contains a plethora of useful performance metrics but might not capture all of the performance metrics that could allow for more in-depth comparative analyses. It is possible that players who had surgery for TOS were missed despite our best efforts, although this is unlikely given

the current injury tracking system implemented with the MLB HITS database. Postoperative rehabilitation was not standardized among players and could have introduced bias in their ability to successfully RTP. However, no standardized postoperative rehabilitation guidelines are available, especially for professional baseball players. Future guidelines in managing overhead thrower rehabilitation after TOS surgery may lead to more standardized protocols and outcomes.

### CONCLUSION

This is the largest evaluation of professional baseball players who underwent surgical management for TOS. Our study shows that surgical intervention for TOS in professional baseball players can be an effective solution to a very challenging problem. Overall, professional baseball players had a nearly 80% chance of returning to play at the same level by 10 months after surgery for TOS. Our study shows that surgery can help prolong a player's career. Also, pitchers who underwent surgery for TOS had no significant difference in performance metrics after surgery compared with matched controls.

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