JSES International 8 (2024) 620–629

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Thoracic outlet syndrome in overhead athletes

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A R T I C L E I N F O

Keywords:
Thoracic outlet syndrome
Overhead athletes
Baseball
First-rib resection
Shoulder joint
Elbow joint

Level of evidence: Level III; Retrospective Cohort Comparison; Prognosis Study

Background: We aimed to retrospectively compare the clinical outcomes of endoscopy-assisted first-rib resection for thoracic outlet syndrome (TOS) between overhead athletes and nonathletes and investigate the return to same-level sports rate in overhead athletes.

Methods: We retrospectively reviewed 181 cases with TOS (75 women, 106 men; mean age, 28.4 years; range, 12-57 years) who underwent endoscopy-assisted first-rib resection. We divided into two groups: 79 overhead athletes and 102 nonathletes groups. A transaxillary approach for first-rib resection and neurovascular decompression was performed under magnified visualization. Endoscopic findings related to the neurovascular bundle, interscalene distance, and scalene muscle were evaluated intraoperatively. We assessed the Roos and Disability of the Arm, Shoulder, and Hand scores, return to same-level sports rate, and ball velocity.

Results: Overhead athletes were significantly more likely to be men, younger, used the dominant side more frequently, and have a larger physique, more shoulder and elbow pain, and shorter symptom duration. The outcomes of the Roos score revealed significant differences in excellent or good results between overhead athletes (91.1%) and nonathletes (62.8%). The two groups significantly differed in preoperative and postoperative Disability of the Arm, Shoulder, and Hand and recovery rate scores ($P = .007$, $< .001$, $< .001$).

Conclusion: Overhead athletes with TOS were more likely to be men, younger, dominant side more frequently, and have more shoulder and elbow pain, and a shorter symptom duration. Endoscopy-assisted transaxillary first-rib resection and neurolysis provided superior clinical outcomes in overhead athletes with TOS compared with nonathletes and a high return-to-same-level-play rate in sports.

Shoulder and elbow disorders are common in overhead athletes. Overhead athletes are at risk for several shoulder or elbow joint pathologies, including biceps-labral complex injuries,[6] internal impingement of the shoulder, anterior instability, posterior contracture, and injury of the ulnar collateral ligament of the elbow.[22] However, other shoulder or elbow joint pathologies should be considered in the differential diagnosis, such as stress fracture of the first rib[11] or olecranon[14] and neurovascular pathologies, including thoracic outlet syndrome (TOS).[13] Notably, several studies have demonstrated that overhead athletes such as baseball, softball, and volleyball players and swimmers are highly associated with TOS.[2,3,7,13,15,35,37] Overhead athletes with TOS may experience anterior or posterior shoulder pain and/or lateral or medial elbow pain, similar to internal impingement of the shoulder or medial ulnar collateral ligament dysfunction of the elbow.[13] Jobe et al reported that TOS, scalene syndrome, suprascapular nerve syndrome, and quadrilateral space syndrome comprise a group of nerve compression syndromes that become more identifiable with improved diagnostic abilities.[20] Furushima et al reported that younger male athletes with TOS may be better candidates for the transaxillary approach for first-rib resection and neurolysis in TOS.[13] Recent studies have reported favorable surgical outcomes after surgical treatment for TOS, particularly in overhead athletes.[2,3,7,15,37]

TOS is a complex disorder characterized by signs and symptoms in the upper limb.[4,16,26,29,33,34,39] TOS is a well-described disorder; however, its accurate diagnosis remains challenging. It presents various symptoms and atypical radiographic findings, leading to the application of less objective diagnostic criteria. Data on the clinical features and surgical outcomes of overhead athletes with TOS are lacking.

This study was approved by the ethical review board of Keiyu Orthopedic Hospital, approval number 3506.

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https://doi.org/10.1016/j.jseint.2023.12.004

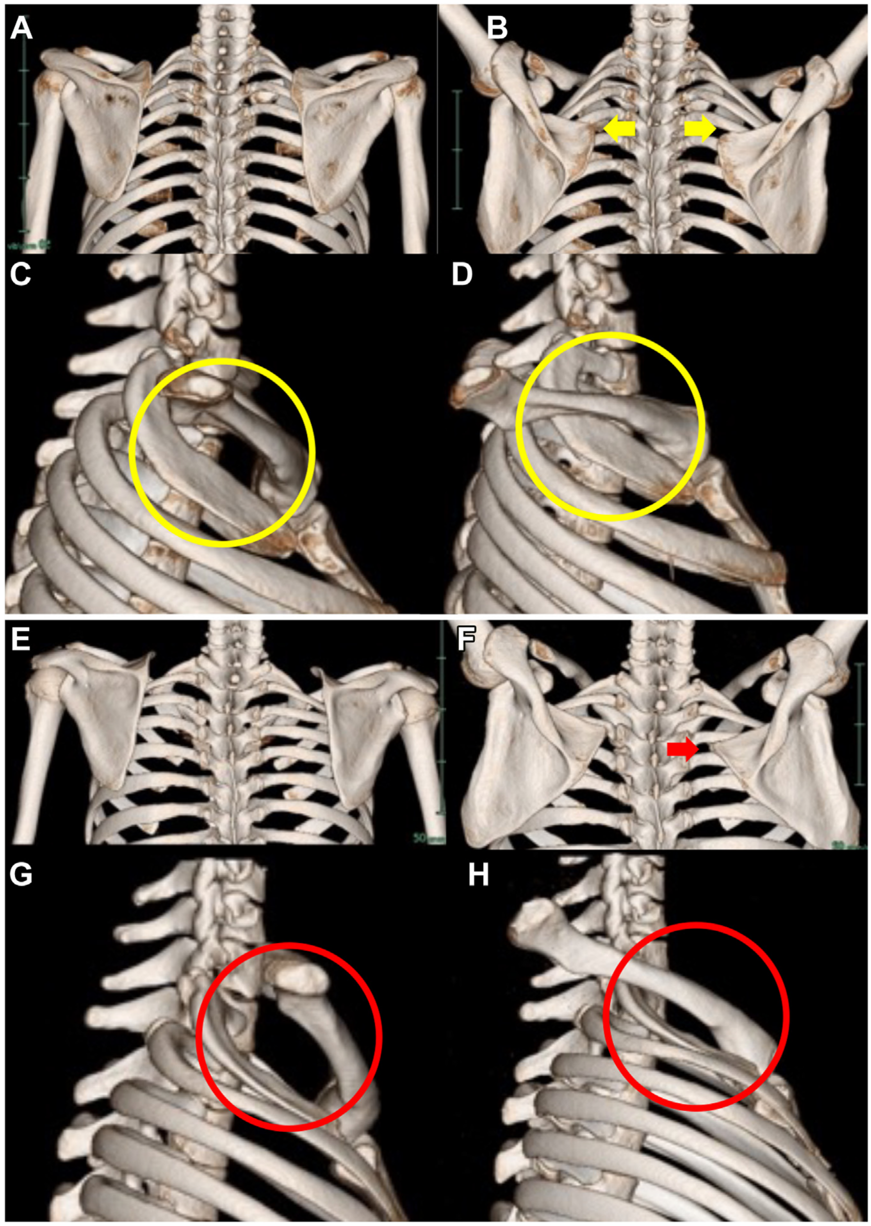

Figure 1 Three-dimensional computed tomography of the preoperative scapular position. (**A**): Nonathlete with right-sided symptomatic thoracic outlet syndrome (TOS) in the resting position. (**B**): Arm-elevated position. Note the inferior displacement on both sides of the scapula *(arrow)*. (**C**); Right costoclavicular space in the resting position *(circle)*. (**D**): Right costoclavicular space in the elevated arm position. Significant narrowing of the costoclavicular space *(circles)*. (**E**): An overhead athlete with right-sided symptomatic TOS in the resting position. Note the asymmetry of the right scapular position. (**F**): Arm-elevated position. Right scapular dyskinesis *(arrows)*. (**G**); Right costoclavicular space in the resting position (*circle*). (**H**): Right costoclavicular space in the arm-elevated position. Significant narrowing of the costoclavicular space *(circles)*.

We aimed to retrospectively compare the clinical outcomes of endoscopy-assisted partial resection of the first rib for TOS between overhead athletes and nonathletes and investigate the return to same-level sports rate in overhead athletes.

Materials and methods

We retrospectively reviewed data from consecutive patients treated for TOS at our hospital. The relevant institutional review boards approved this study.

TOS was diagnosed based on the Wright[18] and Roos[31] tests and clinical features, according to previous studies.[13,17,31] The costoclavicular space was evaluated in the resting and arm-elevated positions using three-dimensional computed tomography (3D-CT) (Fig. 1). Scapular dyskinesis in overhead athletes is often observed on the ipsilateral side (Fig. 1 *E* and *F*). Scapular dyskinesis is often observed bilaterally in patients with joint laxity (Fig. 1 *A* and *B*).

Ultrasonography (US) is a versatile and feasible test for the evaluation of neurovascular disorders owing to its noninvasiveness and inexpensiveness. Interscalene distance (ISD) and neurovascular bundle (NVB) patterns were evaluated using US, as previously reported[13] (Fig. 2 *B-D*). Arterial compression was confirmed by measuring the peak systolic velocity (PSV) of the second part of the axillary artery using Doppler US (Fig. 3 *A-D*) and evaluating for interruption of the subclavian artery using 3D-CT angiography (Fig. 3 *E-H*). PSV was assessed in the resting and maximal arm-elevation positions. A significant alteration in PSV between the resting and elevation positions was defined as an increase or decrease of $\geq$ 50%.

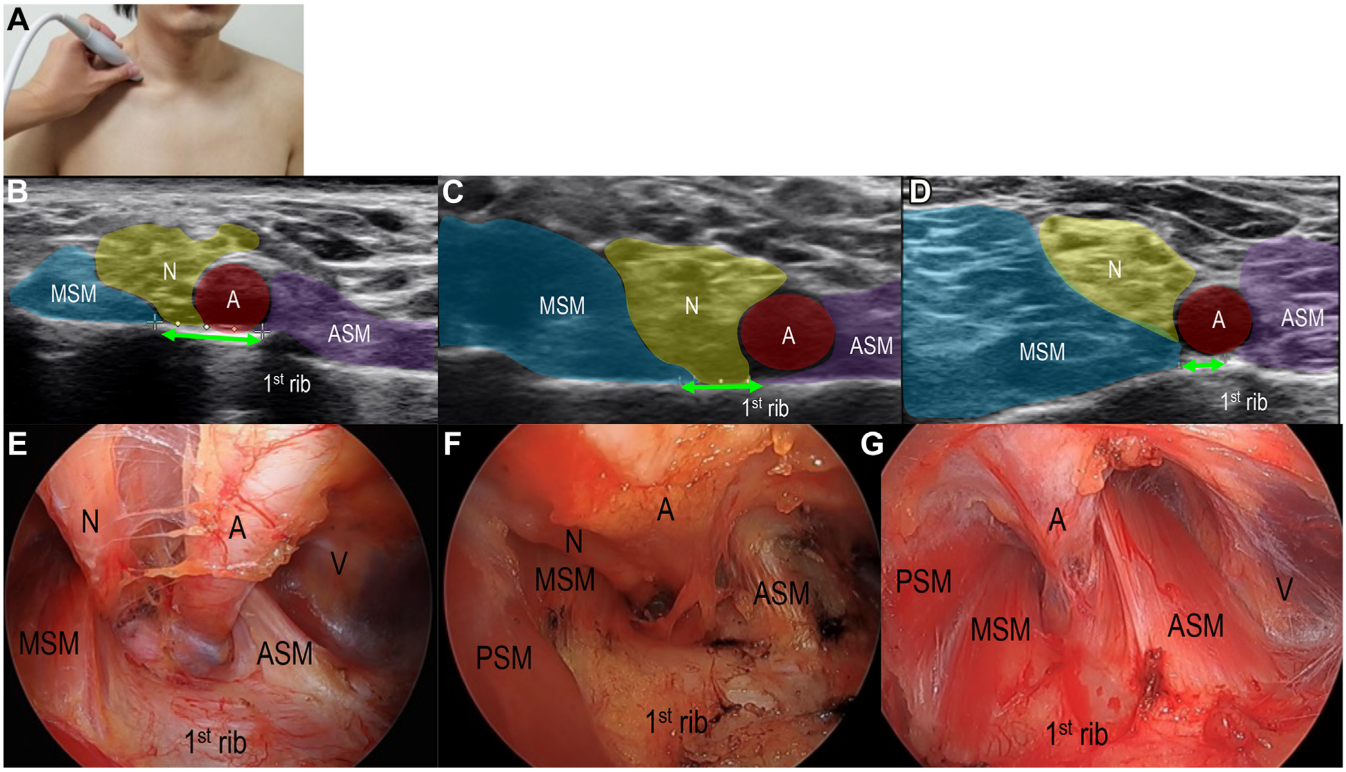

Figure 2 Ultrasonography (US) measurement and endoscopic neurovascular bundle evaluation. (**A**): The interscalene distance (ISD) between the anterior and middle scalene muscles was measured, focusing on the variation in scalene muscle insertion on the first rib. (**B**): ISD measurement in a nonathlete. The ISD was 7 mm. (**C**): ISD measurement in an overhead athlete. The ISD was 7 mm, and the middle scalene muscle was hypertrophic. (**D**): ISD measurement for another overhead athlete. The ISD was 3 mm, and the anterior and middle scalene muscles were hypertrophic. Endoscopic classification of neurovascular bundle patterns was evaluated intraoperatively based on the alignment of the nerve, artery, and vein, as follows: parallel type, in which the artery and nerve travel in parallel; oblique type, in which the nerves were partially behind the artery; and vertical type, in which the nerves were completely behind the middle scalene muscle or an abnormal band. (**E**): Intraoperative ISD and NVB were evaluated in the patient in Fig. 2*B*. Note the parallel type. (**F**): Intraoperative ISD and NVB were evaluated in the patient in Fig. 2*C*. Note the oblique type. The hypertrophic middle scalene muscle compresses the nerve. (**G**): Intraoperative ISD and NVB were evaluated in the patient in Fig. 2 (**D**). Note the vertical type. The hypertrophic anterior scalene muscle compresses the artery. This nerve is located behind the middle scalene muscle. *A*, artery; *N*, nerve; *V*, vein; *ASM*, anterior scalene muscle; *MSM*, middle scalene muscle.

The inclusion criteria were symptomatic neurological, arterial, or venous TOS and a minimum follow-up period of 24 months from surgery. We excluded patients with shoulder or elbow pathologies related to overhead athletes, including biceps labral complex injuries, rotator cuff tears, and ulnar collateral ligament injuries of the elbow. Patients may encounter multiple physicians, leading to potential misdiagnoses and the possibility of undergoing unnecessary shoulder or elbow surgeries; therefore, patients who underwent previous surgical treatment of the shoulder or elbow joint but were still considered symptomatic for TOS were not excluded. Indications for the first rib resection and neurolysis included the failure of conservative treatment for more than 3-6 months and severe TOS symptoms.

The participants were divided into two groups: overhead athletes and nonathletes. Overhead athletes included baseball, softball, volleyball, handball, and swimming athletes. Athletes of other sports were excluded from the study. Nonathletes were defined as individuals who did not participate competitively in sports; however, they included those who participated in recreational dance, fitness, or music or those whose occupations required them to exercise to maintain a necessary level of physical fitness.

Surgical technique

The patient was placed in the lateral decubitus position. All patients underwent an endoscopy-assisted transaxillary approach for partial resection of the first rib and complete anterior and partial middle scalenectomies for neurovascular decompression. Hypertrophy of the serratus anterior and posterior scalene muscles was commonly observed in overhead athletes (Figs. 2 *F* and *G*, and 4*A*).

First, endoscopic classification of NVB patterns was intraoperatively assessed based on the alignment of the nerve, artery, and vein, as follows: parallel type, in which the artery and nerve travel in parallel (Fig. 2*E*); oblique type, in which the nerves are partially behind the artery (Fig. 2*F*); and vertical type, in which the nerves are completely behind the middle scalene muscle or an abnormal band[13] (Fig. 2*G*). In addition, the distance between the anterior and middle scalene muscles at the edge of the first rib and the insertion of the anterior scalene muscle to the first rib were measured as the ISD[12](Fig. 4*B*) and the footprint of the anterior scalene muscle (width and depth), respectively (Fig. 4 *C* and *D*).

Second, the anterior and middle scalene muscles were dissected free of origin at the first rib and divided under adequate visualization, with great care to avoid injury to the subclavian vein immediately anterior to the anterior scalene muscle.

Third, the endoscope ensured the safe removal of the first rib, particularly the posterior part of the first rib, from the inside of the rongeur during transection (Fig. 4 *E*-*G*).

Finally, release and decompression of the artery and brachial plexus were performed under high magnification after partial resection of the first rib, with great care to avoid venous injury or pneumothorax (Figs. 4 *H*, *I* and 5 *A*, *B*).

Consequently, several anatomical anomalies, including scalenus minimus (Fig. 5 *A* and *B*), abnormal bands (Fig. 5 *C* and *E*), cervical

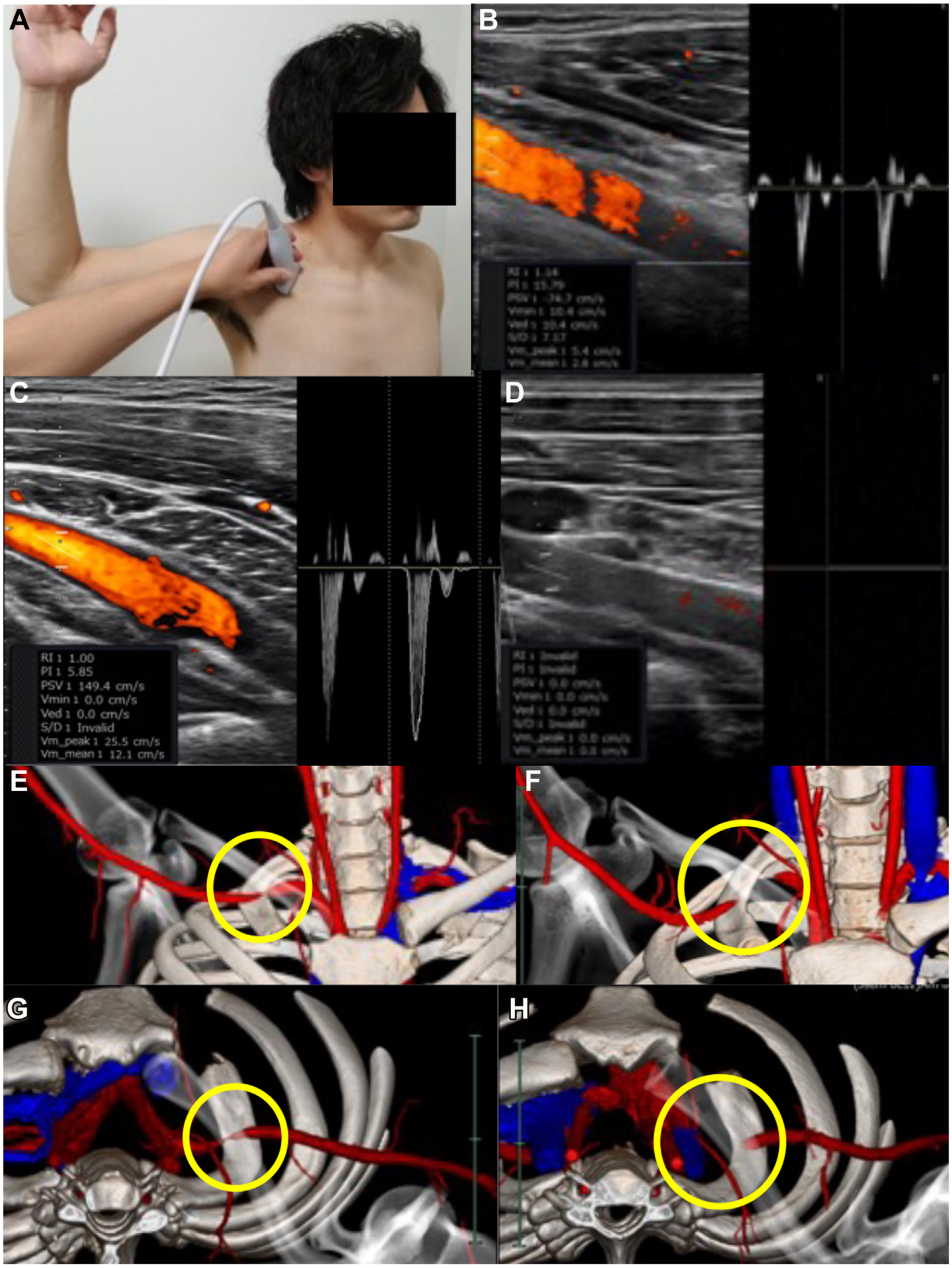

Figure 3 Peak systolic velocity (PSV) measurement. (**A**): PSV of the 2nd part of the axillary artery was measured using pulse Doppler at the resting and arm-elevated positions. (**B**): PSV did not differ between the resting and arm-elevated positions. The PSV was 74.7 cm/s in the arm-elevated position. (**C**): PSV increased from the resting to the arm-elevated position. The PSV was 149.4 cm/s in the arm-elevated position. (**D**): The PSV decreases from the resting to the arm-elevated position. The PSV was 0 cm/s in the arm-elevated position. (**E, G**): Three-dimensional angiography of the same patient in Fig. 3*C* showing obstruction of the subclavian artery at an elevated position (*circles*). (**F, H**): Three-dimensional angiography of the same patient in Fig. 3 (**D**) shows total interruption of the subclavian artery in an elevated position *(circles)*.

ribs (Fig. 5*E*), and stress fractures of the first rib (Fig. 5 *D* and *F*), were noted.

Preoperative and postoperative clinical and imaging assessment

Results were assessed according to the Roos[30] and Derkash's[10] classifications as follows: "Excellent," complete symptom relief with the return to full employment and recreational sports; "Good," mild residual symptoms with the return to employment and some recreational sports; "Fair," partial symptom relief with the return to employment but with an inability to lift heavy objects above head height; and "Poor," no improvement or worsening of symptoms. The disability of the arm, shoulder, and hand (DASH) score was used to assess general clinical outcomes. Arterial decompression was evaluated by changes in the PSV on Doppler US. Overhead athletes who subsequently played one or

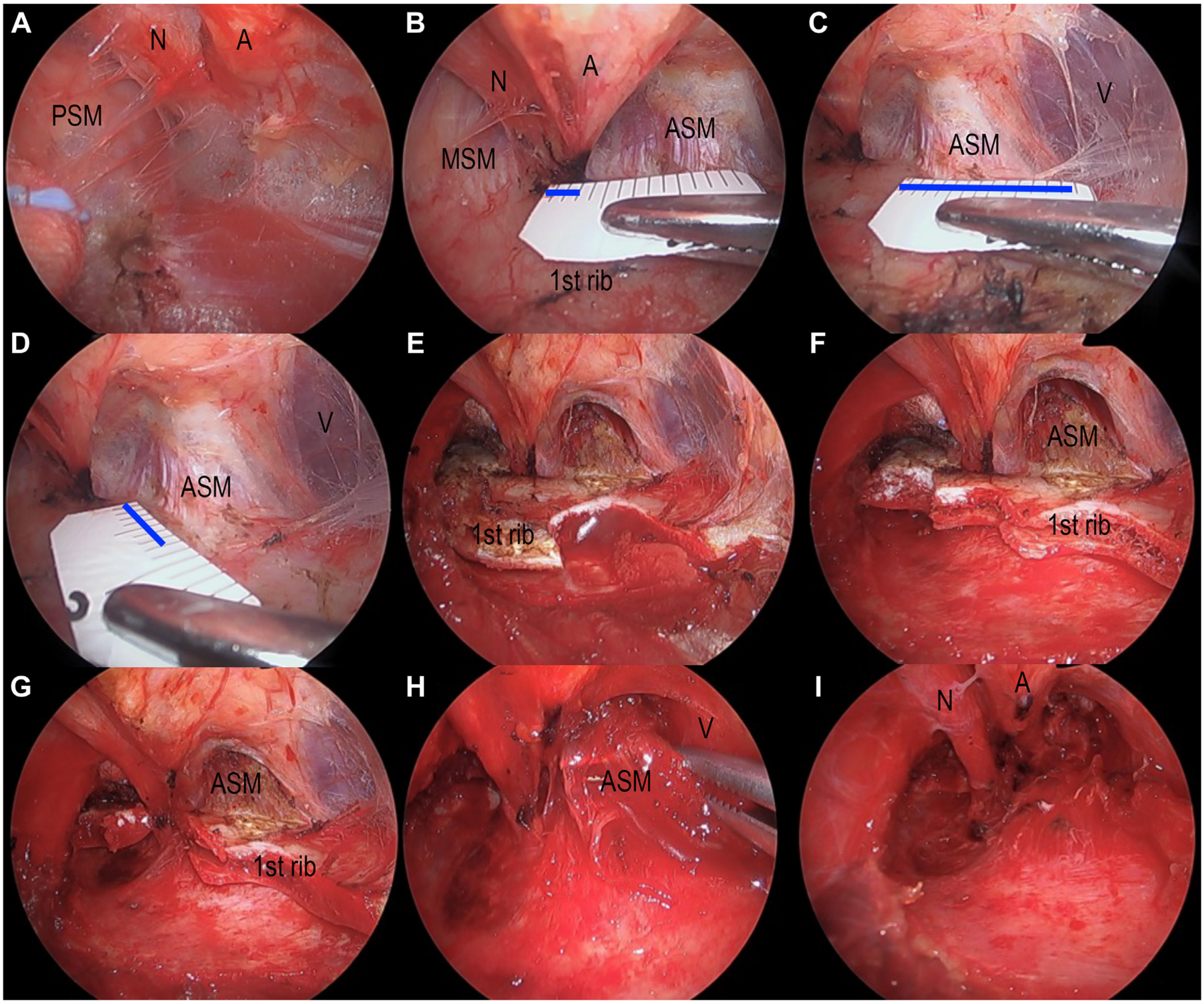

Figure 4 Right transaxillary approach in lateral decubitus position with additional viewing portal. The scope allows for visual identification and confirmation of the first rib and the contents of overhead athletes with thoracic outlet syndrome (TOS). (**A**); Early in surgery, hypertrophy of the posterior scalene muscle is observed. (**B**); The distance between the anterior and middle scalene muscles at the edge of the first clavicle is measured as the interscalene distance. (**C**, **D**): The footprint of the anterior scalene muscle was measured in width and depth. (**E**, **F**, **G**): The first rib is transected anteriorly near the costochondral junction and posteriorly, as close to the transverse process as possible, in a piece-by-piece fashion. The endoscope assists in ensuring the safe removal of the first rib. (**H**): Release and decompression of the artery and brachial plexus were performed under high magnification, with careful attention to avoid venous injury and pneumothorax. (**I**): The subclavian vein, artery, and brachial plexus nerves are relaxed after first-rib resection and subsequent neurolysis. *A*, artery; *N*, nerve; *V*, vein; *ASM*, anterior scalene muscle; *MSM*, middle scalene muscle; *PSM*, posterior scalene muscle.

more competitive games at any level were considered to have returned to play. Based on subjective evaluation, those who played at the level before the injury were considered to have returned to the same level. The ball velocities of baseball pitchers were compared preoperatively and postoperatively. Procedure-related complications were recorded.

Statistical analyses

The Mann−Whitney U and chi-squared tests were used to compare the clinical, intraoperative, and surgical outcomes between overhead athletes and nonathletes. The Student's t-test was used to compare the grip power and anterior scalene muscle footprint of overhead athletes and nonathletes. Fisher's exact test was used to compare the NVB and Roos classifications of overhead athletes and nonathletes. The Wilcoxon signed-rank test was used to compare the ball velocities recorded preoperatively and at the final follow-up. Statistical significance was set at $P < .05$.

Results

Five hundred and sixty-six cases with TOS underwent endoscope-assisted partial resection of the first rib using a transaxillary approach at our hospital between November 2015 and February 2021. In this study, 172 cases were lost to follow-up, 92 had a short follow-up period, 77 had incomplete preoperative or postoperative clinical findings, 30 had other shoulder or elbow pathologies, and 14 had insufficient images for evaluation, leaving 181 cases in 166 patients. We classified 181 cases with TOS (75 women, 106 men; mean age, 28.4 years; range, 12-64 years) who underwent an endoscopy-assisted first-rib resection and neurolysis with transaxillary approach into two groups: 79 overhead athletes

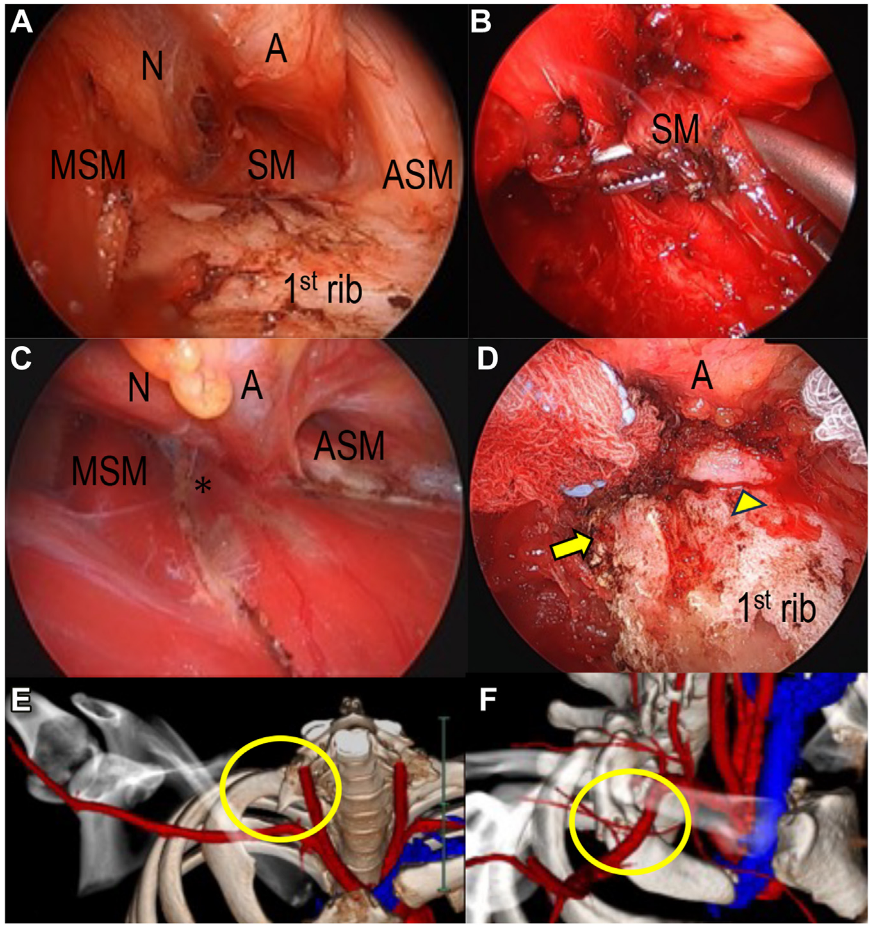

Figure 5 Various patterns in overhead athletes with thoracic outlet syndrome. (**A, B**); Scalenus minimus was identified between the artery and nerves. Fibrocartilaginous bands and scalenus minimus were identified and excised. (**C**): Abnormal band from the cervical region to the first rib. An abnormal band (*) covers the first rib. (**D**): The first rib bulges with a bridging callus *(arrow)* and a nonhealing fracture *(arrowhead)*. (**E**); Three-dimensional computed tomography image showing a cervical rib *(circle)*. (**F**): Three-dimensional angiography image showing the subclavian artery close to the unhealing fracture line. *A*, artery; *N*, nerve; *V*, vein; *ASM*, anterior scalene muscle; *MSM*, middle scalene muscle; *SM*, scalenus minimus.

and 102 nonathletes groups (Table I). Fifteen patients underwent simultaneous bilateral surgeries. The average follow-up period was 31.4 months (24.0-56.1 months).

Tables I and II summarize the demographic data and intraoperative findings of the 181 cases. Overhead athletes were significantly more likely to be men, younger, used the dominant side more frequently, and have a larger physique, more shoulder and elbow pain, and shorter symptom duration (Table I). No significant differences between the two groups were noted in the follow-up duration or rate of abnormal angiography findings (Table I).

No significant differences were recorded in the NVB patterns, ISD, preoperative PSV, anatomical anomalies, adhesion NVB, anterior scalene muscle footprint, or scalene muscle hypertrophy between the two groups (Table II). The mean ISD of the total cases (average 5.6 mm, range 0-13) was smaller than that in previous cadaveric studies (average 10.7 mm,[8] 1.1 cm,[9] 1.2 cm, and 1.5 cm[23]). PSV alterations on Doppler US between the resting and arm-elevated positions were observed preoperatively and diminished postoperatively in the total cases (P = .008). PSV alterations in overhead athletes significantly decreased from 51.9% preoperatively to 16.5% postoperatively (P < .001), whereas they did not significantly decrease in nonathletes (from 48.0% preoperatively to 36.3% postoperatively, P = .089).

The postoperative clinical outcomes of all 181 cases are summarized in Table III. Characteristic clinical findings significantly improved postoperatively in both groups, including tenderness of the scalene triangle and fossa, neurological symptoms, Wright's test, Roos test, and grip power. The outcomes of the Roos and Derkash classifications revealed significant differences in excellent or good results between the overhead athletes (91.1%) and nonathletes (62.8%). The DASH scores of all the patients improved significantly from 40.6 to 17.7 points postoperatively (P < .001). The two groups significantly differed in preoperative and postoperative DASH and recovery rate scores (P = .007, < .001, < .001).

Table IV shows the demographic and clinical data of overhead athletes. In overhead athletes, the return-to-play and return-to-same-level play rates were 97% and 81%, respectively. The ball velocities of baseball pitchers (n = 18) did not significantly differ preoperatively and postoperatively.

No severe complications, including intraoperative neurovascular injuries, were observed. No snapping of the scapula or deep infections were observed. No overhead athletes required additional surgery; however, 11 nonathletes required additional nerve decompression, including one who needed scalenectomy, two who required pectoralis minor release, five who required ulnar nerve anterior transposition, and three who needed shoulder stabilization.

Table I
Demographic data.

Clinical feature	Total (n = 181)	Nonathletes (n = 102)	OHA (n = 79)	P value
Sex, women/men	75/106	68/34	7/72	<.001*
Age at surgery (y)	28.4 ± 13.9	36.4 ± 13.0	18.5 ± 7.3	<.001*
Height (cm)	165.8 ± 8.5	162.6 ± 8.0	169.3 ± 7.8	<.001*
Weight (kg)	61.9 ± 12.5	60.2 ± 13.4	63.9 ± 11.1	.009*
Body mass index (kg/m^2)	22.1 ± 4.1	22.0 ± 4.9	22.2 ± 2.9	.602
Dominant/nondominant	137/44	61/41	76/3	<.001*
Bilateral operation	15	12(11.8%)	3 (3.8%)	.054
Follow-up duration (mo)	31.4 ± 12.0	32.9 ± 12.0	29.3 ± 11.6	.107
Chief complaint (n, %)				
Upper extremity pain	112 (61.9)	57 (55.9)	55 (69.6)	.059
Shoulder pain	100 (55.2)	49 (48.0)	51 (64.6)	.027*
Elbow pain	81 (44.8)	39 (38.2)	42 (53.2)	.045*
Swelling of the upper extremity	6 (3.3)	5 (4.9)	1 (1.3)	.234
Coldness	32 (17.7)	16 (15.7)	16 (20.3)	.424
Upper extremity numbness	104 (57.5)	56 (54.9)	48 (60.8)	.429
Loss of range of motion	34 (18.8)	23 (22.5)	11 (13.9)	.141
Symptom duration (mo)	19.6 ± 31.3	24.3 ± 34.4	13.6 ± 25.9	.001*
Abnormal angiography (n, %)	87 (48.1)	48 (49.5)	39 (49.4)	.758

OHA, overhead athletes.
Values are expressed as the number of patients, percentages, or means ± standard deviations.
*Bold values indicate statistical significance.

Table II
Intraoperative findings between nonathletes and overhead athletes.

Finding	Total (n = 181)	Nonathletes (n = 102)	OHA (n = 79)	P value
Dense fibrous tissue (spider view) (n, %)	109 (60.2)	64 (62.7)	45 (57.0)	.431
NVB (parallel/oblique/vertical) (n)	44/98/39	26/53/23	18/45/16	.828
Interscalene distance (mm)	5.6 ± 3.6	5.2 ± 3.5	5.9 ± 3.7	.237
PSV alteration (>±50%), n (%)				
Preoperative	90 (49.7)	49 (48.0)	41 (51.9)	.607
Postoperative	50 (27.6)	37 (36.3)	13 (16.5)	.003*
P value	<.001*	.089	<.001*	
Anomaly (n)				
Cervical rib (Roos 1 or 2)	2	2	0	
Fibrous string (Roos 3 or 4)	17	6	11	
Scalenus minimus (Roos 5 or 6)	22	16	6	
Other	25	19	6	
Adhesion neurovascular bundle (n, %)	144 (79.6)	82 (80.4)	62 (78.5)	.752
Anterior scalene muscle footprint (width) (mm)	10.8 ± 2.2	11.0 ± 2.2	10.5 ± 2.2	.361
Anterior scalene muscle footprint (depth) (mm)	5.6 ± 2.4	5.7 ± 2.5	5.4 ± 2.2	.545
Anterior scalene muscle hypertrophy (n, %)	101 (55.8)	58 (56.9)	43 (54.4)	.744
Middle scalene muscle hypertrophy (n, %)	100 (55.2)	54 (52.9)	46 (58.2)	.478

NVB, neurovascular bundle; *OHA*, overhead athletes *PSV*, Peak systolic velocity.
Values are expressed as the number of patients, percentages, or means ± standard deviations.
*Bold values indicate statistical significance.

Patient complications included eight cases (4.4%) of pneumothorax, two of incomplete long thoracic nerve paralysis, and one of superficial surgical site infection. Patients with pneumothorax underwent chest drainage for several days. These complications did not require any additional surgical management.

Discussion

Our study showed that overhead athletes with TOS were more likely to be men, younger, used the dominant side more frequently, and have a shorter symptom duration than nonathletes. Intraoperative findings revealed no significant findings in overhead athletes with TOS. Endoscopy-assisted transaxillary first-rib resection and neurolysis provided a higher success rate in overhead athletes with TOS than in nonathletes.

The pathology of TOS is only partially understood. Furthermore, TOS is difficult to diagnose and is often poorly managed. Roos et al reported that TOS is underdiagnosed.[32] Recent reports have shown that TOS is highly associated with overhead athletes[2,3,7,13,15,35,37] owing to the repetitive and cumulative stress in the scalene triangle and costoclavicular space. Interestingly, overhead athletes with TOS occasionally suffer from shoulder or elbow pain during the acceleration phase of the throwing motion, similar to the position of shoulder apprehension test,[21] moving valgus stress test,[28] and Roos test.[31] Therefore, shoulder and elbow surgeons should avoid misdiagnosing TOS in overhead athletes, particularly adolescent athletes, who suffer from shoulder or elbow pain. Illig et al demonstrated that TOS is often underdiagnosed in children and adolescents, leading to undertreatment.[17] Talutis et al reported the risk of TOS in adolescent athletes, with favorable functional outcomes and return-to-sports rate after TOS surgery.[35] Assessment of specific clinical presentations, including episodes, symptoms, and tenderness through the brachial plexus; the Roos test as a special test; US; and US-guided intervention around nerves should be performed to diagnose TOS accurately. We used US to investigate congenital anomalies, scalene triangle shape, NVB patterns, and PSV of the axillary artery to objectively diagnose TOS. A previous study reported the potential feasibility of endoscopic classification of NVB patterns for TOS diagnosis.[13] US may aid in preoperatively identifying the shape and alignment of the neurovascular patterns.

Regarding intraoperative findings, this study found that narrowing of the ISD, PSV alteration at arm elevation, and scalene muscle hypertrophy were characteristic patterns of symptomatic TOS. Notably, all patients with TOS showed diminished PSV alterations on Doppler US between the resting and arm-elevated positions postoperatively ($P < .001$). Overhead athletes had satisfactory results and significant PSV alterations ($P < .001$), whereas nonathletes had unsatisfactory results and no significant PSV alterations ($P = .089$). US is a suitable tool for the objective diagnosis and postoperative evaluation of patients with TOS; however, verification of preoperative US findings is warranted.

Recent studies have reported favorable surgical outcomes after TOS surgery, particularly in overhead athletes.[2,3,7,15,37] Chandra et al reported that most athletes treated for venous and neurogenic TOS (NTOS) might successfully return to participate in competitive sports at their prior high-performance level.[7] Thompson et al showed that pitchers returning to Major League Baseball (MLB) after surgery for NTOS have capabilities equivalent to or surpassing those before treatment on objective performance metrics.[37] Gutman et al reported that 74% of professional pitchers who

Table III
Intraoperative findings between nonathletes and overhead athletes.

	Total (n = 181)	Nonathletes (n = 102)	OHA (n = 79)	P value
Tenderness				
Scalene triangle (n, %)				
Preoperative	146 (80.7)	83 (81.4)	63 (79.7)	.784
Postoperative	58 (32.0)	43 (42.2)	15 (19.0)	<.001*
P value		<.001*	<.001*	
Fossa scalene (n, %)				
Preoperative	167 (92.3)	93 (91.2)	74 (93.7)	.533
Postoperative	49 (27.1)	43 (42.2)	6 (7.6)	<.001*
P value		<.001*	<.001*	
Neurological symptom (n, %)				
Preoperative	96 (53.0)	56 (54.9)	40 (50.6)	.568
Postoperative	42 (23.3)	29 (28.4)	13 (16.5)	.058
P value		<.001*	<.001*	
Wright test (n, %)				
Preoperative	120 (66.3)	64 (62.7)	56 (70.9)	.251
Postoperative	38 (21.0)	29 (28.4)	9 (11.4)	.005*
P value		<.001*	<.001*	
Roos test (n, %)				
Preoperative	175 (96.7)	100 (98.0)	75 (94.9)	.406
Postoperative	51 (28.2)	35 (34.3)	16 (20.3)	.037*
P value		<.001*	<.001*	
Grip power (kg)				
Preoperative	28.2 ± 13.2	23.9 ± 12.1	32.2 ± 12.9	<.001*
Postoperative	30.4 ± 13.3	23.8 ± 14.5	37.8 ± 20.5	<.001*
P value		.974	.003*	
Roos score				
Excellent	105 (58.0)	42 (41.2)	63 (79.7)	<.001*
Good	31 (17.1)	22 (21.6)	9 (11.4)	
Fair	27 (14.9)	23 (22.5)	4 (5.1)	
Poor	18 (9.9)	15 (14.7)	3 (3.8)	
DASH score				
Preoperative	40.6 ± 20.8	43.2 ± 18.8	37.2 ± 22.7	.007*
Postoperative	17.7 ± 20.3	25.5 ± 22.1	7.5 ± 11.3	<.001*
P value		<.001*	<.001*	
DASH score recovery rate (%)	60.2 ± 35.3	41.0 ± 34.7	79.8 ± 30.7	<.001*

DASH, disability of the arm, shoulder, and hand; *OHA*, overhead athletes.
Values are expressed as the number of patients, percentages, or means ± standard deviations.
DASH, score recovery rate (preoperative/postoperative)/preoperative.
*Bold values indicate statistical significance.

Table IV
Postoperative performance of overhead athletes with thoracic outlet syndrome.

Sports (n, %)	N	Poor	Partial return	Same level
Baseball	67	2 (3%)	11 (16%)	54 (81%)
Softball	3	1 (33%)	0	2 (67%)
Tennis	4	0	0	4 (100%)
Volleyball	3	0	1 (33%)	2 (100%)
Swimming	1	0	0	1 (100%)
Handball	1	0	0	1 (100%)
Total	79	3 (4%)	12 (15%)	64 (81%)
Duration of return to sports (mo)	7.3 ± 5.1			

	Preoperative	Postoperative	P value
Ball velocity (kph, n = 18)	126.2 ± 11.0	125.4 ± 11.3	.876
DASH sports module	70.1 ± 29.6	12.9 ± 20.3	<.001*
DASH sports module recovery rate (%)		79.1 ± 33.1	

Values are expressed as the number of patients, percentages, or means ± standard deviations.
*Bold values indicate statistical significance.

underwent surgical intervention for TOS returned to play at the MLB level. Notably, most performance metrics were unchanged compared with the preoperative period, indicating a return to a similar functional level.[15] Arnold et al reported that MLB pitchers who underwent surgical treatment for TOS had high return-to-play rates, improved postoperative performance, and no differences in postoperative career.[2] We found favorable return-to-play and return-to-same-level-play rates and no alterations in ball velocities in baseball pitchers after the resection of the first rib and scalene muscle, consistent with these previous studies.

The reason for favorable surgical outcomes in overhead athletes remains unknown. Several factors were considered favorable outcomes. Our study included relatively young overhead athletes (mean age, 18.5 years) with a short vessel compression and nerve entrapment duration. Younger patients may have a higher tissue healing ability. A previous study indicated that earlier surgical treatment of TOS decreased muscle weakness and denervation compared with later intervention.[1] High-level overhead athletes have a risk of internal impingement of the shoulder or ulnar collateral ligament injury due to increased shoulder or elbow joint stress during their sports activity. In contrast, younger athletes may have an early onset of symptoms with anatomical variations, including a narrow ISD, strict NVB patterns, a wider scalene muscle footprint, and a hypertrophic scalene muscle. Neurovascular symptoms in TOS severely restrict sports activity regardless of the activity level; therefore, younger overhead athletes may undergo earlier surgical management than nonathletes or those with other shoulder or elbow joint pathologies.

Regarding intraoperative endoscopic findings, we demonstrated various patterns of the NVB, ISD, anatomical anomalies, scalene muscle insertion-to-bone site, and hypertrophy in overhead athletes, similar to those in nonathletes. However, PSV alterations significantly improved after surgical management in overhead athletes compared with nonathletes. Notably, several studies have reported vascular pathologies in the upper extremities of overhead athletes.[11,19,27,38] The pathologies of Paget-Schroetter syndrome,[27] quadrilateral space syndrome,[5,24] and circulatory disturbances in the throwing hands of baseball players[19] are consistent with that of arterial TOS. The posterior scalene and serratus anterior muscles may be relatively hypertrophic in overhead athletes compared with nonathletes; however, our study did not investigate this. Prolonged repetitive and cumulative stress in the scalene triangle and costoclavicular space is associated with circulatory disturbances and scalene and serratus anterior muscle hypertrophy. We believe decompression of the subclavian artery and brachial plexus is equally important to first-rib resection. Previous studies have suggested that adequate neurolysis is vital for superior outcomes in TOS.[25,36] Endoscopy-assisted transaxillary first-rib resections and neurolysis provide excellent visualization of the anterior and middle scalene muscles and the nerve in deeper and narrower surgical fields; therefore, endoscopy-assisted surgery with a transaxillary approach may achieve meticulous release and decompression in overhead athletes with TOS. Similarly, various muscles, such as the anterior, middle, and posterior scalene; subclavian; and pectoralis minor muscles, can cause entrapment in patients with TOS. Further studies are required to investigate the causes of entrapment in overhead athletes with TOS.

Postoperative surgical outcomes revealed that 18 patients (three overhead athletes and 15 nonathletes) had poor results, including 14 women (11 aged > 40 years, and six with bilateral symptoms). General joint laxity, particularly scapulothoracic function, is a risk factor for costoclavicular space compression. These factors cannot be resolved using an endoscopic-assisted transaxillary approach for first-rib resection and neurolysis. Therefore, our study indicated that in women overhead athletes, athletes aged > 40 years, or athletes with bilateral symptoms, attention should be paid to the TOS strategy, as the surgical outcomes in athletes with the above risk factors may be inferior compared to those without any risk factor.

Our study had few limitations, including heterogeneous patient backgrounds, different sports levels, various TOS pathologies, less objective diagnostic tools, and a retrospective design. Overhead and nonoverhead athletes were not compared. Sports activity is another risk factor for TOS. In addition, this study included relatively young overhead athletes who were not professionals. We did not classify TOS into neurological, arterial, or venous types. Arterial obstruction was identified in 49.5% of patients, regardless of their symptoms, using 3D-CTA and Doppler US. Endoscopic findings revealed various neurovascular patterns. We believe that minor changes in the anatomy around the nerve and vessels may result in entirely different TOS symptoms. Therefore, we did not distinguish between TOS types. TOS pathologies in overhead athletes are complex, and the relationship between these anatomical variations and clinical presentations should be investigated in future prospective studies.

Conclusions

Overhead athletes with TOS were more likely to be men, younger, used the dominant side more frequently, and have a shorter symptom duration than nonathletes. An endoscopy-assisted transaxillary approach for first-rib resection and neurolysis in TOS provides excellent magnified visualization. It allows safe and sufficient decompression of the NVB, leading to satisfactory surgical outcomes and favorable return-to-same-level-play rates in sports.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.The editor making the decision to accept this paper for publication had no conflicts of interest related to the decision. Further, peer review of this paper was handled independently of any author of this paper.

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