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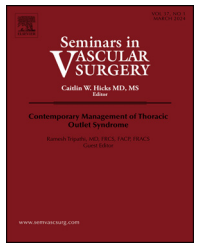

Review article

Diagnosis and management of thoracic outlet syndrome in athletes

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ABSTRACT

The physical demands of sports can place patients at elevated risk of use-related pathologies, including thoracic outlet syndrome (TOS). Overhead athletes in particular (eg, baseball and football players, swimmers, divers, and weightlifters) often subject their subclavian vessels and brachial plexuses to repetitive trauma, resulting in venous effort thrombosis, arterial occlusions, brachial plexopathy, and more. This patient population is at higher risk for Paget-Schroetter syndrome, or effort thrombosis, although neurogenic TOS (nTOS) is still the predominant form of the disease among all groups. First-rib resection is almost always recommended for vascular TOS in a young, active population, although a surgical benefit for patients with nTOS is less clear. Practitioners specializing in upper extremity disorders should take care to differentiate TOS from other repetitive use–related disorders, including shoulder orthopedic injuries and nerve entrapments at other areas of the neck and arm, as TOS is usually a diagnosis of exclusion. For nTOS, physical therapy is a cornerstone of diagnosis, along with response to injections. Most patients first undergo some period of nonoperative management with intense physical therapy and training before proceeding with rib resection. It is particularly essential for ensuring that athletes can return to their baselines of flexibility, strength, and stamina in the upper extremity. Botulinum toxin and lidocaine injections in the anterior scalene muscle might predict which patients will likely benefit from first-rib resection. Athletes are usually satisfied with their decisions to undergo first-rib resection, although the risk of rare but potentially career- or life-threatening complications, such as brachial plexus injury or subclavian vessel injury, must be considered. Frequently, they are able to return to the same or a higher level of play after full recovery.

1. Introduction

Thoracic outlet syndrome (TOS) results from compression of the subclavian artery, vein, or brachial plexus as these structures traverse the thoracic outlet. Epidemiology of this disorder suggests that it develops through repetitive use, as TOS preferentially affects athletes and other patients who perform repetitive upper extremity exercises. The diagnosis is subdivided into three categories. In arterial (aTOS) and venous TOS (vTOS), patients often present with objective signs of upper extremity vascular compromise, including venous thrombosis and swelling or arterial emboli to the digits, whereas in nTOS, diagnosis rests more heavily on the clinical history and a patient's symptomatology. Given the correlation between repetitive use and nTOS, a history of sport or upper extremity physical labor is a positive indicator that a patient's upper extremity use–provoked pain, fatigue, or paresthesias may be due to nTOS.

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Nonsurgical treatments are often composed of physical therapy, scalene muscle injections, postural training, and sometimes avoidance of provocative activities. Surgical treatment usually consists of resection of the first rib and removal or division of various muscle attachments, with adjunct brachial plexus lysis, venous thrombectomy, or arterial reconstruction as necessary.

For athletes in particular, TOS constitutes an occupational risk that can jeopardize careers, but with prompt recognition and treatment athletes may have better outcomes from surgical management of TOS compared with the general population. In this review, we discuss the current approach to diagnosis and management of all three types of TOS in athletes. We also highlight athlete-specific outcomes of various interventions with particular attention to return-to-sport statistics after treatment.

2. Epidemiology

2.1. *Arterial TOS*

Arterial TOS is a rare entity (comprising <1% of TOS cases overall [1,2]) and is usually associated with anomalous patient anatomy, in particular, presence of a cervical rib contributes to aTOS in most cases [3–5]. Anatomically variant first ribs (including hyperplastic, hypoplastic, and fused first ribs) are present in 0.25% [6,7] and cervical ribs are present in approximately 1% of the general population [8]. A small minority of these patients will go on to develop symptoms of TOS. However, cervical ribs are much more prevalent in the TOS population; they are found in 29.5% of all patients with TOS compared with a 1.1% cervical rib incidence overall [9] (Fig. 1).

However, patients who present for symptoms of aTOS often have a history of upper extremity activity or athletic competition, in addition to anatomic risk factors. Baseball has been implicated frequently in the development of aTOS [11]; human and cadaveric studies have found that overhead throwing motions result in repetitive compression of the axillary artery by the humeral head [12]. Gradual trauma can cause aneurysm formation, arterial wall dysplasia, dissection, and thrombosis of the axillary artery [11,13]. Asymptomatic professional baseball pitchers have lower finger perfusion at rest compared with healthy volunteers, suggesting that their occupation induces pathologic circulation changes [14]. Even among baseball players without concrete manifestations of aTOS, such as digital ischemia or axillary artery thrombosis, those with

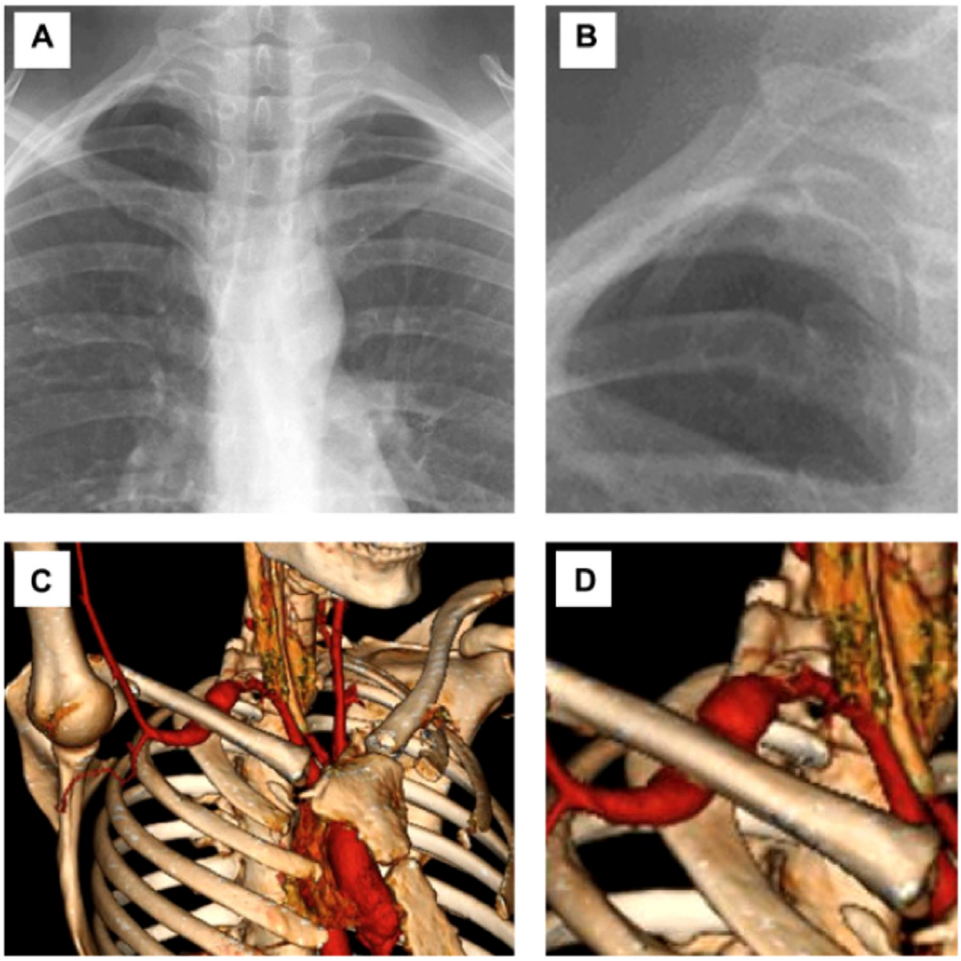

Fig. 1 – (A, B) Chest x-ray demonstrates right cervical rib. (C, D) Three-dimensional reconstruction from upper extremity computed tomography demonstrates post-stenotic subclavian artery aneurysm. From Vemuri et al [10], reprinted with permission.

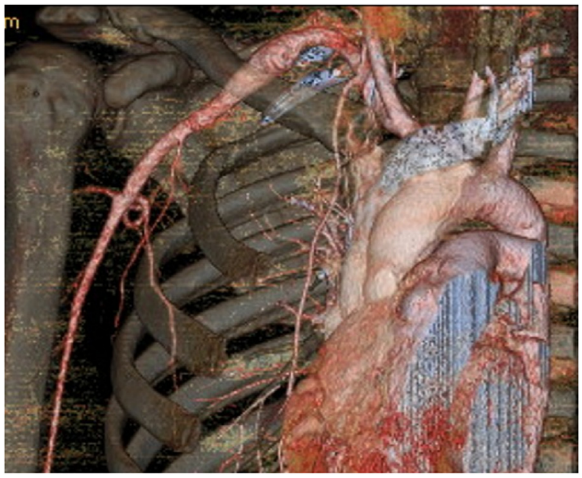

Fig. 2 – Cervical rib seen in collegiate tennis player leading to subclavian aneurysm and subsequent hand discoloration during serving motion.

increased shoulder laxity have lower augmentation in distal hand perfusion after pitching compared with those without significant shoulder laxity [15]. Although baseball players have perhaps been most studied, other sports that involve significant range of motion at the shoulder can also provoke all types of TOS—these include swimming, diving, volleyball, football, tennis, and wrestling [16,17] (Fig. 2). The disorder is, however, not strictly limited to overhead athletes and cases have also been reported in runners [18].

2.2. *vTOS*

Paget-Schroetter syndrome, or exercise-induced thrombosis of the subclavian vein, is the usual presentation of vTOS and accounts for 3% to 5% of TOS cases [1,2]. Of all TOS entities, vTOS is most strongly associated with upper extremity exercise and high-performance athletes [19]. Sixty to eighty percent of effort thrombosis cases are associated with recent vigorous upper body exercise [20]. In a limited review of one professional baseball team and one Division I college team from 1987 to 1997, four cases of Paget-Schroetter syndrome were identified, suggesting that baseball players have increased an incidence compared with the general population [21]. Overall, acute thrombosis from vTOS is estimated to occur at a rate of 2 cases per 100,000 person-years [22].

It has been hypothesized that repetitive compression of the subclavian vein between the clavicle, first rib, subclavius muscle, and anterior scalene muscle result in repetitive cycles of intimal injury, venous scarring, and perivenous scar tissue formation. Patients may gradually develop collateral networks [23] (Fig. 3). Although the clavicle and first rib do not move large distances relative to each other, any movement they do perform has significant force at the subclavian vein. In addition, the anterior scalene and subclavius muscles can become hypertrophied in the athlete or active person [25]. Diagnosis is often made after the stenosis becomes so severe that, in response to a final insult of vigorous activity, thrombosis of the subclavian/axillary vein occurs [26,27]. In addition to repetitive use, patients with Paget-Schroetter syndrome are more likely to have a hypercoagulability disorder [28,29].

Diagnosis is usually made after an individual experiences swelling, cyanosis, and heaviness of the affected arm—symptoms consistent with venous congestion from acute deep venous thrombosis. Treatment usually consists of a combination of anticoagulation, thrombolysis/venoplasty, and optionally first-rib resection [30].

2.3. *nTOS*

Although the literature describes nTOS as more common among patients who have experienced upper extremity, thoracic, or neck trauma [5], it can also be found in those who have a history of repetitive upper extremity use, as in sports or labor [31]. Anatomic predisposing factors also include anomalous musculotendinous insertions or cervical rib [2,27]. It is much more common than aTOS or vTOS, accounting for 95% of all TOS cases [1,2]. Because the diagnosis is clinical, it is more difficult to accurately characterize the nTOS-affected population and the breakdown of all elements contributing to development of nTOS, although newer diagnostic techniques can help to differentiate nTOS from other causes of upper extremity pain [32]. The Society for Vascular Surgery's reporting standards for TOS aim to define diagnostic criteria and aid in reliable comparison of outcomes, which is particularly important in management of nTOS because diagnosis can be somewhat uncertain [33].

Similar to aTOS and vTOS, repetitive injury is thought to be a key explanation for development of nTOS. The brachial plexus is located between anterior and middle scalene muscles and the first rib. An athlete performing upper extremity motions may generate repetitive trauma to the brachial plexus as it is compressed in the interscalene triangle [34,35]. Identifying nTOS in athletes requires a careful history and physical examination, although a history of athletics can certainly account for the repetitive use component of the diagnosis [36].

A positive history will often reveal pain, numbness, and paresthesias that occur in response to provocative movements that narrow the thoracic outlet or stretch the brachial plexus [33]. These findings can be reproduced in the office with the following physical examination maneuvers: elevated arm stress test, Adson's test, and upper limb tension test can all elicit symptoms [37]. However, their diagnostic utility is limited, as they tend to have a high false-positive rate [38], particularly for patients with carpal tunnel syndrome [39], ulnar neuropathy, or fibromyalgia [1]. Patients also exhibit tenderness and reproducibility of symptoms with palpation of the anterior scalene muscle [33].

The DASH (Disabilities of the Arm, Shoulder, and Hand) survey or QuickDASH abbreviated survey are often used to gauge severity of symptoms from nTOS and evaluate for postoperative improvement [40]. When used in an athlete population, the QuickDASH with sports module has a ceiling effect, as many athletes report performing at the highest-level despite perhaps experiencing relative disability from their upper extremity symptoms [41]. Tyser et al [42] advocated for the use of adaptive testing, such as the National Institutes

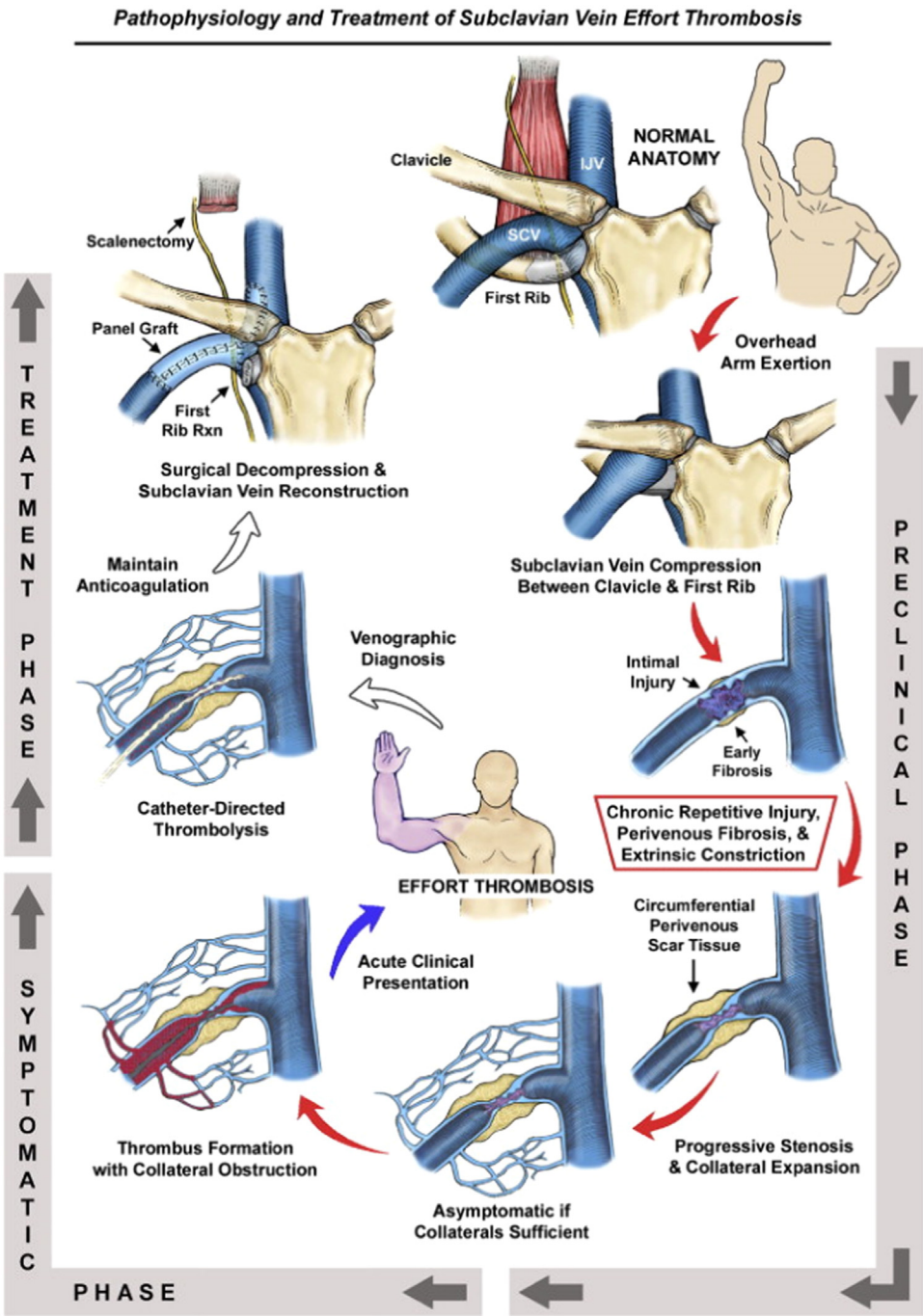

Fig. 3 – Gradual development of venous stenosis and collateral networks over time in Paget-Schroetter syndrome. IJV, internal jugular vein; SCV, subclavian vein. From Melby et al [24], reprinted with permission.

of Health PROMIS (Patient Reported Outcomes Measurement Information System) computer adaptive tests to better evaluate upper extremity function in an elite athlete population (42).

Because nTOS presents with somewhat nonspecific symptoms, particular care must be taken to rule out other athletic-related causes of upper extremity pain or weakness before planning invasive treatment for presumed nTOS. Athletes can be affected by any number of use- or trauma-related injuries that produce upper extremity pain and paresthesias, including rotator cuff and orthopedic injuries, nerve entrapment at other locations, including the ulnar tunnel, carpal tunnel, or cervical roots, or nonmechanical conditions, such as fibromyalgia, multiple sclerosis, or undifferentiated chronic pain [1]. Pectoralis minor syndrome can also mimic or present in conjunction with nTOS and results from compression of the brachial plexus as it travels through the retropectoralis space, rather than in the costoclavicular space as in nTOS.

Risk factors are similar, including engaging in repetitive overhead motion and competition in certain sports; pathology develops due to contracted pectoralis minor muscle. In addition to brachial plexopathy symptoms similar to nTOS, patients tend to present with shoulder or scapular pain secondary to suprascapular nerve entrapment. Treatment involves physical therapy aimed at lengthening the pectoralis minor muscle, or surgical pectoralis minor release if patients do not respond to conservative management [43].

One rare athlete-specific mimic is quadrilateral space syndrome, which involves arm pain and paresthesias from compression of the posterior humeral circumflex artery and axillary nerve within the space bounded by teres minor, teres major, long head of the triceps, and humeral shaft. Similar to TOS, athletes are overrepresented among patients with this condition [44,45]. Unlike in TOS, patients have tenderness and provocation of symptoms with palpation of the quadrilateral space as opposed to palpation of the anterior scalene muscle. Angiography demonstrates compression of the posterior humeral circumflex artery with provocative maneuvers [45]. In select cases, almost exclusively among professional athletes, compression in this space results in aneurysm of the axillary artery or its branches at the quadrilateral space (termed *axillary branch artery aneurysms*). The presentation is similar to that of aTOS [27,46].

3. Diagnosis and testing

For vTOS, diagnosis is dependent on detecting the arterial or venous static or dynamic lesions. The axillary artery usually has vessel stenosis, occlusion, or aneurysm at the costoclavicular space in aTOS. Any imaging modality that demonstrates the vessel lumen of interest can be used to confirm the diagnosis, including angiography or cross-sectional imaging with contrast. Patients with vTOS presenting with Paget-Schroetter are often diagnosed with duplex ultrasound and commonly undergo thrombolysis with catheter-directed contrast venography shortly after the venous occlusion is diagnosed. Duplex ultrasound has a false-negative rate of 30% in Paget-Schroetter syndrome, so venous contrast-enhanced computed tomography or magnetic resonance imaging are typically used when a patient's pretest probability is high, but duplex is negative [24,30].

Finger photoplethysmography (PPG) and transcutaneous oximetry [47] can also detect compression of the artery; in aTOS, reduced PPGs with provocative maneuvers indicate an arterial cause for hand ischemic symptoms. And in nTOS, reduced finger PPGs confirm that certain positions or movements do indeed result in compression in the interscalene triangle [4]. Thus, in our practice, finger PPGs are a standard component in the diagnosis of nTOS in all populations.

Other adjuncts to the challenging diagnosis of nTOS include magnetic resonance imaging of the brachial plexus and upper extremity electromyography (EMG). Magnetic resonance imaging of the brachial plexus can reveal acute perineural inflammation at the interscalene triangle [48]; it can also reveal mimics of nTOS, such as cervical stenosis or disc impingement. Upper extremity EMG has been proposed as a diagnostic tool for nTOS; however, it has not gained widespread use due to disagreements on its utility. Although some authors contend that, with the right thresholds and right diagnostic criteria, it can confirm nTOS, others note that the practical sensitivity and specificity are quite low [3]. EMG findings associated with nTOS include amplitude reductions preferentially in distal upper extremity or hand muscles and reduced transmissions in median, ulnar, and medial antebrachial cutaneous nerves, which is consistent with thenar eminence and intrinsic hand muscle atrophy often seen in patients with nTOS [49,50]. In a patient with suspected nTOS, EMG may be more useful for ruling out other possible causes of upper extremity pain or paresthesias, such as nerve entrapment syndromes or prior traumatic nerve injuries [51].

4. Treatment

In aTOS, surgical treatment is recommended to avoid ischemic and embolic sequela and often entails first-rib/cervical rib resection and arterial reconstruction. Medical management of vTOS with anticoagulation alone has been observed to yield poor outcomes, with failure to recanalize the subclavian vein in >75% of patients and persistent symptoms in up to 91% [20]. Thrombolysis and anticoagulation without first-rib resection had previously been considered an acceptable option for vTOS, particularly in older patients without plans to continue a high level of athletic endeavors [52]. One retrospective study found that patients managed with anticoagulation with or without catheter-directed thrombolysis without open surgical management remained asymptomatic in 85% of cases and had a full-to-partial recanalization rate of 93% [53]. However, a systematic review of treatments for Paget-Schroetter syndrome found that rib resection resulted in symptom relief at most recent follow-up in 93% of patients compared with 54% of patients who did not get their first rib removed, and 40% of patients initially managed without rib resection went on to get rib resection eventually [54]. First-rib resection is thus generally recommended in the treatment algorithm for both vTOS and aTOS. Some authors have also described temporary radiocephalic arteriovenous fistula creation as an adjunct in vTOS to ensure venous patency in the athlete population, although this is performed less commonly [24].

Less clear is the indication for first-rib resection in nTOS, in part due to the nebulousness of the nTOS diagnosis itself. Adjunctive treatments designed to produce temporary symptom relief can be helpful in predicting which patients will benefit from first-rib resection. Physical therapy using the Edgelow protocol is designed to expand the interscalene triangle, reducing brachial plexus compression [34]. Patients who experience improvements in TOS-related disability scores after completing physical therapy are likely to respond well to first-rib resection, and athletes may have a particularly positive result. In one study, competitive athletes who experienced mild to moderate improvement from 3 months of Edgelow protocol physical therapy were offered first-rib resection. After surgery, 83% experienced return to full competitive levels [17].

In addition, blocks of the anterior scalene muscle with local anesthetic or botulinum toxin may predict which patients

Table 1 – Treatment approaches for neurogenic thoracic outlet syndrome and their success rates.

Treatment	Success rate, %	References
Physical therapy (Edgelow Protocol)	31	[62]
Botulinum toxin injection of anterior scalene muscle	65 (symptom reduction approximately 1 mo)	[55,63]
Transaxillary first-rib resection	76	[64]
Supraclavicular first-rib resection	77	[64]

might benefit from first-rib resection [55]. Similar to physical therapy, they relax and expand the interscalene triangle via paralysis of the anterior scalene muscle and simulate the effect of first-rib resection on the brachial plexus [32,56]. Athletes undergoing botulinum toxin injections of the anterior scalene alone can have a good result [57]; although botulinum injections followed by first-rib resections seem to provide more durable improvement compared with botulinum toxin injection alone [32]. The addition of botulinum toxin to our workup has particularly helped long-term return to Division 1 athletics in a multidisciplinary effort with sports medicine and vascular surgery [58].

Athletes have generally good return-to-competition outcomes from first-rib resection for nTOS. A study of Major League Baseball pitchers found that 10 of 13 (77%) managed to return to Major League Baseball competition after first-rib resection for NTOS, and the authors noted that for returning Major League Baseball pitchers, performance metrics post-surgery did not show a significant drop compared with presurgery [58]. At one center, 40% of their nTOS patients were athletes, and approximately 70% of those were able to return to the same or better level of competition after first-rib resection. Ninety-four percent of their participants were satisfied with their decision to undergo surgery, and 94% were able to perform activities of daily living without restriction after rib resection [59]. In athletes, the diagnosis of nTOS is often more clear cut than in the general population; perhaps the reduced diagnostic challenge in the athlete population results in performing first-rib resections more frequently for those who would benefit.

Some evidence even suggests athletes have better functional outcomes compared with their nonathlete counterparts after first-rib resection. Beteck et al [60] used patient-reported surveys to gauge postoperative symptom improvement, function, and satisfaction. They found that although athletes reported satisfaction with their decision at the same rate as nonathletes, they had significantly more symptom resolution, less pain medication use long-term, and were able to perform activities of daily living without impairment more frequently [60].

Conversely, Warrick et al [35] examined nonsurgical treatment options for nTOS. Botulinum toxin block or lidocaine block of the anterior scalene muscle may be used for either diagnosis or treatment, although lidocaine in particular is temporary and has more utility as a diagnostic tool [32,56,57]. One study of nTOS in collegiate athletes found that 42% of athletes who underwent anterior scalene botulinum toxin injection after insufficient response to physical therapy were able to return to competitive play without requiring surgery [61]. However, physical therapy is considered the cornerstone of nonsurgical management. The goal of the Edgelow protocol is to lengthen muscles that compress the interscalene triangle (anterior and middle scalene muscles, sternocleidomastoid muscles) and strengthen muscles that open the posture and widen the interscalene triangle. The position of the scapula affects the interscalene space, such that a head forward, protracted shoulder position results in greater compression of the brachial plexus. Accordingly, physical therapy for patients with nTOS focuses on stretches that elongate the anterior muscle groups that pull the scapula forward and narrow the interscalene triangle, and exercises that strengthen the rhomboids, scapular stabilizers, and middle/lower trapezius muscles [35]. Surgical and nonsurgical treatment options are compared in Table 1.

5. Therapy and recovery

After first-rib resection, athletes planning for a return to sport should engage in physical therapy aimed at maximizing postoperative function. Because surgery itself can generate significant scar tissue around the brachial plexus, manual massage and upper limb tension test maneuvers can be used to break up scar tissue and ensure that the limb does not heal with limited range of motion due to scarring. Although patients will likely be taught in preoperative therapy the importance of breathing exercises, postoperatively, diaphragmatic breathing will continue to be important to take tension off of neck accessory muscles that can place undue stress on healing areas [65].

Within these general principles, Colbert et al [16] proposed a structure to each physical therapy session for a recovering athlete, consisting of tissue mobilization first (massage, stretching), followed by targeted motor control of the thoracic spine, cervical spine, and shoulder. Once the patient has progressed past these first two criteria, the therapist would provide their scapular stabilizers and shoulder muscles with progressive loading. Finally, the athlete would be allowed to engage in upper extremity endurance training. Results were published for a case report of a softball player [16], although a case series or retrospective review with multi-patient outcomes has yet to be produced (Fig. 4).

Return-to-play metrics are varied among sports because kinematic stresses differ for various athletes, but the core concept is that each athlete must be able to perform the functions of their sport without discomfort. An individual's range of motion, muscle strength, and ultimately function are all important diagnostic criteria that practitioners should account for when advising a recovering athlete [35].

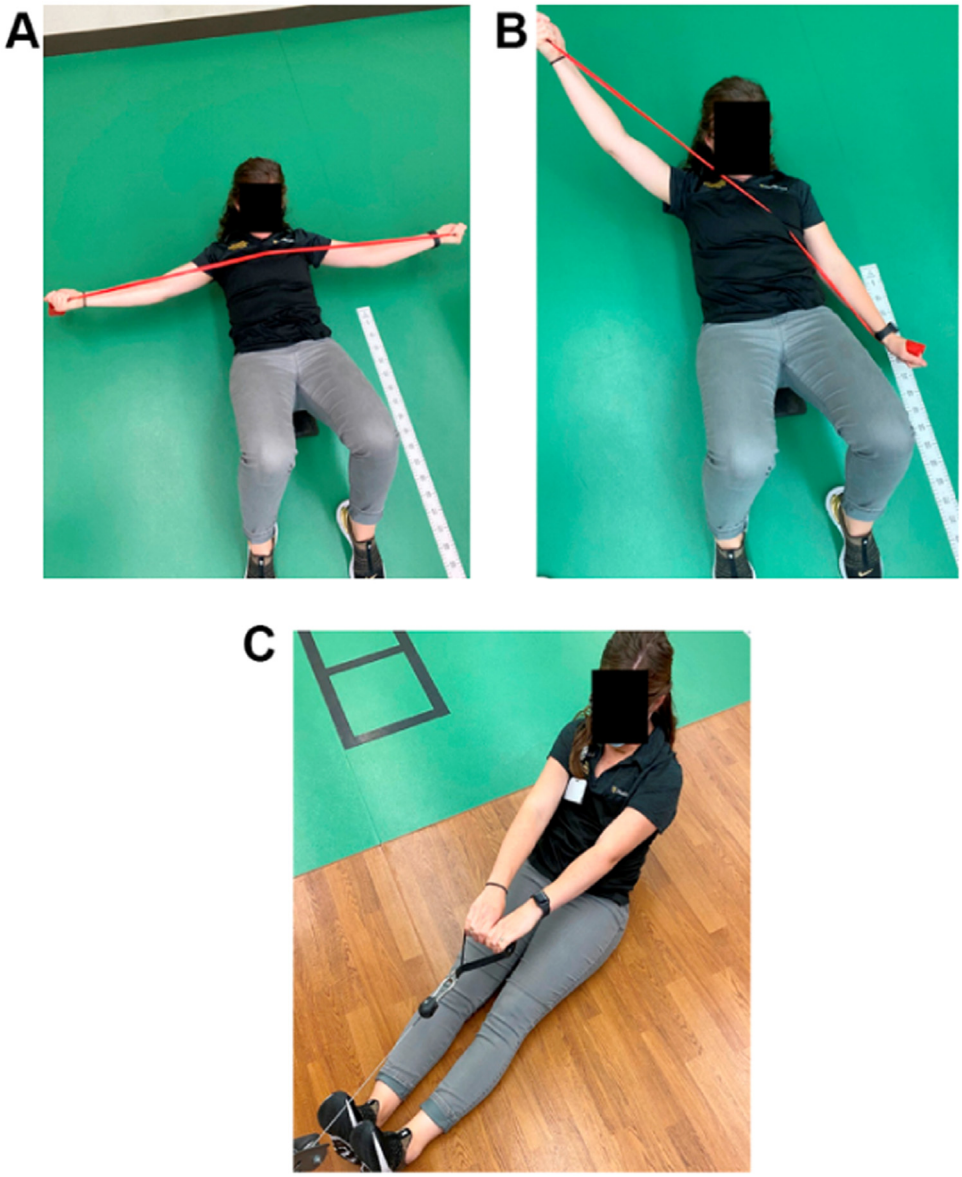

Fig. 4 – (A, B) Active scapular retraction and elevation exercises using resistance band. (C) Thoracic flexion/extension exercises. From Colbert et al [16], reprinted with permission.

6. Summary

Overall, the treatment of all forms of TOS in the athlete requires an intentional, multidisciplinary approach that is personalized for each athlete. Collaboration among orthopedics, sports medicine, rehabilitation experts, vascular surgery, and the vascular laboratory is necessary for optimal results. Early diagnosis, discussion of options, and setting expectations of this challenging patient group remains key to successful outcomes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

CRediT authorship contribution statement

Jason T. Lee: Conceptualization, Supervision, Writing – review & editing.

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