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Publication Date

2022-07-01

DOI

10.1016/j.avsg.2021.12.080

Peer reviewed

A Single Institution 30-Year Review of Abnormal First Rib Resection for Thoracic Outlet Syndrome

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Objectives: Congenital abnormalities of the first rib (ABNFR) are a rare cause of thoracic outlet syndrome (TOS). The range of abnormalities have not been clearly documented in the literature. Surgical decompression in these patients presents with increased complexity secondary to anomalous anatomy. Our goal is to review an institutional experience of first rib resection (FRR) performed for ABNFRs, to present a novel classification system, and to analyze outcomes according to clinical presentation.

Methods: A prospectively collected database was used to identify individuals with ABNFRs who underwent FRR for TOS between 1990-2021. These individuals were identified both by preoperative imaging and intraoperative descriptions of the first rib after resection. Demographic, clinical, perioperative and pathological data were reviewed. ABNFRs were classified into 3 categories according to anatomical criteria: (I) Hypoplastic, (II) Fused, and (III) Hyperplastic. Outcomes were rated using the standardized Quick Disability of Arm Shoulder and Hand Scores (QDS), Somatic Pain Scores (SPS) and Derkash Scores (DkS).

Results: Among the 2200 cases of TOS, there were 19 patients (0.8%) with ABNFR who underwent FRR. Average age at surgery was 30.5 (range 11–74), including 13 men and 6 women. Presentations included 9 arterial (ATOS), 6 neurogenic (NTOS), and 4 venous (VTOS) cases. There were 6 class I, 6 class II, and 7 class III ABNFRs. Among 6 NTOS patients there were 4 abnormal nerve conduction tests and 5 positive anterior scalene muscle blocks. Among the 9 patients with ATOS, thrombolysis was attempted in 5 patients, and of these, 3 ultimately required surgical thrombectomy. Of 4 VTOS cases, 2 were managed with thrombolysis, and 2 with anticoagulation alone. The approach for FRR was transaxillary in all patients. Secondary procedures included 1 pectoralis minor tenotomy, 1 scalenectomy, and 1 contralateral rib resection. No major neurological or vascular complications occurred. There was 1 patient who required surgical evacuation of a hematoma. Intraoperative chest tube placement was required in 5 patients secondary to pleural entry during dissection. There was an overall improvement in symptoms over an average follow-up of 7.4 months. QDS reduced from 49.7 pre-op to 22.1 ($P < 0.05$). SPS improved from 3.4 pre-op to 1.8. DkS scores were good to excellent in 79% of patients. Residual symptoms were noted in 7, and ATOS accounted for 5 (70%) of these. All patients were able to return to work.

Conclusions: Despite increased complexity, ABNFRs may be safely resected via transaxillary approach with low incidence of complications, very good symptom relief, and excellent outcomes. Congenital ABNFRs may by classified into 3 categories (hypoplastic, fused, and hyperplastic) with a variety of presentations, including ATOS, NTOS, and VTOS. Classification of ABNFRs allows concise description of abnormal anatomy which facilitates comparison between series and provides direction for surgical management to ultimately optimize patient outcomes.

Declarations of Competing Interest:None

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Ann Vasc Surg 2022; 83: 53–61
https://doi.org/10.1016/j.avsg.2021.12.080

Manuscript received: August 18, 2021; manuscript revised: December 5, 2021; manuscript accepted: December 22, 2021; published online: 6 January 2022

INTRODUCTION

Anatomic variation at the thoracic outlet may include cervical ribs, supernumerary scalene muscles, abnormal scalene muscle insertion, fibrocartilaginous bands, or abnormal first ribs (ABNFRs).[1-5] The presence of ABNFRs is a rare phenomenon with a reported incidence of about 0.25% in the general population.[6] The majority of these patients do not require any intervention as they do not exhibit any signs or symptoms of thoracic outlet syndrome (TOS). Rarely, anomalous first ribs may lead to neurovascular compression and ultimately require surgical decompression with first rib resection (FRR) and partial scalenectomy.

Due to the rarity of ABNFRs, there is a paucity of literature describing surgical decompression in their presence. Most of the studies covering this topic are case reports or small case series.[7-12] Additionally, there is no current classification system to categorize these types of anomalies. Without a classification system there is inconsistency in reporting clinical outcomes of this rare condition and it is difficult to perform comparison between series. First rib resection in these patients may be challenging secondary to anomalous and complex anatomy.

Our first objective is to review a single institutional experience of FRR performed for ABNFRs. Additionally, we propose a new anatomical classification scheme based on radiographic and anatomical findings. We detail technical modifications required for successful transaxillary resection of each rib class. Lastly, we will review our outcomes according to clinical presentation.

PATIENTS AND METHODS

Study Design

After obtaining approval from the institutional review board, a retrospective chart review was performed using a prospectively collected database. All individuals with symptomatic ABNFRs who underwent FRR for TOS at the University of California, Los Angeles (UCLA) between 1990 and 2021 were identified both by preoperative imaging, pathological specimens, and review of operative reports. Patients with traumatic first rib abnormalities were identified using historical information and excluded from this study. This allowed us to review outcomes of patients with presumed congenital malformations of the first rib. All demographic, clinical, outcome, and pathologic data was collected and reviewed.

Diagnostic Workup and Initial Management

Clinical classification of presentations was carried out in accordance with Society for Vascular Surgery (SVS) reporting standards.[13] Preoperative non-invasive diagnostic studies included chest X-ray, cervical spine X-ray, brachial plexus magnetic resonance imaging (MRI), magnetic resonance angiography (MRA), and computed tomography angiography (CTA).

A diagnosis of neurogenic thoracic outlet syndrome (NTOS) was made based on symptoms, physical exam, and diagnostic testing. To support the diagnosis of NTOS, both anterior scalene muscle blocks and electroconductive testing were used. Initial care consisted of physical therapy, chiropractic manipulation, massage, and/or acupuncture. All patients with NTOS underwent a structured physical therapy program with TOS-specific strengthening, stretching, and postural exercises. Conservative management of TOS with physical therapy was pursued for at least 3 months. Indications for surgery were severe, constant, and disabling symptoms refractory to at least 3 months of conservative management.

Patients with venous (VTOS) presentations were initially identified with ultrasound or CT imaging. All patients with VTOS received an ultrasound which demonstrated axillosubclavian deep venous thrombosis. Positive ultrasounds were followed by venography to confirm the diagnosis and offer thrombolytic therapy when appropriate. Venograms were performed while the patient was supine with the extremity in both the neutral position and the stressed position (arm abducted and externally rotated). Intravascular ultrasound (IVUS) was used in cases where there was ambiguity in venography imaging. Acute thrombotic presentations of VTOS were managed with thrombolysis in conjunction with anticoagulation. Chronic VTOS presentations were patients referred for elective care after a period of initial anticoagulation initiated by the referring physician.

Patients with arterial (ATOS) presentations were evaluated with a combination of ultrasound, axial imaging, and catheter-based angiography. Ultrasound and CTA were used to identify either axillosubclavian arterial thrombosis or subclavian artery aneurysm. Catheter based arteriography was performed in all patients either for diagnostic purposes or in conjunction with an endovascular intervention. Acute thrombotic presentations of ATOS were managed with thrombolysis, thrombectomy, and/or anticoagulation. Arterial reconstruction was reserved for limb-threatening

ischemia or aneurysms (greater than 2 cm, thrombus laden, or saccular morphology). High grade arterial stenosis was treated with plain balloon angioplasty using a 6 mm x 40 mm Charger balloon (Boston Scientific, Marlborough, MA). 1 patient in this study who had a subclavian artery aneurysm was treated with a 6 mm x 50 mm VIABAHN stent (WL Gore, Flagstaff, AZ).

Follow Up

All patients were routinely followed to resolution of acute or evolving symptoms. Typically, they were evaluated at 2 weeks, 6 weeks, 12 weeks, and 6 months after their index operation. Additionally, they were followed at 3-month intervals until symptom resolution. All VTOS patients underwent post-decompression venography to assess patency and provide balloon angioplasty as needed. In addition to the aforementioned follow-up, patients with ATOS or VTOS were followed with annual clinic visits and duplex ultrasound examinations to assess for axillosubclavian vein or artery patency.

Outcome Assessment

Outcomes were assessed via 3 validated patient-reported outcome measures in the preoperative and postoperative periods: the Quick Disability of Arm Shoulder and Hand score (Quick DASH, QDS), the Somatic Pain Scale (SPS), and the Derkash score (DkS).[14] QDS is a standardized and validated survey which assesses a patient's functional outcome based on performance during activities of daily living. In this scoring system, 0 is normal and 100 represents complete inability to use the limb. SPS is a patient self-reported pain scale from 1–10, usually as an average over the previous 4 weeks. The DkS incorporates a patient's ability to perform activities of daily living, any limitations in the work setting, and any severity of complaints. A subjective score from poor to excellent is reported.

Proposed Classification of ABNFR and Modification of Surgical Technique

After review of the preoperative imaging and gross anatomic characteristics of the ribs after resection, it was evident that there were 3 main classes of bony anomalies among this group of patients: hypoplastic (class I), fused (class II), and hyperplastic (class III) (Fig. 1). These classes of ribs deviate from normal first rib anatomy which arises from the transverse process of the first thoracic vertebra and has a curvilinear course which terminates at the costochondral junction. A normal first rib has a horizontal axis at which it may rest on a flat surface at every point. The transaxillary approach to FRR of a normal first rib has been well described previously, but is often less familiar to surgeons.[15] Transaxillary resection of ABNFRs requires modification to the standard technique which is tailored to each individual rib class.

Class I or hypoplastic ribs are also known as rudimentary ribs (Fig. 1A). These result from incomplete bony development and they are typically shorter than the average first rib. They do not extend anteriorly to the manubrium likely due to early fusion of the epiphyseal growth plate. They tend to have a straighter profile with reduced arc length as well as fibrocartilaginous bands which contribute to neurovascular impingement. A standard transaxillary approach is used for this class: the rib is first divided in its midportion with subsequent resection of the anterior and posterior segments.

Class II or fused ribs are also reduced in length. However, they are joined to the second rib with a synovial or synchondrotic articulation (Fig. 1B). The articular junction frequently takes the form of a bulbous bony mass which accentuates compression of neurovascular structures. From the transaxillary approach these are managed by division of the articular junction with the second rib followed by resection of the residual ABNFR. ABNFR separation from the second rib is most readily accomplished by resection of the segment of second rib where the articulation occurs.

Class III or hyperplastic ribs are the result of abnormal growth of bone and cartilaginous tissue along the mid segment of the rib (Fig. 1C). The bony exostosis does not appear to involve the proximal or distal articulation. This osseous hypertrophy may develop into a bony plate or an ovoid mass which then accentuates compression of the neurovascular structures. Transaxillary resection of these ribs often requires piecemeal resection of the bony mass in order to safely remove the ABNFR (Fig. 2). Dividing the rib allows distraction of the segments which in turn improves visualization of nerves and safe dissection of surrounding muscles. Once divided the residual sections may by resected.

Statistical Analysis

Data presented as continuous variables are reported as the mean +/- standard error and categorical variables are reported as frequencies and proportions of the total. Two-tailed paired t tests were used to detect differences between the

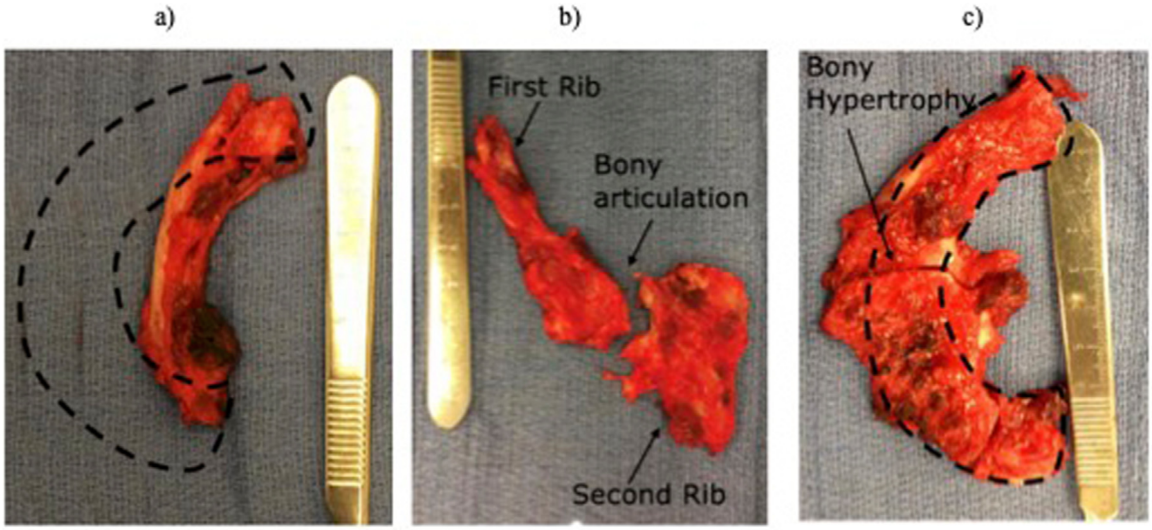

Fig. 1. Classification of abnormal first ribs: (A) Hypoplastic (B) Fused (C) Hyperplastic *Dashed lines delineate the course of normal first rib anatomy*.

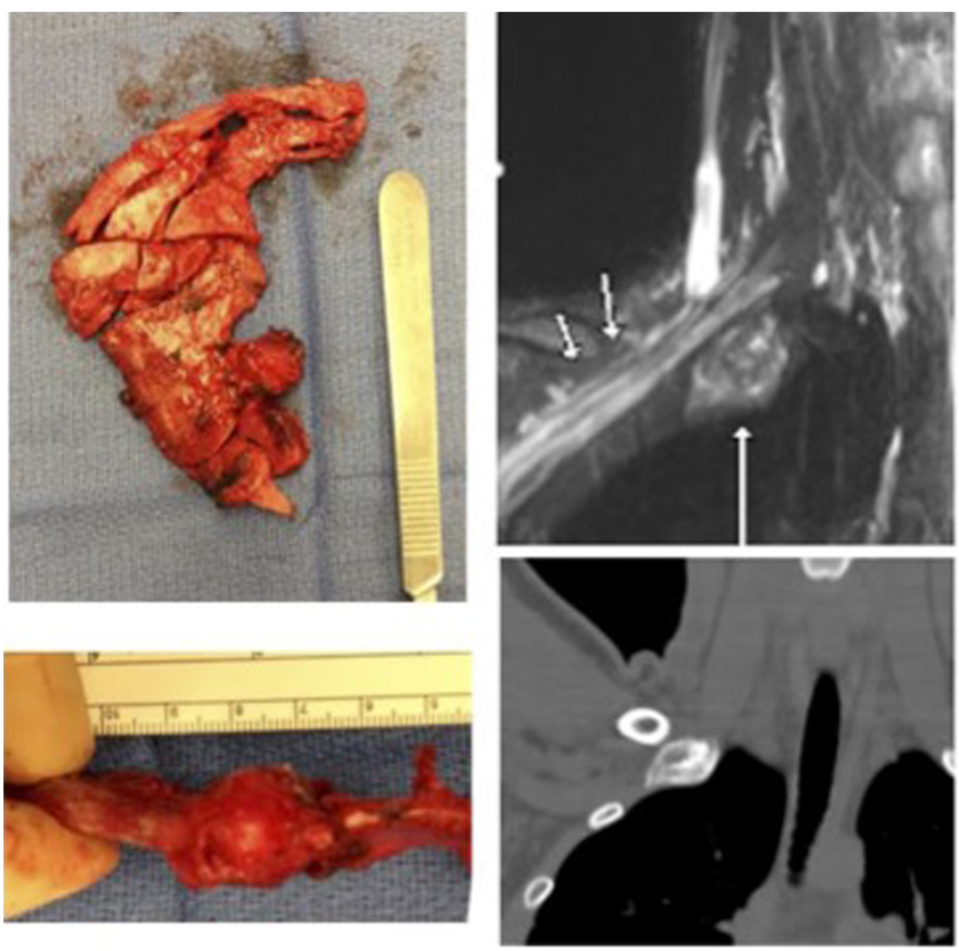

Fig. 2. Class III Abnormal First Rib. *Top Left:* Piecemeal resection of a type III ABNFR due to large exostosis in the midportion. *Bottom Left:* Mid-portion bony hypertrophy is in multiple dimensions, not just at the site of the scalene muscle insertion. *Top Right:* MRI demonstrating osseous hypertrophy impinging on the adjacent brachial plexus. Upward facing arrow indicates hypertrophic bone growth in the midportion of the first rib. Downward facing arrows indicate adjacent hyperintensity of the left brachial plexus divisions. *Bottom Right:* CT demonstrating bony hypertrophy narrowing the thoracic outlet. *Acronyms: Abnormal First Rib (ABNFR), Magnetic Resonance Imaging (MRI), Computed Tomography (CT)*.

means. Statistical significance was determined by a $P < 0.05$.

RESULTS

Demographics

Between the years of 1990–2021, a total of 2200 patients with TOS underwent FRR at the University of California, Los Angeles (UCLA). Among these patients, there were 19 (0.8%) who had an ABNFR and also underwent FRR. All surgical approaches were transaxillary. The average age at surgery was 30 +/- 15 years (range 11–74 years), including 13 men and 6 women. Clinical presentations included 9 ATOS, 6 NTOS, and 4 VTOS. Among the 19 ABNFRs, there were 6 class I, 6 class II, and 7 class III.

Diagnostic Evaluation

All abnormal first ribs were identified pre-operatively. Imaging studies done for all included chest x-rays or cervical spine series. These were able to identify an abnormal first rib in most instances. Additional imaging with CT angiography and MRI was performed for those patients where plain film imaging was not clear in defining the abnormality. CTAs were obtained in 7 patients and MRA for 2 patients. Among patients with NTOS there were 4 abnormal nerve conduction tests and 5 positive anterior scalene muscle blocks. All ATOS and VTOS patients underwent catheter-based arteriography or venography to establish the diagnosis. Of the 9 ATOS patients, 5 were initially managed with thrombolysis. Despite this, 3 required open surgical thrombectomy for persistent hand ischemia. Of the 4 VTOS presentations, 2 were seen in the acute period and underwent successful thrombolysis. The remaining 2 were referred after a period of anticoagulation was initiated by the referring physicians.

ABNFR Classification and Clinical Presentation

The majority of ATOS presentations were class I and II ABNFRs. On the other hand, there was an even distribution of rib classes among patients with NTOS. All VTOS cases were associated with class III ribs (Fig. 3). Overall, males outnumbered females in a ratio 2:1. When analyzed according to class, males predominated in class I and class III ABNFR. The ratio of men to women was equal in class II ABNFR (Fig. 4).

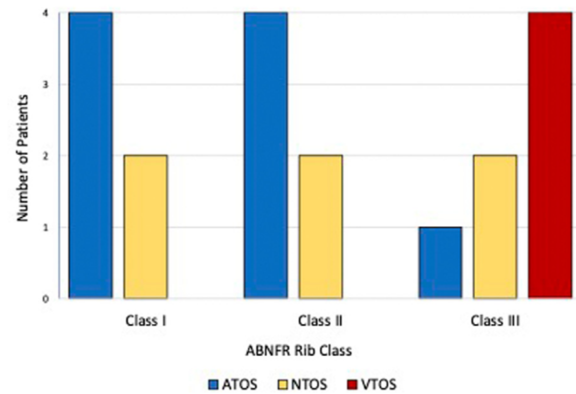

Fig. 3. Abnormal first rib presentation according to rib class. Acronyms: Arterial Thoracic Outlet Syndrome (ATOS), Neurogenic Thoracic Outlet Syndrome (NTOS), Venous Thoracic Outlet Syndrome (VTOS), Abnormal First Rib (ABNFR).

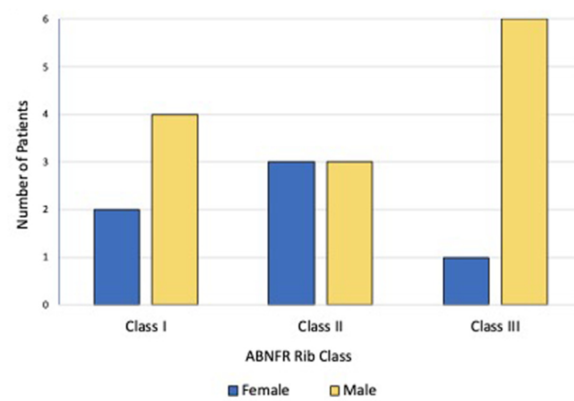

Fig. 4. Gender distribution by rib class. *Acronym: Abnormal First Rib (ABNFR).*

Operative Results

The average operative time was 2.4 +/- 1.5 hr (range 1.3–5.9 hr). There was a significant difference in duration of surgery for cases where arterial reconstruction or thrombectomy were required in addition to rib resection (mean 4.7 +/- 1.5 hr vs. 1.7 +/- 0.5 hours, $P < 0.05$). For cases of isolated FRR, there was no significant difference in operative times among the different clinical presentations: 1.7 +/- 0.4 hr NTOS, 1.9 +/- 0.8 hr VTOS, and 1.8 +/- 0 hr ATOS. The average blood loss was 38 mL +/- 21 mL (range 25–100 mL). There was a significantly higher operative blood loss for cases where arterial reconstruction or thrombectomy were required (60 +/- 36 mL vs. 34 +/- 15 mL, $P < 0.05$). The average length of hospital stay (LOS) was 2.9 +/- 2.3 days (range 1–11 days). Mean LOS for patients requiring arterial reconstruction was significantly longer (4.3 +/- 1.2

days) than patients who underwent isolated FRR with NTOS (2.0 +/- 0.6 days) and VTOS (1.8 +/- 0.5 days).

There were no nerve injuries (brachial plexus, long thoracic, phrenic) which occurred during FRR. Pleural entry was required in 5 cases and these were managed with intraoperative chest tube placements. One ATOS patient developed a postoperative hematoma which was evacuated in the operating room.

Of the 9 arterial cases, 4 required arterial bypass reconstruction using Dacron grafts in 2 patients, saphenous vein graft in 1 patient, and VIABAHN stent graft in 1 patient. Axillosubclavian artery reconstruction was performed by separate supraclavicular and infraclavicular incisions. 1 ATOS patient thrombosed his Dacron bypass graft postoperatively and required return to the operating room for thrombectomy. There were no amputations. Of the VTOS patients, all underwent post-decompression venography and 3 required balloon angioplasty.

Follow-Up

Average follow-up was 7.4 +/- 10.7 months (range 1 month to 43 months). During follow-up, secondary procedures were required for 3 patients: 1 pectoralis minor tenotomy, 1 completion scalenectomy, and 1 contralateral rib resection. All patients with VTOS had sonographic evidence of patent axillosubclavian veins during the follow-up period. All were able to return to work, athletic activities or school.

Clinical Outcomes

Both QDS and SPS improved following surgical decompression for all groups (Fig. 5). Overall QDS scores improved from 49.7 +/- 25.1 preoperatively to 22.1 +/- 22.3 after FRR ($P = 0.02$). When analyzed according to presentation, QDS significantly improved in all groups after FRR: ATOS scores improved from 54.5 +/- 36.1 to 18.9 +/- 20.6 ($p < 0.05$), NTOS scores reduced from 61.5 +/- 15.4 to 37.3 +/- 19.7 ($P < 0.05$), and VTOS scores improved from 22.8 +/-9.1 to 0 +/- 0 ($P < 0.05$) (Fig. 5A). SPS also improved following surgical decompression from 3.4 +/- 2.9 to 1.8 +/- 2.0. When analyzed according to presentation, SPS improved in all groups after surgery although the values were not statistically significant: ATOS reduced from 2.5 +/- 3.0 to 1.3 +/- 2.3, NTOS reduced from 4.8 +/- 2.7 to 3.5 +/- 1.3, and VTOS reduced from 1.5 +/- 2.1 to 0 +/- 0 (Fig. 5B).

When comparing surgical results between class I, class II and class III ABNFRs, there was no significant difference in EBL (33 cc, 43 cc, 35 cc), duration of surgery (1.9 hr, 20.1 hr, 2.8 hr), or length of hospital stay (2.6 days, 2.0 days, 2.2 days). Outcomes between class I, class II and class III ABNFRs, were not significantly different in either the SPS (3.0, 1.2, 1.0) or QUICK DASH (52, 17, 13) scores. Although there was a trend for class I patients to have presenting and final higher scores, the small sample size made this difference statistically insignificant.

Of the 19 patients included in this study, DkS were reported to be good or excellent in a total of 79% of patients after first rib resection (Table I). When stratified by presentation, 100% of patients with VTOS reported excellent outcomes, 67% of patients with NTOS reported good to excellent outcomes, and 68% of patients with ATOS reported good to excellent outcomes. No patients in this study reported poor DkS after abnormal first rib resection.

DISCUSSION

We have proposed a classification system for ABNFRs which has not been previously described. Classifying ABNFRs helps identify features that guide the approach to operative repair, and may ultimately lead to superior outcomes. There are several additional merits to this proposed classification system: it aids in the definition of pathological presentation, it allows correlation with clinical presentations, and it allows comparison of outcomes. This classification system is analogous to the SVS classification of cervical ribs which classifies cervical ribs into 4 classes depending on length and attachment to the adjacent rib.[13] We have proposed classifying ABNFRs according to whether they are unattached or attached to the adjacent rib (class I and class II). Additionally, based on our experience and that reported by other authors, there is a third group of ABNFRs which displays a notable abnormality with hyperplastic growth in the mid-section of the first rib (class III).[5,11] This classification system applies to purely congenital ABNFRs and this does not address post-traumatic deformities.

While the supraclavicular approach to ABNFR resection is reported most commonly in the literature, our series reports a transaxillary approach to FRR. Modifications of the surgical technique for these cases was dependent on the ABNFR class. For Class I ABNFRs the resection is very similar to a routine transaxillary operation. For Class II ABNFRs the resection deviates from the standard

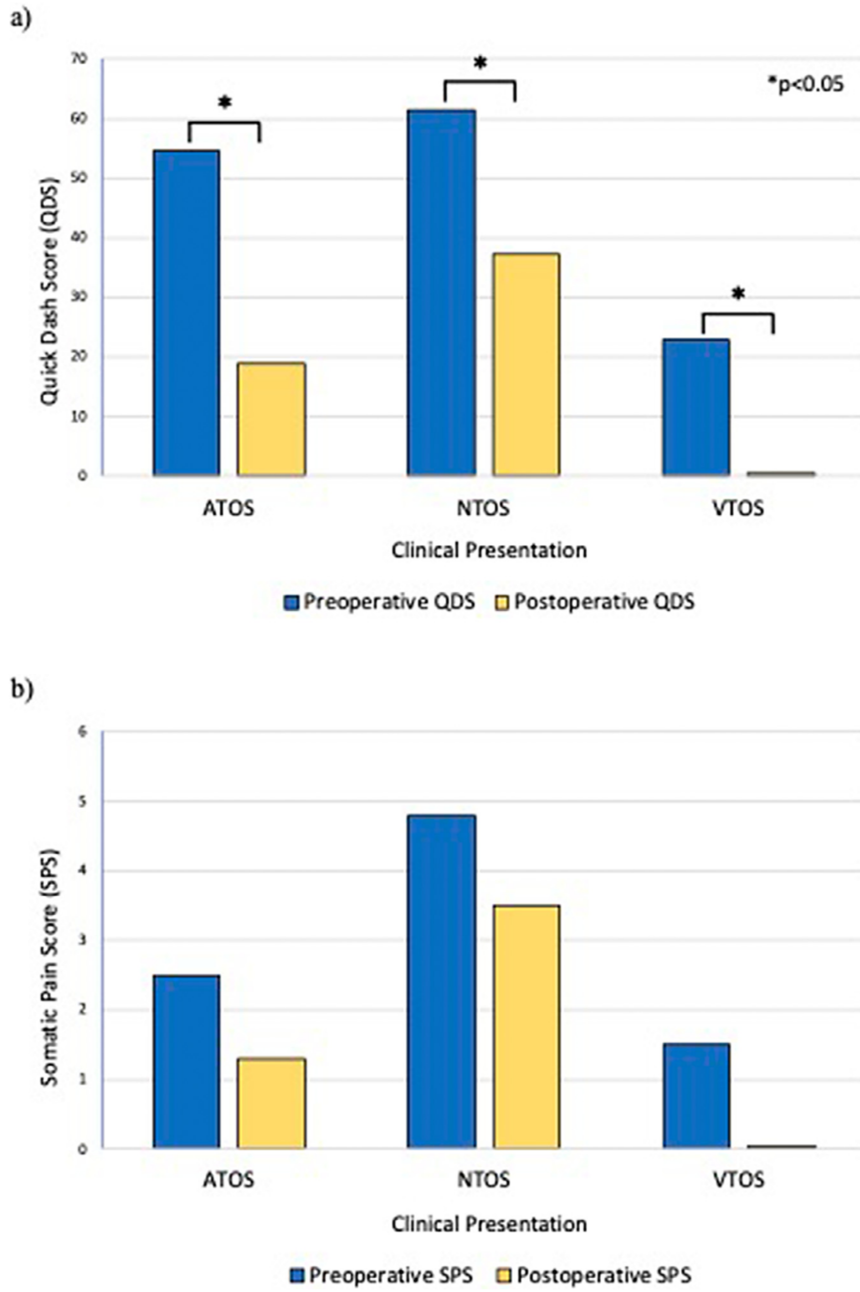

Fig. 5. Outcomes according to clinical presentation. (A) Preoperative and postoperative QDS (B) Preoperative and postoperative SPS. *Acronyms: Arterial Thoracic Outlet Syndrome (ATOS), Neurogenic Thoracic Outlet Syndrome (NTOS), Venous Thoracic Outlet Syndrome (VTOS), Quick Disability of Arm Shoulder and Hand Scores (QDS), Somatic Pain Scores (SPS).*

approach in that a portion of the second rib may require resection due to the abnormal articulation, in a manner similar to the transaxillary resection of a fully formed cervical rib.[16] For Class III ABNFRs, the technique is modified to address the bony exostosis present in the midportion of the rib. In these cases, piecemeal transection may be necessary as the ribs may be too wide or large to allow safe transection with rib shears. While our preferred approach for TOS decompression is transaxillary, it must be recognized that the transaxillary approach has several limitations. Complete resection of scalene muscles cannot be performed. Limitations of the surgical field makes vascular control difficult in the case of inadvertent arterial or venous injury. Visualization of important anatomical structures is limited and so use of endoscopic video assistance is helpful. Lastly, arterial reconstruction is best accomplished via a separate paraclavicular approach.

Table I. Postoperative Derkash Scores according to clinical presentation.

Score	Derkash	aTOS # patients (%)	nTOS # patients (%)	vTOS # patients (%)	All Patients (%)
Excellent	1	5 (56%)	3 (50%)	4 (100%)	12 (63%)
Good	2	2 (22%)	1 (17%)	0 (0%)	3 (16%)
Fair	3	2 (22%)	2 (33%)	0 (0%)	4 (21%)
Poor	4	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Acronyms: Arterial Thoracic Outlet Syndrome (ATOS), Neurogenic Thoracic Outlet Syndrome (NTOS), Venous Thoracic Outlet Syndrome (VTOS).

Our series is the largest reported to date in the literature and represents a contemporary update of surgical decompression of TOS related to ABNFRs. Unique to our series is the identification of a previously unrecognized trend in gender distribution (male predominance) and clinical presentation (even distribution of ATOS, NTOS, VTOS). As expected, cases which required arterial reconstruction or thrombectomy were more complex and were associated with longer operative times, increased blood loss, and thrombotic or bleeding complications when compared to FRR performed in isolation. Despite this, there were no permanent neurological complications and no amputations were performed. The validated patient-reported outcomes used in this study documented improvement in all patients after surgery with return to gainful employment, athletic activity and school. This series further highlights the advantages of standardized outcomes measures. While prior series have noted subjective improvement, use of standardized reporting instruments allows more accurate assessment of outcome and facilitates comparison between studies.

Bony abnormalities have been associated with thoracic outlet syndrome since the initial report of a cervical rib resection by Holmes Coote in 1861.[17] Cervical ribs have been recognized as the predominant congenital bony abnormality associated with TOS with an incidence of about 0.5% in the general population. Congenital first rib abnormalities are less common than cervical ribs, estimated to occur in about 0.25% of the population.[6] The incidence of clinically symptomatic ABNFR requiring FRR in our experience is very low (19 in 2200 cases). For comparison, during the same period we have operated on over 130 cervical ribs. Given the difficulty in identifying ABNFRs, it is possible that these numbers under-estimate the incidence of these abnormalities.

This study has brought to attention several features which distinguish ABNFRs from cervical ribs with regards to demographics and clinical presentation. The gender distribution of cervical ribs is on the order of 2:1 (F:M) or greater with a clinical predominance among women.[18] This predominance is reversed in ABNFRs so that the gender distribution is 1:2 (F:M). Additionally, while cervical ribs are primarily associated with ATOS and NTOS presentations, they are not often associated with VTOS presentations.[18] In this series of ABNFRs there is a somewhat equal distribution of presentations between NTOS, ATOS and VTOS.

Our study has several limitations. First, this is a retrospective analysis and as such, data collection is prone to recall bias and selection bias. Second, although this study provides one of the largest cohorts of patients with ABNFRs who underwent surgery, our results and conclusions are limited by the constraints of a small sample size given the rarity of this condition. Third, all patients in this study underwent FRR via a standardized transaxillary technique at a single institution and results may not be generalizable to other surgeons who utilize a supraclavicular or paraclavicular technique. Lastly, our study is limited by a short follow-up period for our patients with an average of 7.4 +/- 10.7 months. The large standard deviation may be explained by the difference in standardized follow-up after FRR for patients with NTOS versus

patients with ATOS or VTOS. Patients with NTOS are followed at routine intervals up to 6 months and if they have had symptom resolution after this time period, they return to clinic as needed. On the contrary, patients with ATOS or VTOS were followed with annual clinic visits and ultrasounds to assess for axillosubclavian vein or artery patency. Additionally, some patients were lost to follow-up at our institution as they were referred from outside hospital vascular surgeons and returned to their primary vascular surgeon for follow-up.

CONCLUSION

Our study identifies a previously unrecognized association of gender and presentation with abnormal first ribs. Further we present a novel classification system which has several benefits: it provides a concise description of variant anatomy, facilitates comparisons between series, and provides direction for surgical management to ultimately optimize patient outcomes. These bony abnormalities may be described as hypoplastic, fused, or hyperplastic and they may be associated with a range of clinical presentations including arterial, neurogenic, and venous TOS. Surgical decompression of abnormal first ribs via transaxillary approach may be safely accomplished with good symptom relief and excellent outcomes.

AUTHOR CONTRIBUTIONS

Conception and design: MA, JP, MC, TC, RP, HG
Analysis and interpretation: MA, JP, JGU, MC, TC, RP, HG
Data collection: MA, JP, MC, TC, RP, HG
Writing the article: MA, JP, JGU, MC, TC, RP, HG
Critical revision of the article: MA, JGU, JP, MC, TC, RP, HG
Final approval of the article: MA, JP, JGU, MC, TC, RP, HG
Statistical analysis: MA, HG
Obtained funding: Not applicable
Overall responsibility: MA

FUNDING

This study was presented at the main podium at the 2021 Southern California Vascular Surgery Society 39th Annual Meeting, Ojai, California, June 18-22, 2021.

There was no funding received for this study

REFERENCES

1. Walshe F, Jackson H, Wyburn-Mason R. On some pressure effects associated with cervical and with rudimentary and "normal" first ribs, and the factors entering into their causation. Brain 1944;67:141–77.
2. Roos DB. Congenital anomalies associated with thoracic outlet syndrome: anatomy, symptoms, diagnosis, and treatment. Am J Surg 1976;132:771–8.
3. Makhoul RG, Machleder HI. Developmental anomalies at the thoracic outlet: an analysis of 200 consecutive cases. J vasc surg 1992;16:534–45.
4. Learmonth J. Some sequels of abnormality at the thoracic outlet. Thorax 1947;2:1.
5. Weber AE, Criado E. Relevance of bone anomalies in patients with thoracic outlet syndrome. Ann Vasc Surg 2014;28:924–32.
6. Etter L. Osseous abnormalities of the thoracic cage seen in forty thousand consecutive chest photoroentogenograms. Am J Roentogenol 1944;51:359–63.
7. Edwards P, Moody A, Harris P. First rib abnormalities in association with cervical ribs: a cause for postoperative failure in the thoracic outlet syndrome. Eur J Vasc Surg 1992;6:677–81.
8. Henry CK. A case of congenital malformed first dorsal rib. Can Med Assoc J 1936;34:545.
9. Hidlay DT, Graham RS, Isaacs JE. Anomalous first thoracic rib as a cause of thoracic outlet syndrome with upper trunk symptoms: a case report. Hand 2014;9:484–7.
10. Siderys H, Walker D, Pittman JN. Anomalous first rib as a cause of the thoracic outlet syndrome. JAMA 1967;199:133–4.
11. Baumgartner F, Nelson RJ, Robertson JM. The rudimentary first rib: a cause of thoracic outlet syndrome with arterial compromise. Arch Surg 1989;124:1090–2.
12. Reidler JS, De SD, Schreiber JJ, et al. Thoracic outlet syndrome caused by synostosis of the first and second thoracic ribs: 2 case reports and review of the literature. J Hand Surg [Am] 2014;39:2444–7.
13. Illig KA, Donahue D, Duncan A, et al. Reporting standards of the Society for Vascular Surgery for thoracic outlet syndrome. J Vasc Surg 2016;64:e23–35.
14. Hudak PL, Amadio PC, Bombardier C, et al. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder, and head). Am J Ind Med 1996;29:602–8.
15. Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354.
16. Moridzadeh RS, Gelabert MC, Rigberg DA, et al. A novel technique for transaxillary resection of fully formed cervical ribs with long-term clinical outcomes. J Vasc Surg 2021;73:572–80.
17 Coote H. Exostosis of the left transverse process of the seventh cervical vertebra, surrounded by blood vessels and nerves; successful removal. Lancet 1861;1:360–1.
18. Gelabert HA, Rigberg DA, O'Connell JB. Transaxillary decompression of thoracic outlet syndrome patients presenting with cervical ribs. J Vasc Surg 2018;68:1143–9.