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Original Article

Predisposing Anatomy for Thoracic Outlet Syndrome and Functional Outcomes after Supraclavicular Thoracic Outlet Decompression in Athletes

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Purpose: This study aims to examine predisposing anatomic factors and subsequent post-decompression functional outcomes among high-intensity athletes with thoracic outlet syndrome (TOS).

Materials and Methods: A single-institution retrospective review was performed on a prospective database of patients with TOS from 2018 to 2023 who had undergone operative decompression for TOS. Demographics, TOS characteristics, predisposing anatomy, operative details, and postoperative outcomes were examined. The primary outcome was postoperative return to sport. Secondary outcomes included vascular patency.

Results: A total of 13 patients who were engaged in high-demand athletic activity at the time of their diagnosis were included. Diagnoses included 8 (62%) patients with venous TOS, 4 (31%) patients with neurogenic TOS, and 1 (8%) patient with arterial TOS. Mixed vascular and neurogenic TOS was observed in 3 (23%) patients. The mean age of the cohort was 30 years. Abnormal scalene structure was observed in 12 (92%) patients, and abnormal bone structures were noted in 4 (27%) patients; 2 (15%) with cervical ribs and 3 (23%) patients with clavicular abnormalities. Prior ipsilateral upper extremity trauma was reported in 4 (27%) patients. Significant joint hypermobility was observed in 8 (62%) patients with a median Beighton score of 6. Supraclavicular cervical and/or first rib resection with scalenectomy was performed in all patients. One case of postoperative pneumothorax was treated non-operatively. Ten (77%) patients returned to sport. Duplex ultrasonography showed subclavian vein patency in all 8 patients with venous TOS and wide patency with no drop in perfusion indices in the patient with arterial TOS.

Conclusion: Athletes with TOS who required operative intervention had a high incidence of musculoskeletal aberrations and joint hypermobility. Supraclavicular decompression was associated with a high success rate, with overall good functional outcomes and good likelihood of patients returning to preoperative high-intensity athletics.

Key Words: Thoracic outlet syndrome, Upper extremity deep vein thrombosis, Veins, Athletes

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INTRODUCTION

A constellation of symptoms associated with thoracic outlet syndrome (TOS) commonly affects athletes, especially individuals performing at the sustained level necessary for collegiate and professional athletics. Traditional overhead sports such as baseball, volleyball, swimming, and tennis involve repetitive motions of the shoulder and upper extremity, compounded by the risk of external injury, which can further exacerbate the stresses placed on the musculoskeletal structures of the shoulder and neck [1-3]. The combination of these factors predisposes athletes to developing TOS. Substantial inquiry has been reported on best practices for preoperative rehabilitation, physical therapy, operative indications, surgical techniques, and postoperative management of athletes with TOS. However, studies reviewing unique musculoskeletal and joint abnormalities in this patient population are limited [3-6].

Presence of pathologic cervical ribs in TOS is well-documented, and some work has assessed the presence of occult first rib fractures or osteophytic degeneration and costochondral calcification in the pathophysiology of TOS, as well [7,8]. Joint hypermobility or hyperlaxity has been studied in athletes and has been associated with an increased risk of shoulder injuries specifically [9]. More broadly, joint laxity is associated with a wide range of musculoskeletal diseases, including osteoarthritis and knee injury [9,10]. A relationship between joint laxity and TOS has been previously identified and is attributed to the altered material properties of ligamentous tissues in patients with hyperlaxity [11].

This study sought to explore the presence of musculoskeletal and joint abnormalities specifically in a group of high-intensity athletes and to assess the utility of supraclavicular decompression on postoperative functional outcomes.

MATERIALS AND METHODS

1) Study design

A retrospective single-center review of a database of patients with TOS was conducted at NorthShore University Health System, Evanston, IL, USA. The study population was defined as high-intensity athletes who were evaluated for TOS between 2018 and 2023 and subsequently underwent surgical decompression of the thoracic outlet. Detailed preoperative, intraoperative, and postoperative information was abstracted from hospital records, clinic documentation, and operative notes. Patient consent was obtained for research participation. Institutional Review Board of NorthShore University Health System approval was obtained (IRB no. EH23-212).

2) Preoperative evaluation

Initial evaluation of patients involved a thorough history and physical examination in addition to specific assessments for components of vascular and neurogenic TOS. Adson's maneuver and the elevated arm stress test were performed to evaluate for neurogenic thoracic outlet compression. Several patients diagnosed with neurogenic TOS were evaluated by a neurologist or underwent electromyography to confirm brachial plexus involvement and exclude distal neuropathies. Patients presenting with Paget-Schroetter syndrome were primarily diagnosed using venous duplex ultrasonography for complaints of upper extremity pain or swelling. These patients routinely underwent catheter-directed lytic therapy with repeat venograms within 24 to 48 hours to assess for response. Computed tomography angiography or venography and magnetic resonance angiography or venography assisted with diagnosing the remaining patients. Computed tomography was predominantly used to identify vascular abnormalities, and magnetic resonance imaging (MRI) aided in the identification of neurological compression. Joint hyperlaxity was determined using the Beighton scoring criteria, which assesses for laxity of the upper and lower extremities [12-16]. Patients with a Beighton score >4 were considered to have joint hyperlaxity.

3) Surgical management

Following the initial evaluation, all patients were treated by the senior author (CJL), who isexperienced in the management of TOS. Patients presenting with acute Paget-Schroetter syndrome underwent delayed intervention approximately 4 to 8 weeks following initial catheter-directed lytic therapy to allow resolution of inflammation, avoid bleeding complications, and reduce the risk of iatrogenic injury during surgery [17]. All patients underwent supraclavicular decompression, which included first rib resection and scalenectomy of the anterior and middle scalene muscles.

Intraoperative identification of bony and muscular abnormalities was performed by the surgeon (CJL). A broad first rib with abnormal scalene tubercle development was defined as an unexpected early widening of the first rib at the scalene tubercle, which alters the curvature of the rib along with the creation of a larger-than-expected scalene tubercle. As a result, obliteration of a true vascular groove on the rib occurs. Broad anterior scalene musculature was defined as broad muscle fiber insertion on the first rib,

which extends to greater than one-third of the infraclavicular length of the rib.

Resection was performed for the presence of cervical rib. Intraoperative judgement was used prior to proceeding with subclavian venolysis and brachial plexus neurolysis as indicated based on the pathology. When performed, venolysis was extended inferiorly towards the subclavian-innominate confluence via the supraclavicular incision on the right. For left-sided disease, venolysis proceeded to the sternoclavicular junction. Additionally, fibrous scar tissue and connective tissue were removed from the thoracic outlet. A flat, closed suction drain was routinely left in place and removed on postoperative day 1 or 2 if no lymphatic leakage was detected. The subclavian artery and vein were visually assessed for fibrous scarring, dilation, ectasia, and external trauma. No patients in the cohort required arterial or venous resection or reconstruction. Patients with vascular TOS were discharged with anticoagulation therapy, typically direct oral anticoagulants. Patients with Paget-Schroetter syndrome were managed with interval venogram, usually 4 to 6 weeks after the initial operation. A combination of balloon angioplasty, cutting balloon angioplasty, and drug-coated balloon angioplasty were employed to maintain or improve venous patency.

4) Postoperative management

All patients were longitudinally followed in the clinic. Patients with vascular TOS were surveilled using duplex ultrasonography, which has high sensitivity and specificity for venous TOS [18,19]. Specific physical therapy for TOS was initiated postoperatively. Initial therapy focused on range of motion exercises, with a gradual transition to strength training. Return to sport was delayed until at least 6 months following decompression or until assessment was performed by the physical trainer and surgeon for fitness to return to sport. Functional outcomes were assessed postoperatively using the Derkash scoring system [20].

5) Data analysis

The primary outcome assessed in this study was the time required to return to sport, which was holistically assessed regardless of the laterality of intervention. Secondary outcomes included assessment of vascular patency, functional score, joint hyperlaxity, and musculoskeletal abnormalities. Outcomes were assessed relative to the total number of patients in the cohort, unless otherwise specified.

RESULTS

A total of 13 patients, 5 females and 8 males, were included in the study with a mean age of 30 years (range, 19-51 years) (Table 1). Return to sport was not significantly different by sex with 80% of females compared with 75% of males returning to sport. Fifteen total limbs received intervention with 2 patients undergoing staged bilateral operations, while 1 patient with bilateral TOS had unilateral surgery. All operations were accomplished via a single supraclavicular incision. Traditional overhead sports including tennis, swimming, and weightlifting were common among patients. Among the patients, 2 participated in a branded high-intensity fitness regimen, and 1 each participated in hockey, boxing, snowboarding, rock climbing, lacrosse, triathlons, and martial arts (Table 1). Eight (62%) patients were diagnosed with venous TOS, with 7 patients treated for acute upper extremity deep venous thrombosis. One (8%) patient was diagnosed with arterial TOS, and 7 (54%) were diagnosed with neurogenic TOS. Three (23%) patients had combined vascular and neurogenic TOS. Two (15%) patients had concomitant venous and neurogenic TOS, and 1 (8%) had concomitant arterial and neurogenic TOS (Table 1). One (8%) patient was diagnosed with McCleery syndrome. A similar number of patients were able to return to sport when stratified by type of TOS. Patients were predominantly right-hand dominant (85%). The median Beighton score for the cohort was 6 (range 0-8), and 8 (62%) patients had a Beighton score ≥4, which was consistent with joint hyperlaxity. Among these 8 patients, 6 were able to return to athletics, while the remaining 2 patients were unable to return. Four patients had prior trauma to the upper extremity ipsilateral to the decompressive operation, including 3 (23%) with prior clavicular fracture and 1 (8%) with prior shoulder and back injury. The cases of prior clavicular fracture consisted of 2 with venous TOS and 1 with neurogenic TOS (Table 1).

Abnormal hypertrophy or insertion of the anterior scalene muscle was the most common musculoskeletal abnormality and was observed in 10 (67%) patients. Insertion onto the upper surface of the first rib between the subclavian vein and artery was defined as typical insertion [21]. Abnormal hypertrophy of the middle scalene muscle was identified in 2 (13%) patients, while 13% had overlapping insertions of the anterior and middle scalene muscles onto the first rib. An enlarged scalene tubercle was identified in 1 (7%) patient, and the presence of a scalenus minimus was observed in 1 (7%) patient (Table 2) [22]. MRI provided evidence of bilateral scalene muscle hypertrophy in one case of a rock climber with neurogenic and venous TOS, which was not observed in a non-athlete with the same combined

Table 1. Patient demographics including the sport in which the patient competed prior to diagnosis, laterality of TOS symptoms, and final diagnosis

No.	Sex	Age (y)	Sport	Symptom laterality	Operative laterality	Primary symptom	TOS	Beighton score	Musculoskeletal abnormality	Additional intervention	Return to sport (mo)
1	Female	51	Triathlon	Left	Left	Arm pain, swelling	Arterial, neurogenic	0	Cervical rib, scalene hypertrophy	-	9
2	Male	29	Weightlifting	Left	Left	Arm pain	Neurogenic	6	Broad first rib, scalene hypertrophy	-	6
3	Male	19	Hockey	Right	Right	Arm pain	Neurogenic	7	Broad first rib, prior clavicular fracture, scalene hypertrophy	-	Did not return
4	Male	30	Snowboarding	Bilateral	Bilateral	Right arm pain	Neurogenic	6	Cervical rib, previous trauma, scalene interdigitation	-	7
5	Female	19	Lacrosse	Right	Right	Arm pain	Neurogenic	8	Broad first rib, scalene hypertrophy	-	8
6	Male	41	Swimming	Left	Left	Arm swelling	Venous	0	Broad first rib	Venoplasty	6
7	Male	21	Boxing	Bilateral	Right	Right arm pain	Venous	0	Prior clavicular fracture, scalene hypertrophy	Venoplasty	7
8	Male	37	Branded fitness regimen	Right	Right	Right arm pain, swelling	Venous	6	Scalene hypertrophy	Venoplasty	Did not return
9	Female	40	Competitive obstacle course training	Left	Left	Arm pain, paresthesia	Venous	0	Broad first rib, scalene hypertrophy	Venogram	Did not return
10	Male	20	Rock climbing	Right	Right	Arm swelling	Venous	6	Broad first rib, prior clavicular fracture, scalene hypertrophy	Venoplasty	6
11	Female	22	Tennis	Right	Right	Arm pain	Venous	0	Broad first rib, scalene hypertrophy	Venoplasty	8
12	Female	32	Branded fitness regimen	Bilateral	Bilateral	Arm pain, rhabdomyolysis	Venous, neurogenic	6	Broad first rib, scalene interdigitation	Venoplasty	6
13	Male	29	Martial arts	Right	Right	Arm pain	Venous, neurogenic	6	Broad first rib, scalene hypertrophy	-	7

Age indicates the age of diagnosis.
TOS, thoracic outlet syndrome.

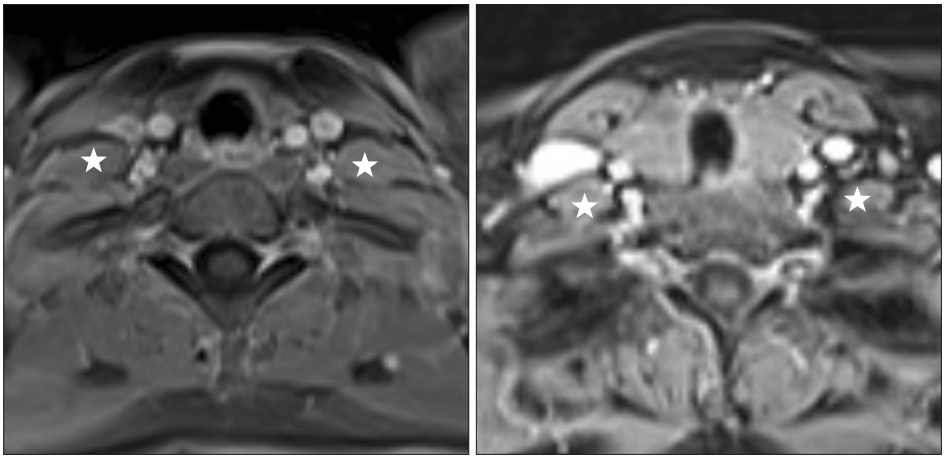

Fig. 1. Preoperative magnetic resonance imaging demonstrated substantial hypertrophy of the bilateral anterior scalene muscles in a competitive athlete with neurogenic and venous TOS (left panel) compared to the relatively normal scalene musculature observed in a non-athlete with neurogenic and venous TOS (right panel). Red stars identify the anterior scalene muscle. TOS, thoracic outlet syndrome.

Table 2. Musculoskeletal abnormalities in a cohort of athletes undergoing surgical decompression for thoracic outlet syndrome

Musculoskeletal abnormality	Number (%)
Broad first rib	9 (60)
Cervical rib	2 (13)
Scalenus minimus present	1 (7)
Enlarged scalene tubercle	1 (7)
Overlapping insertion	2 (13)
Scalenus medius hypertrophy	2 (13)
Scalenus anterior hypertrophy or abnormal insertion	10 (67)
Total	15 (100)

Percentage of total number of operations performed is indicated. Presence of broad first rib with an abnormal scalene tubercle was the most commonly observed bony abnormality. Hypertrophy or abnormal insertion of the scalenus anterior muscle was the most common muscular abnormality.

Table 3. Derkash functional score for individual patients following surgical decompression of the thoracic outlet

Derkash score	Number (%)
Excellent	9 (69)
Good	2 (15)
Fair	1 (8)
Poor	1 (8)
Total	13 (100)

Excellent indicates no pain and easy return to preoperative professional and leisure daily activities. Good indicates intermittent pain that is well tolerated with possible return to preoperative professional and leisure daily activities. Fair indicates intermittent pain with poor tolerance and difficulty in returning to preoperative professional and leisure daily activities. Poor indicates failure to show improvement in symptoms or even aggravation of pre-existing symptoms.

TOS condition (Fig. 1).

Bony abnormalities were common in this cohort of high-intensity athletes. Diagnosis of bony abnormality was made on visual inspection of the resected rib with comparison to typical first rib morphology. A broad first rib defined by an abnormal scalene tubercle was the most common skeletal abnormality and was present in 9 (60%) patients. Abnormal angulation and bone spurring was concomitantly identified in several of the abnormal scalene tubercles. Prior clavicular bone fracture was identified in 3 (23%) patients, including 1 who developed neurogenic TOS and 2 with venous TOS. The presence of a supernumerary cervical rib was observed in 2 (13%) operations including one with fusion of the cervical and first rib that contributed to arterial and neurogenic compression (Table 2).

The postoperative length of stay was 2 days on average (range, 1-6 days). One complication was identified, which was a case of pneumothorax that was managed conservatively and subsequently resolved. Seven (88%) patients with venous TOS returned for interval venogram and 6 (75%) required additional venoplasty (Table 1). No patients with vascular TOS presented with recurrent thrombosis after their initial operation. A majority of patients with vascular TOS were discharged home on direct oral anticoagulant therapy, which was continued postoperatively. Ten patients (77%) were able to return to competitive athletics, including 7 without any limitation and 3 with some limitations that did not allow them to return to athletic participation. The 3 patients that were unable to return to sport included one with neurogenic TOS and joint laxity, and 2 cases of venous TOS, 1 with joint laxity and 1 without. Scalene hypertrophy was observed in all 3 patients. The mean time to return to competitive athletics was 7 months (Table 1). Derkash score evaluation demonstrated 9 (69%) patients with excellent results consistent with no pain and easy return to

preoperative activities, 2 (15%) patients with good result indicating intermittent pain that was well tolerated, 1 (8%) patient with fair result indicating intermittent pain that was poorly tolerated, and 1 (8%) patient with re-aggravation of symptoms due to premature return to sport (Table 3).

DISCUSSION

Arterial, venous, and neurogenic TOS are clinically and anatomically different pathologies that afflict unique subsets of the population [4,5,7,8,23]. Repetitive behavior is a mutual risk factor for all three forms of TOS. Recurrent injury of the subclavian vein, subclavian artery, or brachial plexus leads to inflammation, scar tissue formation, and degeneration over time that ultimately presents as TOS. Supernumerary cervical ribs, scalene hypertrophy, subclavius hypertrophy, and impingement of the costoclavicular space are all potential inciting anatomic factors [3,24]. Cervical ribs have been shown to be most commonly associated with TOS, more than anomalous first ribs [25]. High-intensity athletes are a subset of the population who have important differences in behavior and risk factors for the development of TOS and seem to be at higher risk of developing TOS compared to that in the general population [5,7]. Concurrently, there is data to support that athletes also tend to exhibit a greater incidence of joint laxity or instability [14,16,26,27]. We hypothesized that high-intensity athletes are predisposed to developing TOS due to 2 synergistic processes common among athletes: (1) training from high-intensity athletics contributing to early musculoskeletal abnormalities and (2) increased joint laxity, resulting in an inherent instability of the thoracic outlet and increased risk of neurovascular compression.

Our cohort presented with TOS largely consistent with trends among athletes, with a predominance of venous and neurogenic etiologies and only one case of arterial TOS. A variety of common overhead sports, such as tennis and weightlifting, were represented among the patients in this study, in addition to several more niche athletics, including triathlons, snowboarding, and martial arts. Branded fitness regimen participation was also represented in our cohort, and patients participating in these activities should be assessed with a high index of suspicion when presenting with upper extremity symptoms. Right-hand dominance was most common in this group; however, at least 20% of patients had contralateral symptomatology, and 2 patients required bilateral decompression, which may reflect the ambidextrous nature of athletes, especially those participating in collegiate and professional level activities. Vascular surgeons should remain alert to patients presenting with TOS symptoms in either upper extremity.

Most notably, only 1 patient in the entire cohort did not have identification of a bony abnormality, and only 1 other patient did not have a muscular abnormality. In our experience, the degree of bony abnormality appeared to be more severe in this group than in our non-athlete patients. Broad first rib with abnormal scalene tubercle was the most common bony abnormality identified intraoperatively. We believe that this anatomic variant is due to altered curvature of the rib contributing to obliteration of a true vascular groove on the rib and the formation of a larger than anticipated scalene tubercle. This may contribute to unwanted subluxation and elevation of the rib from scalene muscle hypertrophy or spasm, which predisposes athletes to developing thoracic outlet compression. Prior clavicular fracture was also found in this patient cohort and is a known risk factor for TOS [3]. These findings were consistent with prior seminal studies of patients with TOS, including approximately 10% incidence of cervical rib and scalenus minimus abnormalities [22]. Bone development begins in utero and continues well into adolescence and early adulthood [28]. Therefore, in collegiate and professional athletes who begin participating in high-intensity sports at an early age, an extended window of time during mid-to-late adolescence when imbalances in strength, muscular development, and joint laxity may occur often results in abnormal musculoskeletal findings.

Joint laxity has been suggested as one possible mechanism for the development of TOS, whereby, compensation for laxity of the atlantoaxial joint and the cervical vertebrae is provided by shortening and tightening of the scalene muscles, leading to compression of the thoracic outlet [11]. The prevalence of generalized joint hypermobility in the general population is variably quantified, with estimates of approximately 26% overall and a predisposition in females [14,16]. This is substantially lower than the 62% of patients in our cohort who had a Beighton score ≥4. The mechanical response properties of cartilaginous and connective tissues in patients with joint hyperlaxity may also be fundamentally different than that in the normal population [22]. A discrepancy in inflammation and healing after injury or repetitive behavior in athletes may further predispose them to neurovascular compression [11]. Intraoperatively, we identified relatively taut and hypertrophied scalene musculature in a majority of the patients, consistent with a compensatory response to increased joint laxity. Functionally, baseball pitchers with shoulder laxity have measurably reduced upper extremity blood flow with exertion compared to that in pitchers without laxity, which is conceivably attributable to a greater range of motion at the shoulder and neck and the potential for long-term injury to the vessels in the area [29]. Joint hyperlaxity did not appear to contribute

to whether athletes returned to sport participation after decompression in our cohort, which is consistent with past results demonstrating the success of full decompression of the thoracic outlet [5].

Supraclavicular decompression was performed in all patients in the study. This approach has been preferred by our surgical team as it achieves adequate resection of any supernumerary ribs and also offers reasonable exposure for a near-complete first rib resection. Importantly, the supraclavicular approach allows for the most complete brachial plexus examination and subsequent neurolysis, which is critical in cases of undiagnosed, concomitant neurogenic TOS. Combined cases of vascular and neurogenic TOS were observed in 23% of patients, and the true incidence may be even higher; therefore, the ability to adequately decompress the brachial plexus is vital and may not readily have been achieved through an infraclavicular or transaxillary approach. Proximal resection of the infraclavicular rib is achieved via 2 maneuvers from the supraclavicular incision. First, mobilization and division of the proximal rib segment at the transverse process of the spine allow for detachment of the scalene and intercostal muscles, promoting the caudal shift of the anterior segment of the clavicle. As a result, greater visualization of the outer and inner curvature of the rib at the sternal junction is achieved. Second, blunt dissection is used to clear the subclavius tendon once the rib shifts caudally, and then a Kerrison side-biting rongeur (V. Mueller) is used to divide the infraclavicular rib near its sternal insertion. Vascular reconstruction was not necessary in this group, and sufficient subclavian venolysis was performed via the supraclavicular incision. If necessary, our practice is to convert to a paraclavicular approach to achieve adequate venolysis when indicated.

A staged postoperative venogram was performed in cases of Paget-Schroetter syndrome, and no cases of interval re-thrombosis occurred. This venogram is performed at four weeks postoperatively to avoid ongoing inflammation associated with the surgery and potential complications from endovascular venoplasty while the patient is experiencing active mechanical manipulation and scar remodeling from early physical therapy. In the case of McCleery syndrome, surgical decompression was performed given the high anticipated risk for thrombosis and potential for undiagnosed deep venous thrombosis. Gradual return to sport was an important feature of the postoperative management paradigm; as a result, athletes were not allowed to participate in sports until after 6 months of follow-up. In this cohort, the mean time of return to sport was approximately seven months, which was shortly after clearance to participate with predominantly excellent functional results. In the 3 patients unable to return to athletics, re-injury was identified in one case. Collaborative assessment and communication between the physical therapy team and surgeon are therefore a key component of recovery. No notable differences in musculoskeletal abnormalities contributed to the inability to return in the 2 cases of venous TOS; although both patients were relatively older.

This study is limited by its retrospective observational design and small sample size. The lack of a control group of non-athletes to compare the incidence of musculoskeletal abnormalities limits our ability to link causative pathways between high-intensity athletics and the abnormalities observed in our cohort. Results of prior research support our findings of musculoskeletal changes, such as occult first rib fractures and costochondral calcification in patients with TOS [7]. Furthermore, the possibility exists that the findings in this study, although common among patients with TOS, are not contributory to the development of TOS as the study was not designed to assess causation, and the natural prevalence of these abnormalities in the general population is not well defined. Future studies should develop a more comprehensive understanding of the prevalence of different bony and muscular abnormalities in both athletes and non-athletes with TOS, in addition to better understanding the prevalence of joint laxity in the athlete and non-athlete general population.

CONCLUSION

High-intensity athletes are a unique cohort of patients among those diagnosed with TOS. Challenges exist in diagnosis, preoperative management, surgical therapy, and postoperative treatment. This retrospective review of a single-center cohort of athletes treated for TOS highlights the significance of musculoskeletal abnormalities and joint hypermobility, which predispose athletes to developing symptomatic TOS. More importantly, supraclavicular decompression achieved excellent functional results with a relatively short time to return to sport and no recurrence of TOS symptoms in a majority of patients.

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CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHOR CONTRIBUTIONS

Concept and design: DJ, BL, OM, CL. Analysis and interpretation: all authors. Data collection: BL, OM, CL. Writing the article: DJ, RW, CL. Critical revision of the article: DJ, RW, CL. Final approval of the article: DJ, CL. Statistical analysis: DJ. Obtained funding: none. Overall responsibility: DJ, CL.

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