The supraclavicular approach in the management of cervicothoracic-junction benign neurogenic tumors: A real-world analysis

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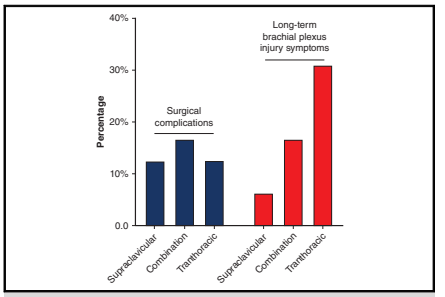
ABSTRACT

Objectives: The study objectives were to evaluate the safety, feasibility, and risk of neurologic complications with the supraclavicular approach in the operative management of cervicothoracic-junction benign neurogenic tumors.

Methods: Between January 2012 and April 2023, 115 patients who underwent surgical resection for cervicothoracic-junction benign neurogenic tumors were retrospectively enrolled. Patients were divided into 3 groups based on the surgical approach: supraclavicular alone (Supraclav-Alone), n = 16; Transthoracic-Alone (video-assisted thoracoscopic surgery/Open), n = 87; and supraclavicular combined with transthoracic (Supraclav + video-assisted thoracoscopic surgery/open), n = 12. Clinicopathologic variables and postoperative morbidity including neurologic complications were summarized among the groups. Logistic regression analysis was performed to identify predictors for long-term (>6 months) brachial plexus injuries.

Results: The cohort comprised 28 patients (24.3%) who underwent surgical resection using a supraclavicular approach. The Supraclav-Alone group portended the most cephalad location of tumor, the smallest pathologic tumor size, the shortest operative time, the least blood loss, and the least postoperative pain. The incidence of surgical complications, phrenic nerve neuropraxia, recurrent laryngeal nerve neuropraxia, or Horner's syndrome was similar among the groups postoperatively. However, use of the supraclavicular-alone approach (adjusted odds ratio, 0.165; 95% CI, 0.017-0.775) was a predictor for long-term brachial plexus injury complications. Among patients who experienced brachial plexus injury complications, the proportion of patients achieving complete resolution was higher among those undergoing a supraclavicular approach group (Supraclav-Alone: 80.0% vs Supraclav + video-assisted thoracoscopic surgery/Open: 60.0% vs video-assisted thoracoscopic surgery/Open: 25.8%).

Conclusions: The supraclavicular approach may be a safe and feasible strategy in the management of cervicothoracic-junction benign neurogenic tumors that does not increase surgical complications and minimizes the severity of brachial plexus injury. (JTCVS Techniques 2024;25:214-25)



The incidence of surgical and neurologic complications among the 3 surgical approaches.

CENTRAL MESSAGE

The supraclavicular approach, either by itself or in combination with a transthoracic approach, may be a safe and feasible for cervicothoracic-junction benign neurogenic tumors.

PERSPECTIVE

The surgical management of cervicothoracic-junction benign neurogenic tumors is controversial because of the proximity of critical neurovascular structures. Compared with the traditional transthoracic approach, the supraclavicular approach might be a safe and feasible alternative because it has the potential to alleviate the degree of BP injuries and does not increase other postoperative morbidity.

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This study was supported by the National Natural Science Foundation of China (Grant 82172848).

Institutional Review Board approval: This study was approved by the Ethical Review Board of the Shanghai Pulmonary Hospital (No. K23-290, Approval date: August 2023).

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Read at the 104th Annual Meeting of The American Association for Thoracic Surgery, Toronto, Ontario, Canada, April 27-30, 2024.

Received for publication Aug 4, 2023; revisions received Dec 29, 2023; accepted for publication Jan 8, 2024; available ahead of print April 28, 2024.

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2666-2507

https://doi.org/10.1016/j.xjtc.2024.01.018

Abbreviations and Acronyms

BP = brachial plexus
CR = complete resolution
IQR = interquartile range
PN = phrenic nerve
PR = partial remission
RLN = recurrent laryngeal nerve
SD = stable disease
ST/SG = sympathetic trunk/stellate ganglion
VATS = video-assisted thoracoscopic surgery

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Mediastinal lesions are relatively uncommon, with a reported prevalence ranging from 0.21 to 0.77% according to lung cancer screening studies.[1,2] Of those located at the posterior mediastinum, neurogenic tumors are the most prevalent etiology.[3,4]

Given that intrathoracic neurogenic tumors are generally benign in nature, surgical resection remains the mainstay of treatment with excellent prognosis.[5] Numerous studies have reported that a video-assisted thoracoscopic surgery (VATS) approach is associated with less pain, decreased hospital length of stay, and less blood loss compared with a traditional open thoracotomy.[6,7] However, there are some scenarios that require special consideration when determining the optimal surgical approach, such as tumors with intraspinal extension or those located at the costodiaphragmatic junction or cervicothoracic junction. Of these, there is some consensus on using a posterior midline approach with laminectomy for tumors with intraspinal extension and an open thoracotomy for large tumors or those located at the costodiaphragmatic-junction.

The surgical approach for tumors located at the cervicothoracic-junction has been controversial because of their rarity and a paucity of prospective studies. Several studies have demonstrated that VATS is suitable.[6,8] However, others have considered the tumors located at the thoracic apex to be a contraindication for VATS due to the proximity to critical neurovascular structures at the cervicothoracic-junction zone.[7,9,10] As an alternative, the supraclavicular approach has been recommended in the management of benign neurogenic tumors located at the cervicothoracic junction because it allows surgeons to directly identify critical neurovascular structures and theoretically protect them with appropriate handling.[11-14] However, the studies investigating the utility of the supraclavicular approach are limited to primarily case reports, so several issues remain unclear about the supraclavicular approach, including the safety and feasibility of this strategy and the associated incidence and course of any postoperative neurologic complications.

In these contexts, our study aimed to investigate the postoperative complication profiles and subsequent recovery of neurologic function among various surgical approaches in the management of cervicothoracic-junction benign neurogenic tumors in real-world practice.

MATERIAL AND METHODS

Study Population

Between January 2012 and April 2023, 123 patients who presented with cervicothoracic-junction neurogenic tumors were retrospectively collected. The exclusion criteria were as follows: (1) patients without preoperative high-resolution computed tomography scans; (2) patients with a dumbbell-shaped tumor; or (3) patients diagnosed with malignant tumors. Ultimately, 115 patients with cervicothoracic-junction benign neurogenic tumors were eligible for further analysis (Figure E1). This study was approved by the Ethical Review Board of the Shanghai Pulmonary Hospital (No. K23-290, approval date: August 2023) and was conducted in accordance with the Declaration of Helsinki (as revised in 2013). For its retrospective nature, written consents were waived by the Institutional Review Board.

Radiological Evaluation

Within 1 month before surgery, patients underwent contrast-enhanced high-resolution computed tomography scanning at full inspiration. The radiological features of the tumor were evaluated under the setting of lung and mediastinal window settings (level/width: 40/400 and 450/1500 Hounsfield units). Magnetic resonance imaging was routinely performed to exclude the possibility of cysts or intraspinal extension and to better define the relationship between tumor and neurovascular structures. Additionally, the upper pole of all included tumors was above the reference level, which was determined to be the horizontal plane of the subclavian artery passing through the scalene hiatus on the first rib (Figure 1, *A* and *B*). To further clarify tumor localization, we used the term "lower" or "upper/flush" to indicate whether the maximum transverse section of the tumor was situated below the reference plane or above/flush to it (Figure 1, *C*), respectively.

Algorithm of Surgical Approach Choosing

Surgical resection is typically considered for the highly suspected benign neurogenic tumor located at the cervicothoracic-junction if the tumor is large enough (>3 cm), symptomatic, extends into intervertebral foramen (dumbbell-shaped), or continues to grow after shorter-term follow-up (≤1 year). A supraclavicular approach could be considered if the following conditions were met: (1) tumor is highly suspicious to be of neurogenic origin with a benign nature based on preoperative radiologic findings and laboratory tests; (2) tumor diameter of 5 cm or less; (3) tumor max-transverse section is above or flush with the reference level, and (4) tumor without intraspinal extension (Figure 2, *A*). When the tumor extends into the cervical region (ie, the upper pole higher than the reference level) with the tumor size larger than 5 cm or the max-transverse section lower than the reference level, the combination of supraclavicular and transthoracic approach (Figure 2, *B*) or transthoracic approach alone was considered according to the surgeon's preference. In our study, 12 patients underwent a combination of supraclavicular and transthoracic approaches, all of whom were initially intended to have a hybrid approach preoperatively.

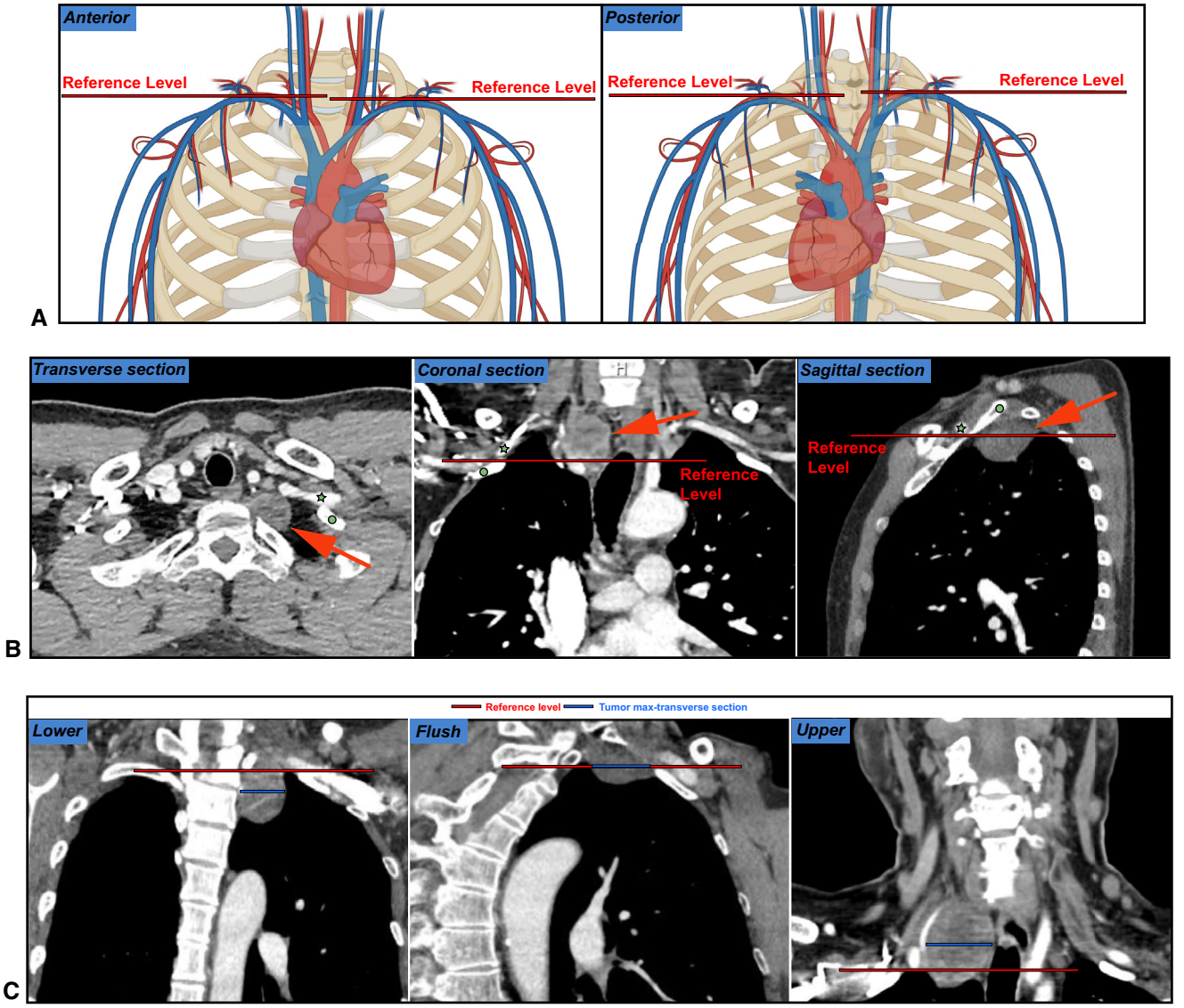


FIGURE 1. Radiologic evaluation of tumor anatomic location: schematic diagram of reference level from the anterior and posterior position (A); computed tomography scan of reference level at the transverse, coronal, and sagittal section (B); max-transverse section of tumor below, flush with, or above the reference level (C); *pentagram*: subclavian artery; *dot*: the first rib; *red line*: reference level; *blue line*: max-transverse section of tumor; *red arrow*: the tumor.

Surgical Technique

A detailed description of our VATS approach has been described by our center.[9] In the supraclavicular procedure, patients were placed in the supine position with a shoulder roll and the head was turned to the contralateral side in slight extension. Anesthesia was performed without muscle relaxants to enable observation of intraoperative neuromuscular reflexes. A transverse skin incision approximately 8 cm in length was made 2 cm above and parallel to the clavicle (Figure 2, *C*). After transection of the superficial layers, the clavicular end of the sternocleidomastoid and the omohyoid muscles were separated. The anterior scalene muscle was divided close to the clavicle after the phrenic nerve (PN) and brachial plexus (BP) were identified and retracted separately. After the subclavian vessels were exposed and retracted, the apical parietal pleura was opened to obtain entry into the thoracic cavity. After exposure of the tumor, the capsule of the tumor was opened with a bipolar electroscalpel, and then the tumor was carefully dissected from the capsule. Finally, the supraclavicular wound was closed with a single 12F tube inserted for drainage. Neurosurgical consultation, neuromonitoring, and intraoperative stimulation were performed as needed throughout the operation to avoid injury to the nerves located at the cervicothoracic junction. In our study, the resections using the supraclavicular approach were all under the cooperation with the neurosurgeon, and neuromonitoring was performed as needed during the surgery.

Neurologic Complications, Postoperative Pain, and Follow-up

Postoperative neurologic complications were defined as any newly developed symptoms or radiologic-manifestations related to the PN, recurrent laryngeal nerve (RLN), sympathetic trunk/stellate ganglion (ST/SG), or BP, as well as any progressive deterioration of preexisting symptoms related to these nerves postoperatively. Patients experiencing any postoperative neurologic complications were routinely administered corticosteroids

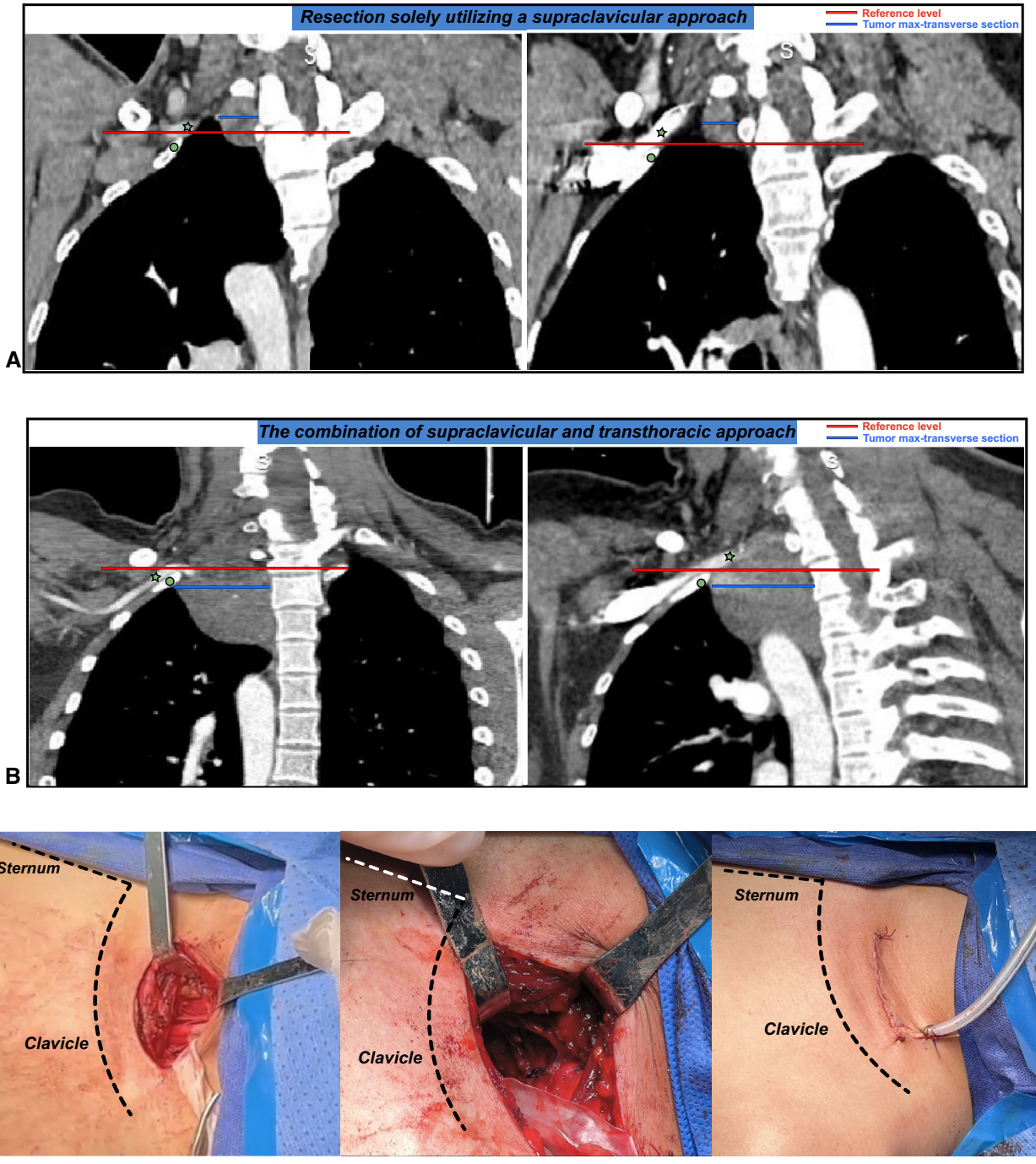


FIGURE 2. Examples of patients underwent resection using supraclavicular approach solely (A) or combined with transthoracic approach (B), and the intraoperative photograph demonstrating the access to thoracic apex from the supraclavicular incision (C); *pentagram*: subclavian artery; *dot*: first rib; *red line*: reference level; *blue line*: max-transverse section of tumor.

(methylprednisolone 40 mg for 2 days)[15] and mecobalamin during their hospitalization. After discharge, they were referred to a neurologist for further consultation.

The duration and course of any neurologic complications were documented. Specifically, the duration was classified as "short-term" and "long-term" based on whether the symptoms were perceptible for longer than 6 months postoperatively, and the course was classified as "complete resolution (CR)," "partial remission (PR)," or "stable disease (SD)." CR was defined as symptoms being imperceptible during the past 3 to 6 months of normal daily life, PR was defined as symptoms that were still perceptible during the past 3 to 6 months of normal daily life but had improved compared with the postoperative period, and SD was defined as persistent symptoms that had not improved compared with the postoperative period.

Postoperative pain was subjective evaluated by the numerical rating scale (0-10, with 0 = no pain and 10 = worst pain imaginable).[16,17] A follow-up protocol was conducted with outpatient visits. Imaging included

a chest x-ray performed 3 weeks postoperatively and a computed tomography scan 6 months postoperatively and then annually thereafter. Additionally, telephone interviews were conducted annually as a complement.

Statistics

Continuous variables were expressed as median and interquartile range (IQR). Categorical variables were summarized with proportions. To explore the predictors of long-term duration of BP injury symptoms, multivariable logistic regression model using the enter method was performed to investigate independent risk factors with adjusted odds ratios (95% CI). Given the relatively small sample sizes, logistic regression using the Firth bias reduction method was also used to diminish the risk of bias.[18]

All analyses were performed with IBM SPSS Statistics 26.0 (IBM) or R version 4.1.2 (R Foundation for Statistical Computing).

RESULTS

Patients' Characteristics

Table 1 lists the detailed demographic and clinicopathologic characteristics of the entire cohort (n = 115), including 54 (47.0%) female patients and 61 (53.0%) male patients with a median age of 42 years (range, 15-76 years); 23.5% of all patients (n = 27) were symptomatic preoperatively (Table E1). Histologically, the most prevalent histologic subtype was neurilemmoma/schwannoma (n = 96, 83.5%), followed by ganglioneuroma (n = 17, 14.8%) and neurofibroma (n = 2, 1.7%). Most tumors originated from the sympathetic chain (n = 68, 59.1%). All tumors were completely resected. The median postoperative length of stay was 3 days (IQR, 2-4 days).

Surgical Approaches

The cohort comprised a total of 28 patients (24.3%) who underwent resection using a supraclavicular approach. Among them, 16 patients (57.1%) underwent resection solely using a supraclavicular approach (Supraclav-Alone), and the remaining 12 patients (42.9%) underwent a supraclavicular approach plus VATS/Open thoracotomy (Supraclav + VATS/Open). In patients who underwent resection solely using the transthoracic approach (VATS/Open), the majority underwent a VATS approach (n = 76, 85.4%), followed by open thoracotomy (including conversion, n = 10, 11.4%) and supra-sternal plus sternotomy (n = 1, 1.1%).

From the patient's characteristics, the Supraclav-Alone group portended the most cephalad location of tumor (all tumors' max-transverse section was above or flush with the reference level), the smallest pathologic tumor size (median [IQR], 3.8 [2.8-4.9), and the highest proportion of tumors originating from BP (31.3%) (Table 1).

Perioperative Outcomes and Follow-up

The Supraclav-Alone group demonstrated the shortest operative time, the least blood loss, and the least postoperative pain (Table 2). The incidence of general thoracic surgical complications was similar among groups (Supraclav-Alone: n = 2, 12.5% vs Supraclav + VATS/Open: n = 2, 16.7% vs VATS/Open: n = 11, 12.6%). The specific complications and frequencies are listed in Table 2. Major blood vessel injuries did not occur perioperatively in our cohort. Transfusions in patients (n = 5) were all due to massive intraoperative hemorrhage (n = 4) and postoperative drainage (n = 1). With the exception of 1 patient who experienced chylothorax, the remaining were classified as grade I/II according to the Clavien–Dindo classification and treated with conservative therapy.

During the follow-up period (median, 42 months; IQR, 15-74 months), there were no mortalities or recurrences. Among patients with preoperative symptoms, all symptoms improved except for 3 cases with remaining Horner's syndromes whose tumor originated from the sympathetic chain.

Postoperative Neurologic Complications

Eight patients (7.0%), 6 patients (5.2%), 53 patients (46.1%), and 41 patients (35.7%) experienced postoperative neurologic complications related to the PN, RLN, ST/SG, and BP, respectively (Figure 3, *A*). The most common presentation was partial ptosis in cases with Horner's syndrome (n = 44, 83.0%) and finger numbness in cases with BP injury (n = 27, 65.9%) (Figure 3, *B* and *C*).

The specific neurologic complications are listed in Table 2. Additionally, the proportion of patients who experienced complications related to BP injury was similar among the groups (Supraclav-Alone: n = 5, 31.3% vs Supraclav + VATS/Open: n = 5, 41.7% vs VATS/Open: n = 31, 35.6%) (Figure E2), but the patients with BP injury complications experienced a variable duration of symptoms, with those undergoing a supraclavicular approach experiencing a shorter duration of symptoms (Table 2). Furthermore, multivariable analyses suggest that use of a supraclavicular approach alone (adjusted odds ratio, 0.165; 95% CI, 0.017-0.775; $P = .02$) was an independent factor for long-term BP injury complications (Table 3).

Course of Neurologic Complications

During the follow-up period, PN/RLN neuropraxia was temporary and patients recovered completely within 6 months postoperatively; however, fewer patients with postoperative Horner's syndrome experienced improvement (Table 2). Among patients who experienced complications related to BP injury, 15 (36.6%) achieved CR and 18 (43.9%) achieved PR. Furthermore, more patients in the Supraclav-Alone group achieved CR compared with the other 2 groups (CR: 80.0% vs 60.0% vs 25.8%, non-CR (including PR and SD): 20.0% vs 40.0% vs 74.2%) (Figure E2).

DISCUSSION

We retrospectively reviewed 115 consecutive patients presenting with a cervicothoracic-junction benign neurogenic tumor. We found that (1) patients undergoing a sole

TABLE 1. Baseline characteristics of all patients grouped by surgical approach (n = 115)

Variables	Total (n = 115), n (%)	Supraclavicular approach alone (n = 16), n (%)	Supraclavicular approach plus VATS/Open thoracotomy (n = 12), n (%)	Transthoracic approach alone (n = 87), n (%)
Age, y, median (IQR)	42 (32-59)	36.5 (32-52)	28 (22-64)	44 (36-59)
Gender				
Female	54 (47.0%)	9 (56.3%)	6 (50.0%)	39 (44.8%)
Male	61 (53.0%)	7 (43.8%)	6 (50.0%)	48 (55.2%)
Smoking history				
Never	91 (79.1%)	14 (87.5%)	8 (66.7%)	69 (79.3%)
Past or current	24 (20.9%)	2 (12.5%)	4 (33.3%)	18 (20.7%)
ECOG performance status				
0	98 (85.2%)	13 (81.3%)	10 (83.3%)	75 (86.2%)
1	15 (13.0%)	3 (18.8%)	1 (8.3%)	11 (12.6%)
2	2 (1.7%)	0 (0.0%)	1 (8.3%)	1 (1.2%)
Charlson Comorbidity Index				
0-1	108 (93.9%)	15 (93.8%)	11 (91.7%)	82 (94.3%)
2	5 (4.3%)	0 (0.0%)	1 (8.3%)	4 (4.6%)
≥3	2 (1.7%)	1 (6.3%)	0 (0.0%)	1 (1.1%)
Lateral				
Right	60 (52.2%)	10 (62.5%)	4 (33.3%)	46 (52.9%)
Left	55 (47.8%)	3 (37.5%)	8 (66.7%)	41 (47.1%)
Max-transverse section elevation*				
Upper/flush	70 (60.9%)	16 (100.0%)	6 (50.0%)	48 (55.2%)
Lower	45 (39.1%)	0 (0.0%)	6 (50.0%)	39 (44.8%)
Symptoms				
Asymptomatic	88 (76.5%)	13 (81.3%)	9 (75.0%)	66 (75.9%)
Symptomatic	27 (23.5%)	3 (18.8%)	3 (25.0%)	21 (24.1%)
Surgical approach				
Sole supraclavicular	16 (13.9%)	16 (100%)	-	-
Supraclavicular plus VATS	11 (9.6%)	-	11 (91.7%)	-
Supraclavicular plus Open thoracotomy	1 (0.9%)	-	1 (8.3%)	-
VATS	76 (66.1%)	-	-	76 (85.4%)
Open thoracotomy	7 (6.1%)	-	-	7 (8.0%)
VATS conversion to Open thoracotomy	3 (2.6%)	-	-	3 (3.4%)
Supra-sternal plus sternotomy	1 (0.9%)	-	-	1 (1.1%)
Tumor origin				
BP	11 (9.6%)	5 (31.3%)	3 (25.0%)	3 (3.4%)
Sympathetic chain	68 (59.1%)	6 (37.5%)	6 (50.0%)	56 (64.4%)
Intercostal nerve	32 (27.8%)	2 (12.5%)	3 (25.0%)	27 (31.0%)
Vagus nerve	4 (3.5%)	3 (18.8%)	0 (0.0%)	1 (1.1%)
Histologic subtype				
Neurilemmoma/Schwannoma	96 (83.5%)	13 (81.3%)	7 (58.3%)	76 (87.4%)
Ganglioneuroma	17 (14.8%)	2 (12.5%)	5 (41.7%)	10 (11.5%)
Neurofibroma	2 (1.7%)	1 (6.3%)	0 (0.0%)	1 (1.2%)
Pathologic tumor size, cm, median (IQR)	4.0 (3.1-5.5)	3.8 (2.8-4.9)	6.0 (4.0-6.9)	4.0 (3.0-5.0)

VATS, Video-assisted thoracoscopic surgery; *IQR*, interquartile range; *ECOG*, Eastern Cooperative Oncology Group; *BP*, brachial plexus. *The level of the subclavian artery passes through the scalene hiatus was used as reference, relative to the maximum transverse section of tumor.

supraclavicular approach portended the most cephalad location of tumor and the smallest tumor sizes, and the sole supraclavicular approach had the shortest operative time, the least blood loss, the least postoperative pain, and similar surgical complication rates compared with the sole transthoracic or combination of transthoracic and

TABLE 2. Perioperative outcomes among the 3 groups (n = 115)

Perioperative outcomes	Supraclavicular approach alone (n = 16), n (%)	Supraclavicular approach plus VATS/Open thoracotomy (n = 12), n (%)	Transthoracic approach alone (n = 87), n (%)
Intraoperative/postoperative outcomes			
Operation time, min, median (IQR)	88 (61-120)	165 (121-210)	90 (65-120)
Blood loss, mL, median (IQR)	40 (20-50)	75 (50-175)	50 (30-100)
Intraoperative transfusion	0 (0.0%)	0 (0.0%)	4 (4.6%)
Postoperative pain (third postoperative day*), median (IQR)	2 (2-3)	4 (4-5)	4 (4-5)
Postoperative stay (d), median (IQR)	4 (3-4)	3 (2-4)	3 (2-4)
General thoracic surgical complications			
Atelectasis	0	1	1
Conversion to open thoracotomy	0	0	3
Chylothorax	1	0	0
Deep vein thrombosis	0	0	1
Pneumonia	1	0	2
Pleural effusion	0	1	1
Blood transfusion	0	0	5
Total	2 (12.5%)	2 (16.7%)	11 (12.6%)
Neurologic complications			
PN neuropraxia†	2 (12.5%)	2 (16.7%)	4 (4.6%)
RLN neuropraxia‡	2 (12.5%)	0 (0.0%)	4 (4.6%)
Horner's syndrome§	6 (37.5%)	6 (50.0%)	41 (47.1%)
BP injury symptoms			
No	11 (68.8%)	7 (58.3%)	56 (64.4%)
Short-term	4 (25.0%)	3 (25.0%)	4 (4.6%)
Long-term	1 (6.3%)	2 (16.7%)	27 (31.0%)

VATS, Video-assisted thoracoscopic surgery; *IQR*, interquartile range; *PN*, phrenic nerve; *RLN*, recurrent laryngeal nerve; *BP*, brachial plexus; *PR*, partial remission. *If patients were discharged within 2 days postoperatively, the score was assessed on their last inpatient day. †Patients presented with temporary hemidiaphragm elevation and recovered within 6 months after surgery. ‡All patients recovered within 6 months after surgery. §Four patients with partial ptosis had CR, of whom 3 received neurotrophic therapy and 1 received plastic surgery; in addition, 3 patients (2 with partial ptosis, 1 with facial anhidrosis) experienced PR.

supraclavicular approach; and (2) in patients who experienced neurologic complications related to BP injury, those undergoing resection using a supraclavicular approach were more likely to have symptom relief in a shorter period.

Given that intrathoracic neurogenic tumors are generally benign lesions, especially in adults,[19] a more minimally invasive approach is preferred over open thoracotomy if feasible. The optimal approach remains controversial in managing cervicothoracic-junction benign neurogenic tumors with various approaches described: VATS, open thoracotomy, transcervical, transclavicular/sternal, and supraclavicular. The transcervical approach (skin incision along the anterior border of the sternocleidomastoid) has been reported to have a higher incidence of postoperative neurologic complications.[8] Additionally, the transcervical approach may require extra osteomuscular resections to achieve improved field exposure, and the transclavicular/sternal approach may yield potentially unsatisfactory functional and cosmetic outcomes,[20,21] although some scholars do not consider the location of tumor at the cervicothoracic junction to be a contraindication to VATS.[6,8] However, Cardillo and colleagues[7] prefer an open thoracotomy, supported by data indicating that open thoracotomy has a lower incidence of BP injury.[9] Venissac and colleagues[22] also favor open thoracotomy for tumors larger than 6 cm and VATS for smaller tumors. The supraclavicular approach has been recommended because of its superior visualization.[11-13] However, previous studies were conducted based on small case series or included all intrathoracic neurogenic tumors. Additionally, the specific anatomic location of cervicothoracic-junction neurogenic tumors was ambiguous without a highlighted description because the tumor location would influence the selection of surgical approach.

In our cohort, similar to previous studies, tumor recurrence and disease-associated death rates were negligible.[5,6,19] Additionally, the complication rates were comparable among the 3 groups. The Supraclav + VATS/Open group portended the longest operative times and the most blood loss, which could be interpreted by the increased complexity of surgical procedure caused by the combinative surgical approach and the largest pathologic tumor size. Postoperative pain was

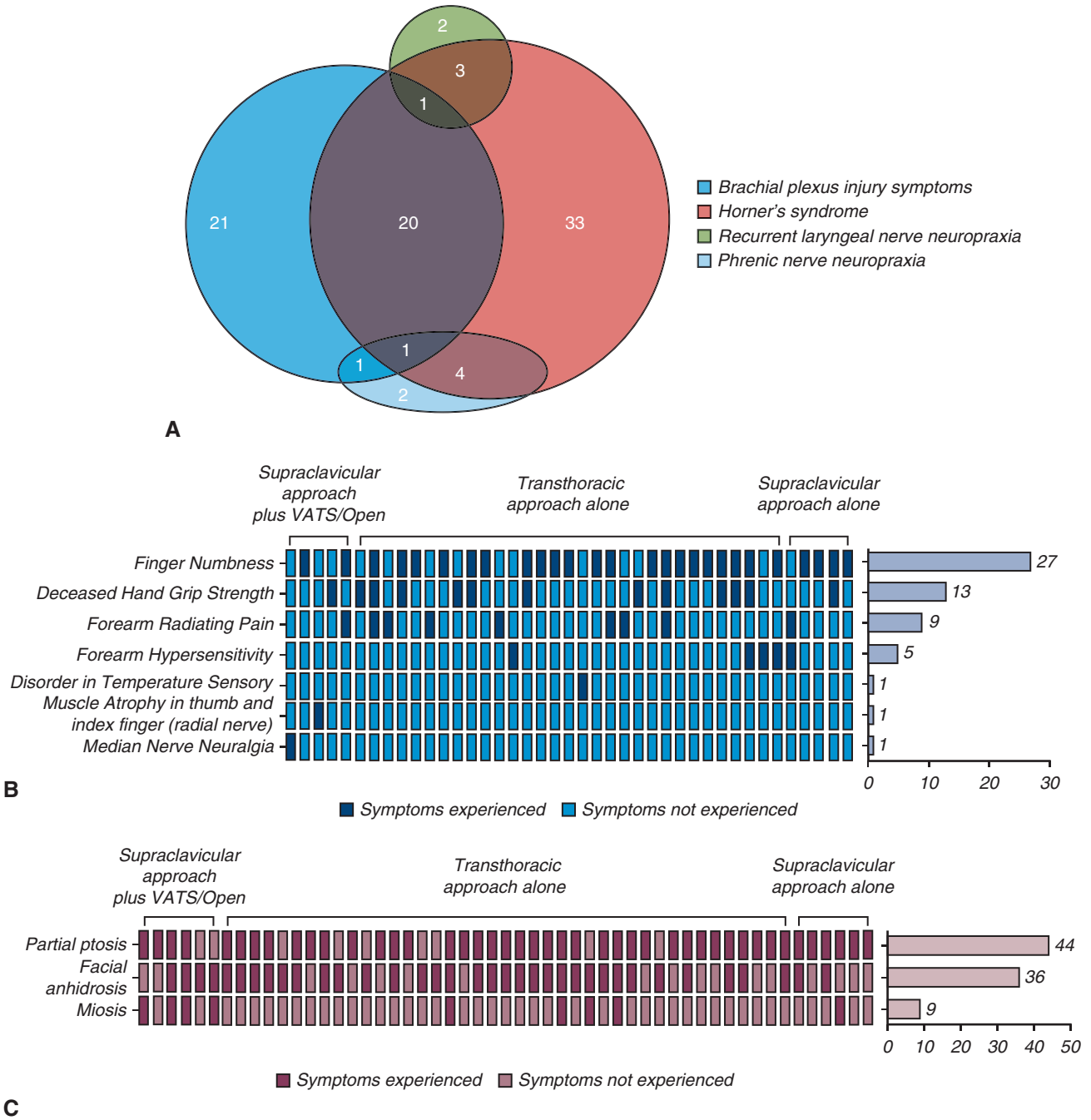


FIGURE 3. Depiction of neurologic complications: the specific numbers and the overlapping situation among different nerve neuropraxia (A), the specific symptoms and corresponding number of patients experienced BP injury (1 column represents 1 patient) (B), and the specific symptoms and corresponding number of patients experienced Horner's syndrome (1 column represents 1 patient) (C). *VATS*, Video-assisted thoracoscopic surgery.

lowest with the sole supraclavicular approach, potentially because receiving a supraclavicular incision portends milder nociception postoperatively. Notably, 1 patient with a left tumor underwent chylothorax after a sole supraclavicular approach, and the incidence of PN neuropraxia in surgery containing supraclavicular approach was higher, although the difference was insignificant (12.5% vs 16.7% vs 4.6%, $P = .252$). Those might suggest that the protection of PN and thoracic duct (left side) is necessary during the surgery using supraclavicular approach as mentioned in previous studies.[23,24]

As for the incidence of neurologic complications related to PN, RLN, and ST/SG, the PN/RLN neuropraxia complications were transient, but few patients who developed

TABLE 3. Logistic regression analysis of factors associated with long-term duration of brachial plexus injury symptoms (n = 115)

Variables	Univariable		Multivariable*		Multivariable†	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Age	1.014 (0.987-1.041)	.316	1.018 (0.986-1.051)	.273	1.014 (0.985-1.046)	.328
Gender (female)	1.414 (0.613-3.528)	.417	1.925 (0.657-5.640)	.232	1.727 (0.650-4.864)	.276
Smoking history	0.931 (0.331-2.619)	.892	0.967 (0.241-3.879)	.962	1.009 (0.268-3.672)	.989
Charlson Comorbidity Index (≥2)	0.000 (0.000 to NA)	1.000	0.000 (0.000 to NA)	1.000	0.153 (0.001-1.631)	.137
Lateral						
Right	1		1		1	
Left	0.539 (0.229-1.270)	.158	0.459 (0.173-1.215)	.117	0.522 (0.206-1.256)	.149
Max-transverse section elevation						
Upper/flush	1		1		1	
Lower	0.714 (0.298-1.711)	.450	0.622 (0.203-1.904)	.405	0.648 (0.224-1.808)	.409
Symptoms						
Asymptomatic	1		1		1	
Symptomatic	1.595 (0.624-4.077)	.329	2.262 (0.765-6.690)	.140	1.999 (0.738-5.475)	.171
Operation time	0.998 (0.989-1.007)	.724	1.005 (0.993-1.018)	.420	1.005 (0.993-1.017)	.400
Intraoperative transfusion	0.000 (0.000 to NA)	1.000	0.000 (0.000 to NA)	1.000	0.692 (0.004-19.113)	.841
Histologic subtype						
Neurilemmoma/Schwannoma	1		1		1	
Ganglioneuroma/neurofibroma	0.479 (0.129-1.778)	.271	0.607 (0.132-2.790)	.521	0.739 (0.164-2.695)	.660
Pathologic tumor size	0.836 (0.654-1.069)	.153	0.913 (0.638-1.306)	.617	0.930 (0.656-1.260)	.647
Surgical approach						
Transthoracic approach alone	1		1		1	
Supraclavicular approach alone	0.148 (0.019-1.179)	.071	0.102 (0.012-0.890)	**.039**	0.165 (0.017-0.775)	**.020**
Supraclavicular approach plus VATS/Open	0.444 (0.091-2.168)	.316	0.429 (0.052-3.535)	.432	0.501 (0.066-3.007)	.456

Boldface indicates statistical significance. *OR*, Odds ratio; *NA*, not available; *VATS*, video-assisted thoracoscopic surgery. *Logistic regression model using enter method. †Logistic regression model using Firth's bias reduction method.

Horner's syndromes experienced improvement. Those might be due to different etiologies (eg, tension during retraction resulting in temporary PN/RLN neuropraxia[10,23] vs tumor originating from the sympathetic chain resulting in Horner's syndromes) (86.8% of all cases with Horner's syndromes were of sympathetic chain origin, $P < .001$).

In our study, the incidence of postoperative BP injury complications in resections using the supraclavicular approach was similar to previous studies (35.7% vs 31.3%[13] vs 33.3%[25]). Our results revealed that patients undergoing resection using the supraclavicular approach are more likely to have symptom relief in a shorter period. From a technical point, the upper pole of cervicothoracic-junction benign neurogenic tumors may not be fully visualized with a thoracoscope approach sometimes, which may compromise the surgical flexibility and increase the risk of injury to neurovascular structures. This might be one of the reasons for postoperative neurologic sequelae.[9,26] From another perspective, during the supraclavicular procedure, the cooperation from the neurosurgeon, the use of neuromonitoring, and the achievement of better exposure all contributed to nerve protection.

In our study, we excluded tumors that exhibited an upper pole that was lower than the reference level because those tumors exist a safe distance from the cervicothoracic-junction zone, which may obviate the need for a supraclavicular approach. Among patients undergoing a resection with the supraclavicular approach, the majority had tumors with max-transverse section above or flush with the reference plane. This further indicates that the choice of surgical approach for these tumors is secondary to the tumor's characteristics and surgeons' preference. For selected patients with more cephalad location of tumor and smaller tumor size, a sole supraclavicular approach could be considered. Additionally, for tumors that exhibit an upper pole above the reference level of a large size or with max-transverse section lower than the reference level, the combination of supraclavicular and transthoracic approach could be considered because supraclavicular incision allows dissection of the upper pole of the tumor and ligation of the nutrient vessels of the tumor (if the tumor is nourished by vessels from the cervical zone).

Study Limitations

To our knowledge, our study represents the largest dataset among studies focusing on cervicothoracic-junction benign neurogenic tumors. However, this study has several limitations. First, as with any retrospective research, it is vulnerable to inherent shortcomings such as selection bias

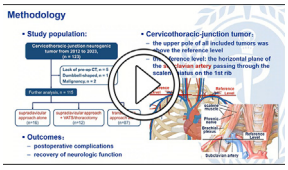
from the surgical approach chosen, which may impact the level of evidence. Second, although our study has the largest dataset of patients undergoing resection using the supraclavicular approach, the relatively small samples in the Supraclav-Alone and Supraclav + VATS/Open groups may slightly limit statistical power. Last, the conclusion was validated in a single-center database, and it remains uncertain whether the results can be generalized to populations from other regions.

CONCLUSIONS

Our study suggests that the supraclavicular approach may be a safe and feasible strategy regardless of whether it was used solely or combined with the transthoracic approach in the surgical management of cervicothoracic-junction benign neurogenic tumors. Additionally, a sole supraclavicular approach may be considered for selected patients with a more cephalad location of tumor and smaller tumor size, which contribute to shorter operative time, less blood loss, and less postoperative pain.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/the-supraclavicular-approach-i-7239.



Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

The authors thank Lin Chen (Department of Hand Surgery, Huashan Hospital, Fudan University; Key Laboratory of Hand Reconstruction; Shanghai Key Laboratory of Peripheral Nerve and Microsurgery) for her technique support during the surgery.

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Key Words: benign neurogenic tumor, cervicothoracic-junction, postoperative neurologic complication, supraclavicular approach, thoracic apex

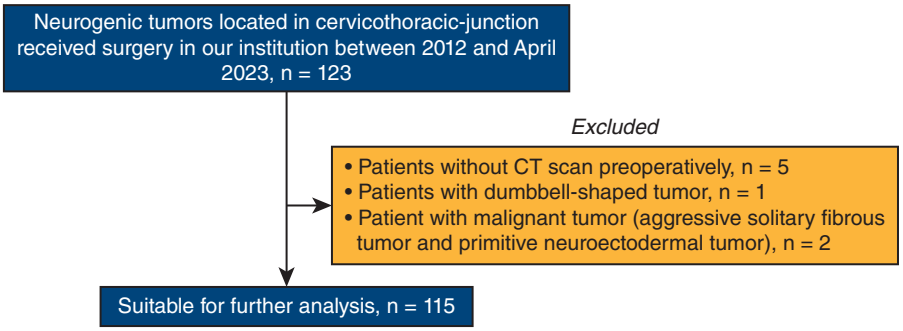

FIGURE E1. Patient flowchart. *CT*, Computed tomography.

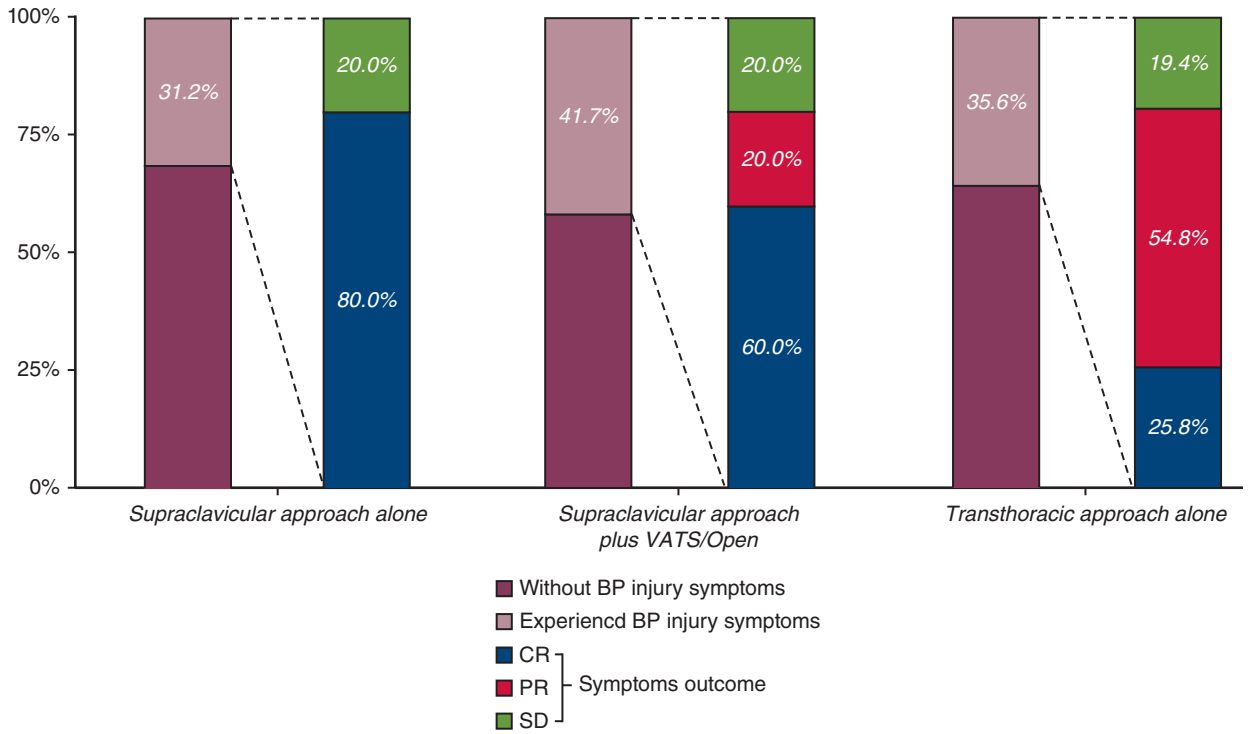

FIGURE E2. The course of patients experienced BP injury grouped by different surgical approaches. *VATS*, Video-assisted thoracoscopic surgery; *BP*, brachial plexus; *CR*, complete resolution; *PR*, partial remission; *SD*, stable disease.

TABLE E1. Preoperative symptoms of all patients grouped by supraclavicular approach

Preoperative symptoms	Supraclavicular approach alone (n = 16)	Supraclavicular approach plus VATS/Open thoracotomy (n = 12)	Transthoracic approach alone (n = 87)
Back discomfort	0	0	2
Back pain	0	1	0
Chest discomfort	0	0	4
Chest pain	1	2	0
Cough	0	0	9
Dyspnea	0	0	2
Diagnosed as neurofibromatosis for 23 y	1	0	0
Fever	0	0	1
Finger numbness	1	0	1
Horner's syndrome	0	1	5
Partial ptosis	0	1	1
Facial anhidrosis	0	0	4
Neck discomfort	0	0	1
Total	3 (18.8%)	3 (25.0%)	21 (24.1%)

VATS, Video-assisted thoracoscopic surgery.