Neurogenic Thoracic Outlet Syndrome in Division 1 Collegiate Athletes: Presentation, Diagnosis, and Treatment

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Abstract

Objective: Athletes who engage in repetitive upper-extremity exercise are susceptible to neurogenic thoracic outlet syndrome (nTOS). We sought to identify typical presenting symptoms and common findings on diagnostic workup, in addition to evaluating rates of return to play following various treatment interventions. **Design:** Retrospective chart review. **Setting:** Single institution. **Participants:** Medical records of Division 1 athletes containing the diagnosis of nTOS between the years 2000 and 2020 were identified. Athletes with arterial or venous thoracic outlet syndrome were excluded. **Independent Variables:** Demographics, sport, participation status, clinical presentation, physical examination findings, diagnostic workup, and treatments provided. **Main Outcome Measures:** Rate of return to play (RTP) to collegiate athletics. **Results:** Twenty-three female and 13 male athletes were diagnosed and treated for nTOS. Digit plethysmography showed diminished or obliterated waveforms with provocative maneuvers in 23 of 25 athletes. Forty-two percent were able to continue competing despite symptoms. Of the athletes who were initially unable to compete, 12% returned to full competition after physical therapy alone, 42% of those remaining were able to RTP after botulinum toxin injection, and an additional 42% of the remaining athletes RTP after thoracic outlet decompression surgery. **Conclusions:** Many athletes diagnosed with nTOS will be able to continue competing despite symptoms. Digit plethysmography is a sensitive diagnostic tool for nTOS to document anatomical compression at the thoracic inlet. Botulinum toxin injection had a significant positive effect on symptoms and a high rate of RTP (42%), allowing numerous athletes to avoid surgery and its prolonged recovery and associated risks. **Clinical Relevance:** This study demonstrates that botulinum toxin injection had a high rate of return to full competition in elite athletes without the risks and recovery needed for surgical intervention, suggesting that this may be a good intervention especially among elite athletes who only experience symptoms with sport-related activities.

Key Words: neurogenic thoracic outlet syndrome, return to play, elite athlete, diagnosis and treatment

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INTRODUCTION

Thoracic outlet syndrome (TOS) is a condition that results from compression of neurovascular structures in the thoracic outlet[1] The myriad symptoms of TOS are attributed to intermittent compression of the neurovascular structures running through the thoracic outlet from either congenital or acquired anatomical differences.[2] As a result, TOS is generally thought of as neurogenic, arterial, or venous depending upon which structure is implicated.[3] Notably, approximately 90% of TOS cases are categorized as neurogenic TOS (nTOS).[4] Neurogenic TOS often presents with weakness, numbness, and tingling that may radiate distally through the affected arm. If symptoms have been present for a prolonged period, people may present with muscle wasting. Symptoms may evolve or become exacerbated with specific activities, but they do not localize to a specific nerve.[5]

Given the lack of specificity of symptoms, nTOS can be difficult to diagnose and remains a clinical diagnosis. Several maneuvers that may reproduce symptoms or decrease pulse strength in the affected arm are used in the workup of suspected TOS.[6] Objective testing, including electromyography and various imaging modalities, is used to elucidate the specific TOS subtype.[7] Imaging findings of thrombus formation or embolization are consistent with arterial and venous TOS.[8]However, nTOS will often have normal electromyography and imaging results because of the intermittent nature of nerve compression.[3] For this reason, the true incidence of nTOS is poorly understood.[4]

Treatment is often viewed as both diagnostic and therapeutic. If patients improve with TOS-focused physical therapy, such as the Edgelow protocol, they are thought to be more likely to have nTOS.[9] Similarly, lidocaine, corticosteroid, or botulinum toxin injections (BTI) have been used in both a diagnostic and therapeutic fashion. Botulinum toxin has significant therapeutic potential because it decreases muscle bulk, albeit temporarily, as demonstrated in this study on children with

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spastic hemiplegic cerebral palsy. This has not been studied in nTOS; however, a decrease in muscle bulk following injection could theoretically increase space in the thoracic outlet. Although some case series have demonstrated benefits with BTI,[10–13] 1 randomized controlled trial did not demonstrate long-term benefit.[14] Surgical management, including first rib resection and scalenectomy, has been shown to be an effective treatment for nTOS.[15] However, it is a major surgery and should not be undertaken if the diagnosis is still unclear.

Athletes are at high risk of developing TOS, especially in sports requiring repetitive upper-extremity motion.[16] There are several biomechanical and anatomical considerations that may predispose overhead athletes to TOS. As seen in throwing athletes like baseball pitchers, maximal shoulder abduction and external rotation narrow the thoracic outlet, leading to brachial plexus compression.[17] Similarly, repetitive overhead elevation may result in compression of the brachial plexus by the pectoralis minor. Other anatomical considerations include direct compression from scalene muscles that have hypertrophied as a result of repetitive and forceful overhead motions.[17] In a 2014 study by Chandra et al, nTOS was most commonly diagnosed in competitive athletes who participated in swimming, baseball, and water polo.[18] A recent systematic review of TOS in sport identified that most cases were reported in baseball pitchers and swimmers and that upper-extremity strength training is by itself a risk factor of TOS.[18] Athletes who participate in competitive rowing, also known as crew in the United States, are similarly at risk because of the repetitive upper-extremity motions required to manually propel a boat.

Although the pathophysiology behind nTOS has been described, there is limited data on presentation, management, and outcome in elite athletes with nTOS. Our institutional experience with the presentation, management, and outcomes of he tNational Collegiate Athletic Association (NCAA) Division 1 varsity athletes diagnosed with nTOS is presented in this article. Division 1 is the most elite level of collegiate athletic competition in the United States. These athletes have participated in sport for many years, although the transition to collegiate athletics generally results in an increase in overall workload, which can lead to or exacerbate overuse type injuries. In addition, they have increased access to medical care, including athletic trainers, physical therapists, and physicians, which can lead to increased recognition of injuries and access to treatment. Of note, only 2% of NCAA athletes go on to professional-level competition. The majority have a substantial decrease in athletic workload immediately after graduation. Therefore, this population is both at higher risk of developing TOS and having increased access to medical care, making it an excellent population in which to study nTOS and response to treatment.

METHODS

Study Design

Division 1 athletes at a single university who were diagnosed with TOS between 2000 and 2020 were retrospectively reviewed for study eligibility. Approval was obtained from our institutional review board before chart review and data retrieval. Athletes were identified using ICD 9 and 10 diagnoses codes, then reviewed to confirm a diagnosis of TOS. A single surgeon and/or sports medicine trained physician performed the clinical assessments and determined whether the athlete met clinical criteria for diagnosis. Other clinicians were involved in initial screening of the athletes; however, only these 2 provided the final diagnosis. The 2 athletes with arterial or venous thoracic outlet syndrome were excluded based on dynamic digit plethysmography and/or computed tomography angiography findings of thrombus or emboli. All athletes underwent dynamic digit plethysmography when they were assessed by the vascular surgeon. Alterations in waveform with digital plethysmography with provocative maneuvres, although evidence of dynamic vascular compression, is not considered diagnostic of arterial or venous TOS because these conditions must have findings of thrombus or emboli. Therefore, these athletes are still considered to have nTOS and were not excluded.

Participants

A total of 36 athletes were identified and included in this analysis of nTOS athletes. Patient demographics, sport participation status, clinical presentation, physical examination (including supraclavicular tenderness, cervical and shoulder range of motion, neurovascular status, and provocative maneuvers), diagnostic workup, and treatment were extracted from the charts (n = 36) and listed in Table 1. Clinical muscle wasting was not assessed because these athletes have immediate access to medical care, and therefore, diagnosis was made early before the development of wasting.

Treatment Options

Treatment modalities included TOS-specific physical therapy (PT), anterior scalene BTI, first-rib resection and anterior scalenectomy, or a combination of all three. All athletes were started in PT automatically. Physical therapy was provided by a group of physical therapists who work with the varsity athletes using a modification of the Edgelow Neurovascular Entrapment Self Treatment protocol. If they had inadequate or temporary relief of their symptoms, they were offered BTI. Anterior scalene BTI were done under ultrasound guidance using GE LOGIQ S8 and E9 machines (GE Healthcare Inc., Wauwatosa, WI) with a 6 to 15 MHz linear array ultrasound transducer by a single sports medicine–trained physician. Under sterile protocol, 50 units of botulinum toxin mixed with 0.5 mL of preservative-free normal saline was injected into the anterior scalene of the affected side using a 27-G 1.25-inch needle. Athletes were able to return to play as tolerated without required downtime following the injection. Following BTI, if they continued to have inadequate or temporary relief of their symptoms, they were given the option to continue with intermittent BTI or proceed with surgical intervention. If athletes had no improvement with TOS-specific PT and BTI, then surgical intervention was not recommended because BTI was used as both a diagnostic and prognostic tool. Without any improvement with BTI, they were felt to be less likely to have nTOS and less likely to benefit from surgical intervention.[15] Surgical intervention was a supraclavicular decompression including first rib resection and anterior scalenectomy performed by a single surgeon at a single institution.

Outcome Measures

The primary outcome of interest was return to play (RTP) at the same level (Division 1 collegiate athletics). Athletes were

TABLE 1. Demographics of Competitive Athletes Diagnosed With nTOS

	n (%)
Gender	
Female	23 (64)
Male	13 (36)
Race	
White	26 (93)
Black/African American	2 (7)
Undisclosed	8
Asian	0
American Indian	0
Native Hawaiian	0
Other	0
Symptom duration	
<3 mo	23 (64)
6 mo–1 yr	6 (17)
>1 yr	7 (19)
Affected extremity	
Dominant	25 (81)
Nondominant	6 (19)
Unknown	5
Sport	
Crew	15 (42)
Swimming	7 (19)
Baseball	5 (14)
Basketball	1 (3)
Diving	1 (3)
Golf	1 (3)
Softball	1 (3)
Squash	1 (3)
Tennis	1 (3)
Track and field	1 (3)
Volleyball	1 (3)
Wrestling	1 (3)
History of shoulder injury	10 (28)
History of neck injury	1 (3)
History of mental health diagnosis	7 (19)

only monitored during the time they were participating as collegiate athletes. If an athlete was unable to return to sport before graduation, this is noted in the results. Study participants were given a QuickDASH score survey to complete at baseline and again at follow-up appointments to determine symptom severity, disability, and response to treatment. The QuickDASH outcome measure is a self-reported quality-of-life measure, which uses 11 questions to measure physical function and symptoms in people with musculoskeletal disorders of the upper limb.[19] Further clinical response was extracted from subjective data as described in progress notes from physicians and physical therapists.

Statistical Analyses

Categorical data were interpreted using χ^2 analysis and Fisher exact test. Mann–Whitney *U* and *T* tests were used to interpret nonparametric continuous and parametric continuous data, respectively. *P* values of <0.2 were included in the multivariate logistic regression with *P* values of <0.05 considered to be statistically significant.

Ethical Considerations

As a retrospective study, the primary ethical consideration was maintenance of patient anonymity. Data were securely maintained throughout the project, and all results were reported cumulatively without identifying information.

RESULTS

Baseline Findings

Twenty-three female and 13 male athletes were diagnosed with nTOS from 2000 to 2020 and included in the study. Mean age at presentation was 19.9 years (SD: 1.2), and 64% of athletes were female. Twelve sports were represented, with most athletes participating in crew (n = 15), swimming (n = 7), and baseball (n = 5). Swimming involves significant overhead repetitive motion with various strokes. Baseball involves regular overhead throwing in all positions. Crew is an endurance sport involving significant upper-limb repetitive motion. All sports represented spend time doing overhead weights for conditioning and injury prevention guided by trained professionals. Symptoms on presentation are listed in Table 2, with numbness and tingling in the affected extremity being the most common (78% and 86%, respectively); 89% of athletes reported sport-specific activity to be an aggravating factor, with only 33% reporting symptoms at rest and 29% reporting interference with activities of daily living (ADLs). The QuickDASH survey was used to determine the level of functional impairment and disability. Fifty-five percent of athletes completed an initial QuickDASH score, and only 19% completed the initial Sport score. The QuickDASH score ranges from 0 (no impairment) to 100 (severe impairment). The average initial QuickDASH ADL score was 33.1 (SD: 19.7), indicating mild impairment with activities of daily living. For comparison, the mean scores for patients with a radius fracture range from 60 to 70, whereas those with epicondylitis are 39 to 43.[20] The average initial QuickDASH Sport score was 69.7 (SD 25.7), suggesting more severe impairment during sport-specific activity.

On physical examination, 17% of athletes were tender to palpation along the affected supraclavicular fossa and had limited cervical range of motion in at least 1 plane. Sixty-seven percent of athletes had intact upper-extremity muscle strength (n = 24); 61% of athletes had preserved upper-extremity sensation (n = 22). In those who had sensory deficits, alterations were predominantly seen along the ulnar nerve distribution (n = 7). Three athletes presented with sensory changes along the medial nerve distribution, and the remaining athletes had sensory changes across the upper arm and forearm. Sixty-one percent of athletes had reproduction of symptoms with Adson test, 42% with the costoclavicular maneuver, and 33% with the Roos/elevated arm stress test.

TABLE 2. Clinical Presentation and Symptoms of Athletes Diagnosed With nTOS

Presenting Symptom	n (%)
Tingling	31 (86)
Numbness	28 (78)
Weakness	20 (55)
Edema	5 (14)
Skin changes	3 (9)
Provoking factor	
Sport-specific activity	32 (89)
Symptoms at rest	11 (33)
Activities of daily living	8 (28)

Diagnostic Evaluation

Athletes underwent a myriad of diagnostic studies outlined in Figure 1. Twenty-five athletes had an x-ray (cervical or shoulder or chest), but none were found to have a cervical rib, anomalous first rib, or elongated C7 spinous process on imaging. Five athletes had a brachial plexus MRI, but none with identifiable brachial plexus abnormalities. In some cases, cervical spine or shoulder MRI was ordered to rule out other causes. Most athletes had a dynamic digit plethysmography performed (n = 28), with 82% having diminished or obliterated waveforms with provocative maneuvers. Electromyography or nerve conduction study was performed on 19 athletes, with 21% having nerve conduction abnormalities, including abnormal, medial, antebrachial, cutaneous sensory nerve action potential (SNAP), median compound motor action potential, and ulnar SNAP.

Treatment

Treatment algorithm used is outlined in Figure 2. Those athletes who had partial or temporary relief following each intervention were given the option to proceed with more aggressive interventions in a stepwise fashion. All athletes engaged in intensive TOS-specific PT at least twice per week in addition to a rehabilitation program with their athletic trainer. After PT alone, 83% of athletes reported subjective improvement in their symptoms, with 47% reporting significant (>50%) subjective improvement at follow-up visit; 56% athletes went on to receive at least 1 BTI (n = 20). After BTI, 71% of athletes reported significant (>50%) subjective improvement in their symptoms. Their QuickDASH ADL score improved an average of 18.4 points as compared with preinjection surveys; however, only 11 athletes were included in this analysis because of incomplete preinjection and postinjection data. Thirteen athletes ultimately underwent first rib resection and anterior scalenectomy by a single vascular surgeon based on improvement with PT or symptomatic relief with BTI. Patients who did not have any symptomatic improvement with PT or BTI were not offered surgery. The BTI was targeting the anterior scalene, thereby mimicking the effects of surgery including anterior scalenectomy. Therefore, if there was no improvement with BTI, it was assumed that the athlete was unlikely to respond to surgery given that we did not have any athletes with congenital anomalies such as a cervical rib, anomalous first rib, or elongated C7 spinous process on imaging; 84% reported significant (>50%) subjective improvement, and their QuickDASH scores decreased by an average of 20.8 points postoperatively. The minimum clinically important difference of QuickDASH scores is 16 to 26 points depending on the diagnosis.[20]

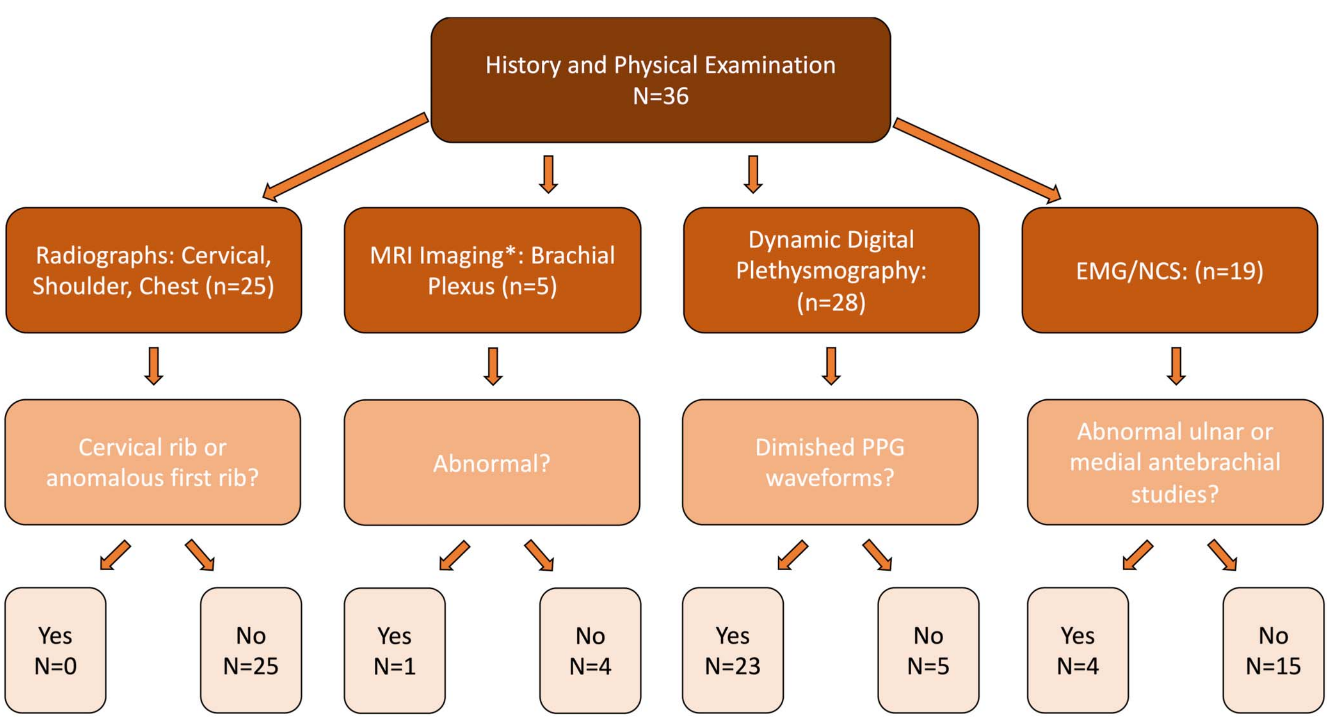

Figure 1. Diagnostic tests used in diagnosis of nTOS. *Cervical and shoulder MRI were also performed to rule out other causes of presenting symptoms.

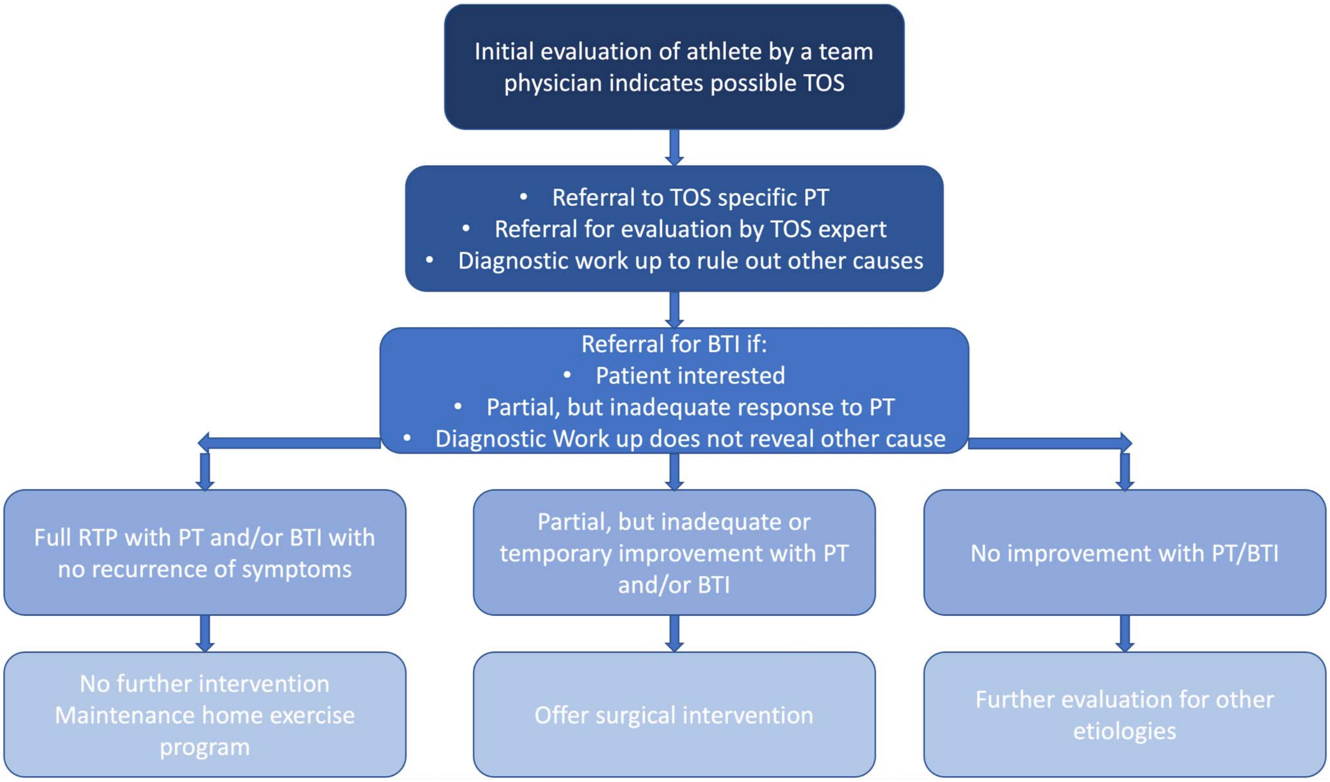

Figure 2. Treatment algorithm followed for nTOS.

Return to Play

On initial evaluation before any treatment, 42% of athletes were able to continue competing despite symptoms. The remaining athletes were limited to practice, conditioning, or were out of training altogether. After PT alone, 12% of previously restricted athletes were able to return to full competition. Thirty-eight percent were able to return to unrestricted play after BTI and 40% after surgery (Figure 3). Time to RTP after surgery ranged from 66 to 247 days, and postoperative outcomes should be interpreted with caution because 2 athletes graduated before full RTP and 2 were still undergoing the recovery process at the conclusion of this study. Variables that were assessed as potential predictors of RTP are described in Table 3; however, on multivariate analysis, there were no statistically significant variables that predicted RTP regardless of treatment received.

DISCUSSION

Our study demonstrates that athletes across many sports involving repetitive upper-extremity activity are at risk for the development of nTOS, with a high prevalence of crew athletes in our sample. This is consistent with the findings of a recent systematic review by Garraud et al,[18] suggesting that athletes in sports involving repetitive movement of the arm are at an increased risk of developing TOS. Interestingly, 42% of athletes were able to continue competing at an elite level without intervention other than physical therapy. Of note, most athletes with nTOS had symptoms only while participating in their sport, whereas only approximately 30% reporting symptoms outside of athletic activity. This is important when considering treatment for athletes specifically. For example, with collegiate athletes, many are planning on discontinuing their sport or significantly decreasing their participation immediately after graduation. Therefore, treatment could be focused on obtaining more temporary relief of symptoms while the athlete completes his or her athletic career, with the expectation that symptoms could be controlled with a physical therapy home exercise program alone after graduation.

The most sensitive physical examination maneuver was Adson, with 60% of athletes developing symptoms. However, given the limited sensitivity of all the physical examination maneuvers in our sample, it is likely preferable to perform a thorough examination with multiple examination maneuvers, rather than relying on a single test. This finding is supported in other literature, which demonstrate a high false-positive rate of all physical examination maneuvers (Roos/EAST, Adson, supraclavicular tenderness to palpation, costoclavicular test) individually, however, significantly improved diagnostic accuracy when looking for positive findings (pain or paresthesias) in 2 or more tests.[17,21] Of all the diagnostic testing, dynamic digit plethysmography assessing neurovascular compression in provocative positions was the most sensitive; however, we were unable to assess specificity in our sample. This is much more sensitive than has been seen in studies assessing dynamic vascular compression on ultrasound evaluation, which demonstrate closer to 50% of those with nTOS having dynamic vascular compression.[22] This difference could be related to differences between ultrasound and digit plethysmography or related to specific provocative positioning chosen for testing because Fouasson-Chailloux assessed for compression in the sitting position with the head turned to the contralateral side with a shoulder retropulsion of

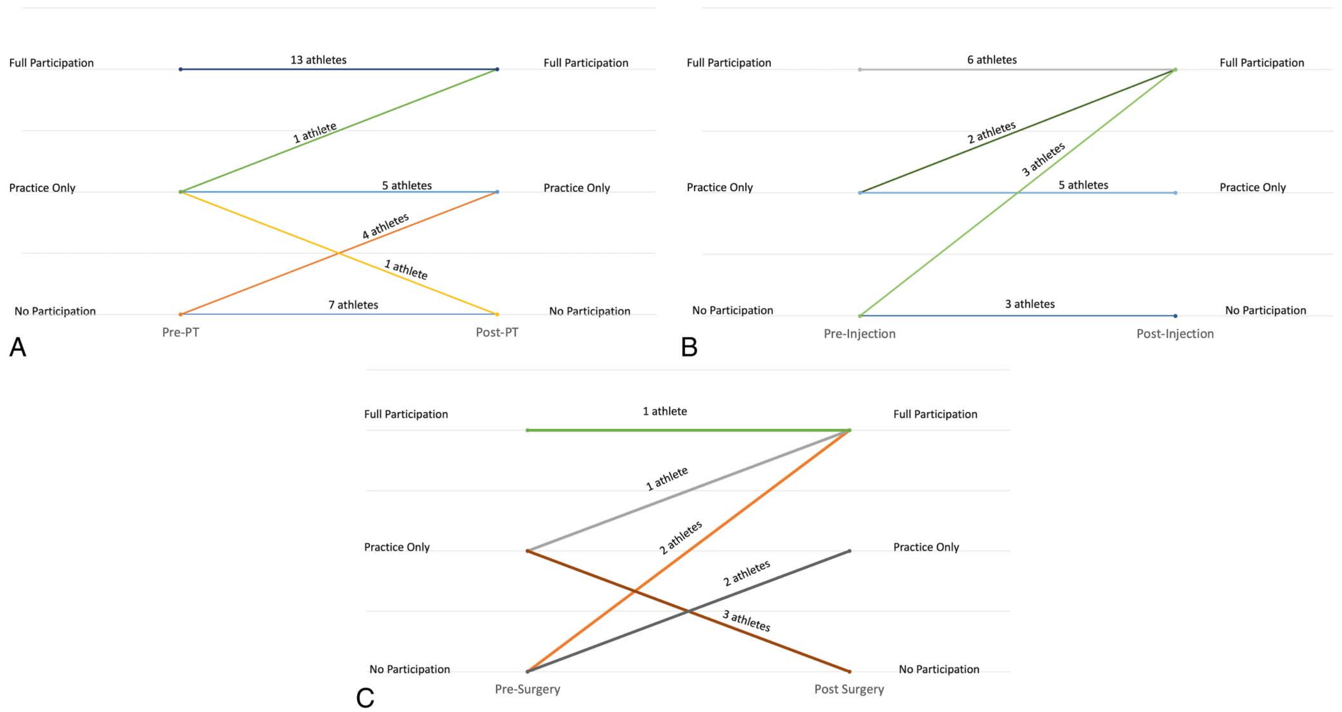

Figure 3. A-C, Return to play status after each treatment modality. A, Three athletes were excluded from analysis because missing baseline sport participation status. B, One participant was excluded from analysis because of missing participation status after injection. C, Two participants were excluded from analysis because of missing postoperative return-to-play data. Out of the athletes who underwent surgery, 1 required revision, 1 medically disqualified, 2 graduated before return to full competition, and 2 are at partial participation at the time that this study was conducted.

30 degrees, at 90 degrees and 120 degrees of abduction,[22] whereas we assessed the patient in a supine position with the shoulder at neutral, 90 degrees and full abduction in addition to military east positioning with the head to both the ipsilateral and contralateral sides, and whatever position elicited the most pain in the patient. This finding of dynamic vascular compression in most athletes with nTOS supports the hypothesis that TOS exists along a spectrum with dynamic compression of neurovascular structures eventually leading to neurologic symptoms and potentially advancing to the development of a thrombus or emboli later. Other diagnostic testing had limited benefit for establishing the diagnosis of nTOS but rather was more beneficial to rule out other potential diagnoses. Given this, the final diagnosis of nTOS remained a subjective clinical diagnosis based on the collective results the history, physical examination, and diagnostic testing after having ruled out other conditions.

Of note, 42% of those athletes diagnosed with nTOS in this study were able to continue competing throughout while managing their symptoms with PT and occasionally further interventions. Given that our population consisted of elite Division 1 collegiate athletes, they had access to extensive PT that may be out of reach to the majority of the population. However, we did demonstrate that with extensive rehabilitation, 83% noticed improvement, 47% reported significant (>50%) improvement, and 12% of the previously restricted athletes were able to return to competition. It is important to note that understanding of the biomechanics of scapulohumeral and scapulothoracic movement has significantly advanced since the start of this study in 2000. Individualized PT programs based on this new understanding of the individual variation in shoulder girdle, thoracic ring, and rib mechanics and muscle activation patterns may improve outcomes with PT alone. Of the athletes in our study, 88% of those who received at least 1 BTI reported improvement, 71% noted significant improvement, and 38% were able to return to full competition. Without surgical management, 58% of athletes were able to compete with a combination of rehabilitation and BTI. Of the 13 who underwent surgical management, 11 (84%) reported significant improvement. However, only 3 of those athletes returned to full participation postoperatively. Many athletes experienced an extended period of rehabilitation/recovery following surgery. Two athletes graduated before completing this rehabilitation process and 2 other athletes are currently still undergoing rehabilitation and may return to full competition in the future, limiting our ability to interpret these data. However, it is helpful for athletes to know that RTP postoperatively is not guaranteed and may require extensive rehabilitation for greater than 6 months before full return to competition. This is comparable to the success rate reported by Peek et al for TOS patients with surgical intervention. Although clinical improvement was obtained in 90% of patients (incluing nTOS and vascular TOS), complete resolution of symptoms was reported by only 54%. They also noted that the improvement in the QuickDASH score and functional outcomes was less robust for those with nTOS compared with those with vascular TOS.[23] Given the RTP data following surgical intervention for nTOS, for those athletes who plan to discontinue participation in their sport after graduation, it may be reasonable to discuss ongoing management of symptoms with PT and intermittent BTI on a temporary basis rather than proceeding with surgical management if they received benefit from their injection, albeit temporarily. This is especially true for athletes who were

TABLE 3. Predictors of Return to Play After Any Treatment Modality

Any Modality	Did Not Return (n = 12)		Return to Full Competition (n = 10)		
	N	%	N	%	*P*
Gender					
Female	9	75	5	50	0.378
Male	3	25	5	50	
Shoulder surgery					
No	11	92	9	90	>0.999
Yes	1	8	1	10	
Mental health dx					
No	8	67	8	80	0.646
Yes	4	33	2	20	
Discomfort with ADLs					
No	4	57	6	67	>0.999
Yes	3	43	3	33	
Symptoms at rest					
No	8	67	6	67	>0.999
Yes	4	33	3	33	
Skin changes					
No	10	83	8	80	>0.999
Yes	2	17	2	20	
Weakness					
No	5	45	4	50	>0.999
Yes	6	55	4	50	
Numbness					
No	2	17	2	20	>0.999
Yes	10	83	8	80	

not found to have a cervical rib, anomalous first rib, or elongated C7 spinous process on imaging contributing to compression. These athletes with dynamic compression related to muscle activation may benefit from a different treatment algorithm.

Our study is limited in that it is a retrospective descriptive analysis. To further assess the benefit and risk of various treatment modalities, a prospective, randomized, control trial would need to be conducted. In addition, given that this is a retrospective analysis, we had inconsistent availability of data with many missing data points especially regrding the QuickDASH scores, which limited our analysis. Finally, we had a relatively small population size given that we were only evaluating Division 1 collegiate athletes with nTOS at a single institution. Given the low prevalence of nTOS, future research would benefit from conducting a multicenter evaluation to increase the sample size.

CONCLUSIONS

Our retrospective evaluation of Division 1 collegiate athletes with nTOS provides valuable insight into the presentation of nTOS in athletes, the value of various diagnostic tests, and the potential role of specific interventions to both manage symptoms and allow athletes to return to full competition. It is important to note that 47% noted significant improvement in symptoms with physical therapy alone. With the improvements in our understanding of biomechanics over time, the impact of physical therapy will likely improve and will continue to be the mainstay of treatment especially for athletes with dynamic compression related to muscle activation patterns and alignment. Of note, we demonstrated that 71% of athletes who received a botulinum toxin injection had significant improvement in their symptoms, suggesting that this may be a valuable intervention for those seeking temporary management of their sport-related symptoms while finishing their athletic career. Although very effective at reducing symptoms, surgical intervention for such athletes needs to be considered carefully given the potential for a prolonged recovery time before RTP.

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