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Original Article

Tumors of the brachial plexus region: A 15-year experience with emphasis on motor and pain outcomes and literature review

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ABSTRACT

Background: Brachial plexus region tumors are rare. In this study, we reviewed our experience with resection of tumors involving or adjacent to the brachial plexus to identify patterns in presentation and outcome.

Methods: We report a retrospective case series of brachial plexus tumors operated on by a single surgeon at a single institution over 15 years. Outcome data were recorded from the most recent follow-up office visit. Findings were compared to a prior internal series and comparable series in the literature.

Results: From 2001 to 2016, 103 consecutive brachial plexus tumors in 98 patients met inclusion criteria. Ninety percent of patients presented with a palpable mass, and 81% had deficits in sensation, motor function, or both. Mean follow-up time was 10 months. Serious complications were infrequent. For patients with a preoperative motor deficit, the rate of postoperative motor decline was 10%. For patients without a preoperative motor deficit, the rate of postoperative motor decline was 35%, which decreased to 27% at 6 months. There were no differences in motor outcome based on extent of resection, tumor pathology, or age.

Conclusion: We present one of the largest recent series of tumors of the brachial plexus region. Although the rate of worsened postoperative motor function was higher in those without preoperative weakness, the motor deficit improves over time and is no worse than antigravity strength in the majority of cases. Our findings help guide patient counseling in regard to postoperative motor function.

Keywords: Brachial plexus, Nerve sheath tumor, Neurofibroma, Outcome, Schwannoma, Tumor

INTRODUCTION

Tumors of the brachial plexus region are uncommon, making up no more than 5% of all tumors of the upper extremity and hand.[10] These lesions may arise from nerve tissue itself as benign nerve sheath tumors (BNSTs), of which schwannoma and neurofibroma are most common.[9,18] Each tumor type may be associated with genetic syndromes such as neurofibromatosis type 1 (NF1) or schwannomatosis, especially in the case of multiple lesions. Some tumors arising from the nerve sheath may be malignant, termed malignant peripheral nerve sheath tumors

(MPNSTs), especially in the setting of NF1. MPNSTs are rare with an incidence of 0.001% and a mean survival of 3.7 years.[4,9] In addition, tumors may arise from tissues surrounding the brachial plexus and have benign or malignant features. Examples of non-neural brachial plexus tumors include desmoid tumor, lipoma, hemangioma, and osteosarcoma.[8,17] Metastatic tumors affect the brachial plexus region and most commonly originate from the lung or breast. A focused history and physical examination are required for diagnosis, and magnetic resonance imaging (MRI) remains the diagnostic modality of choice to delineate anatomic relationships between the tumor and surrounding structures.[7] Surgical treatment is the mainstay for symptomatic, rapidly enlarging lesions and those thought to be malignant. Adjuvant therapies, such as chemotherapy and radiation, are administered on an individualized basis depending on extent of resection, pathology, and recurrence.

Due to the relative rarity of these tumors, we set out to further characterize patterns ranging from clinical presentation to postoperative findings to improve the care of patients with these lesions and to provide prognostic information. Most of the larger series of brachial plexus tumors are from several decades ago,[5,12] and some more recent series focus exclusively on primary brachial plexus tumors[3,10] or include few patients.[11,16] We report a single surgeon experience over an extended period of time that includes all tumors of the brachial plexus, including those in the surrounding region. We compare our findings to a prior report[9] from the same institution over a 10-year period preceding the current study as well as other relevant series in the literature. We focus on patterns of presentation, treatment, and outcome, with an emphasis on postoperative motor function and pain outcomes.

MATERIALS AND METHODS

Study design

In this retrospective case series, we reviewed the medical records of patients undergoing surgery for tumors of the brachial plexus region by a single senior neurosurgeon at an academic institution. Subjects were identified from the surgeon's operative case log. Patients of all ages were included, although the surgeon's practice is primarily adult-based. In addition to tumors originating from nerves and their coverings, tumors or metastatic lesions of the surrounding region that impinged on the brachial plexus were included in the study. The tumor itself was considered the unit for analysis. Thus, patients with tumors in more than one location within the brachial plexus that was operated on at different time points were included separately in the analysis. Tumors previously resected at outside hospitals were excluded from the analysis. Patients studied in a prior institutional study of brachial plexus tumors were excluded from the current investigation.[9] The study was approved by the Institutional Review Board and a waiver of consent was obtained. We also include two representative cases.

Data extraction

Office notes, radiological images, and pathology reports were reviewed. Data extracted from the medical record included demographics and presenting symptoms, including pain, weakness, and sensory change. Data on surgical approach were collected. In general, an anterior supraclavicular approach was taken for tumors involving the spinal nerves and trunks, whereas an anterior infraclavicular approach was taken for tumors involving the cords and distal plexus elements. Combined approaches and axillary approaches were used in select cases. Neuromonitoring was used intraoperatively. Final tumor pathology was recorded in all cases. For postoperative data, patients were required to have a minimum of 1-month follow-up, which typically was in the form of a formal postoperative visit. Separate analyses were performed for patients with more than 6 months of follow-up. Data from the time of most recent follow-up were collected and included changes in preoperative symptoms, motor strength, and sensation. Pain was numerically rated pre and postoperatively on a visual analog scale ranging from 0 (no pain) to 10 (worst pain possible). Postoperative pain at most recent follow-up was categorized as worse, improved, or unchanged based on the difference between pre- and postoperative pain ratings or lack thereof. Improved or worsened motor strength was considered as a one-point change in manual muscle testing based on the Medical Research Council (MRC) Scale for muscle strength for tested muscles. Gross total resection (GTR) was defined as resection of 95% or more of the mass as determined by the radiology report. Recurrences were defined as patients with tumor growth on postoperative MRI such that additional surgery or treatment was performed.

Statistical analysis

Descriptive statistics were used to summarize baseline characteristics. Subgroup analysis was performed to determine the relationship between motor outcome versus follow-up time (1 month vs. greater than months), pathology (benign vs. malignant/non-neural nerve sheath tumors), extent of resection (subtotal vs. gross total), and age (greater than or less than the median age of all subjects). Chi-square was used to compare categorical variables, and Fisher's exact test was used for sample sizes of five or fewer within a category. Univariate and multivariate regression were performed to assess the relationship between several variables and improved postoperative motor outcomes. The threshold for statistical significance was set at $P < 0.05$. Statistical tests were performed using Stata 11 software (College Station, Texas).

RESULTS

Patient and tumor characteristics

From 2001 to 2016, 120 patients with brachial plexus tumors were identified that underwent surgery by the senior neurosurgeon at a single institution. Among these patients, 22 were excluded due to incomplete or unavailable medical records, leaving 98 patients for analysis. Four patients had more than one surgery due to the presence of two or more separate brachial plexus tumors. Three had NF1 (each with two tumors) and one had schwannomatosis (with three tumors). Thus, 98 patients with 103 tumors were included in the analysis. Other patients had additional tumors, but the additional tumors were operated on at different hospitals and therefore were not included in the analysis. Patient demographics and presenting symptoms are detailed in Table 1. Sensory deficit or paresthesia was a common presenting symptom and present in 42 patients (40%). Of note, although nine patients (8%) presented with motor weakness as a complaint, 39 patients (38%) were found to have a motor deficit based on physical examination. Six patients (6%) presented with dyspnea. A palpable mass was noted in all but ten patients (10%). Maximum tumor size refers to the largest single dimension of the tumor. Six patients (6%) had a maximum tumor size of >10 cm. Although not a routine part of the preoperative workup, 18 patients (17%) had preoperative electromyograms, most commonly to evaluate a prior neurological deficit. Tumors were most commonly located in the supraclavicular space (56%) followed by the infraclavicular space (40%). Tumors extended from the supra- to the infraclavicular space in 1% of cases. Tumors with an infraclavicular location included tumors located in the axilla and those that extended into the proximal upper extremity. Tumors were located in the mediastinum in 3% of cases.

Table 1: Baseline characteristics.

Variable	Value
Age (years)	
Mean±Std	47±18
Median±IQR	49±26
Range	3–85
Gender	
Male, *n* (%)	51 (50)
Female, *n* (%)	52 (50)
Pain at presentation	
Local	28 (27%)
Distant	8 (8%)
Local and distant	52 (50%)
No pain	15 (15%)
Sensory or motor symptoms at presentation	
Motor deficit	9 (8%)
Sensory deficit/paresthesias	42 (40%)
Both	32 (31%)
Neither	20 (19%)
Palpable mass	
Present	93 (90%)
Absent	10 (10%)
Symptom duration (years)	
Mean±Std	2.7±2.8
Median	1.5
Range	0.2–11
Genetic syndrome	
Neurofibromatosis-1	18 (17%)
Schwannomatosis	10 (10%)
None	75 (73%)
Tumor size (cm)	
Maximum tumor dimension	20
Mean maximum tumor dimension±Std	4.6±3
Preoperative biopsy	
Obtained	14 (14%)

103 tumors were studied in 98 patients (excluding same tumor recurrences). IQR: Interquartile range. Denominators refer to tumor count (not patient count). n: number. Std: Standard deviation. Local pain refers to localized pain in close proximity to a tumor, while distant refers to pain distal to tumor location

Intraoperative and pathological findings

The most common surgical approach was supraclavicular [Figure 1]. In two separate cases (one schwannoma and one hemangioma), the supraclavicular approach was combined with a posterior cervical approach for resection of a portion of tumor that extended through the neural foramen into the spinal canal. The infraclavicular approach included cases in which the operative field was lengthened for resection of lesions extending into the proximal upper extremity. The supraclavicular and infraclavicular approaches were combined for tumors that involved the supraclavicular and infraclavicular portions of the brachial plexus. The clavicle was retracted instead of being divided when exposure of the divisions of the brachial plexus was required. Nerve sheath tumors made up over 65% of the tumor types [Figure 2]. Metastatic tumors to the brachial plexus included thyroid, breast ($n = 3$), diffuse B-cell lymphoma, follicular lymphoma, and Hodgkin's lymphoma.

Outcome data

Data regarding outcome variables are listed in Table 2. Among patients for which follow-up data was available regarding motor function ($n = 89$), overall postoperative motor function was worse in 22 patients (25%), unchanged in 50 patients (56%), and improved in 17 patients (19%) [Figure 3]. Among 50 patients with no preoperative weakness, motor strength was worse in 18 patients (35%) and unchanged or improved in 32 patients (65%). Among 39 patients with preoperative deficit, motor strength was worse in 4 patients (10%), unchanged in 18 patients (46%), and improved in

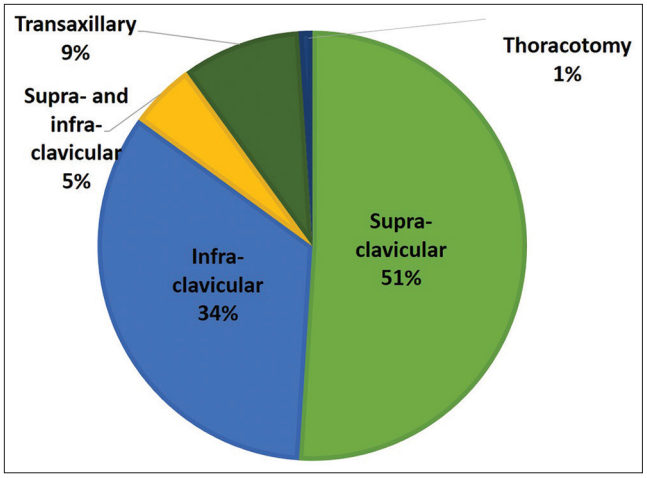

Figure 1: Surgical approach.

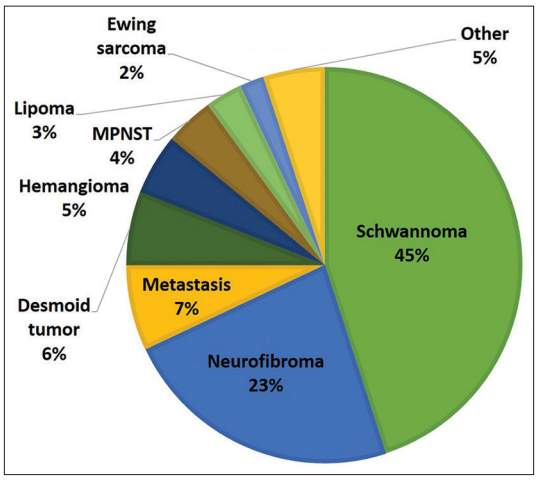

Figure 2: Tumor types. "Other" tumor types refer to atypical teratoid rhabdoid tumor, chordoma, osteogenic sarcoma, and inflammatory fibrous nodule. MPNST: Malignant peripheral nerve sheath tumor.

17 patients (43%) [Figure 3]. Among the 18 patients (36%) without preoperative motor deficits who worsened in strength postoperatively, the postoperative strength was 4/5 (MRC) in nine patients (50%). When these patients were followed for >6 months, the rate of any postoperative motor decline was 27%. Among patients with follow-up data regarding pain (n = 85), 13 patients had no pain at presentation and two of these patients (2%) had worsened pain at follow-up after the surgery. Among patients with pain at presentation (n = 72), after surgery, 48 patients (66%) had improvement or resolution of pain, 11 patients (16%) had unchanged pain, and 13 patients (18%) had worsening of pain.

For tumors with follow-up information, 16 patients underwent postoperative radiation for MPNST (n = 5), desmoid tumor (n = 5), metastasis (n = 2), lymphoma (n = 1), atypical teratoid rhabdoid tumor (n = 1), Ewing sarcoma (n = 1), and

Table 2: Outcomes.

Variable	Value
Follow-up (months)	
Mean±Std	10±20
Median±IQR	2±9
Range	1–127
Pain at postoperative follow-up (n=85)	
Worse	13 (15%)
Unchanged	11 (13%)
Improved	33 (39%)
Absent	28 (33%)
Postoperative motor function (n=89)	
Worse	22 (25%)
Unchanged	50 (56%)
Improved	17 (19%)
Resection (n=89)	
GTR	68 (76%)
STR	21 (24%)
Postoperative radiation	
Yes	16 (17%)
No	79 (83%)
Tumor recurrence	
Yes	6 (6%)
No	89 (94%)

Only patients with sufficient follow-up data are included (95 tumors in 90 patients). When listed in parentheses following a variable, "n" denotes the number of tumors included when different from 95. GTR: Gross total resection, IQR: Interquartile range, Std: Standard deviation, STR: Subtotal resection

osteogenic sarcoma (n = 1). Fourteen patients within the most recent follow-up period had postoperative imaging consistent with tumor recurrence, and pathologies included NF (n = 8), schwannoma (n = 3), chordoma (n = 1), desmoid tumor (n = 1), and MPNST (n = 1). Six of these patients required additional treatment, such as repeat surgery or radiation therapy and the remaining patients did not undergo adjuvant therapy at time of most recent follow-up. Surgical complications included phrenic nerve paralysis (n = 1), vessel damage (n = 1) not requiring additional surgical intervention, and hematoma requiring return to the operating room for evacuation (n = 1).

In a subgroup analysis, there was no difference in rates of postoperative motor decline among patients with benign or malignant tumors (Fisher exact statistic = 1) [Table 3]. Furthermore, there were no differences noted in postoperative motor function based on gross total versus subtotal resection (STR) (Chi-squared statistic = 0.95, P = 0.33) or age above or below the median age (Chi-square statistic = 0.24, P = 0.62). On univariate analysis, preoperative motor symptoms and preoperative MRC scale <5 were associated with improved motor function outcome. In a multivariate regression model, preoperative MRC scale <5 was associated with improved postoperative motor function (P = 0.02), whereas tumor type (nerve sheath vs. non-nerve sheath tumor; benign vs.

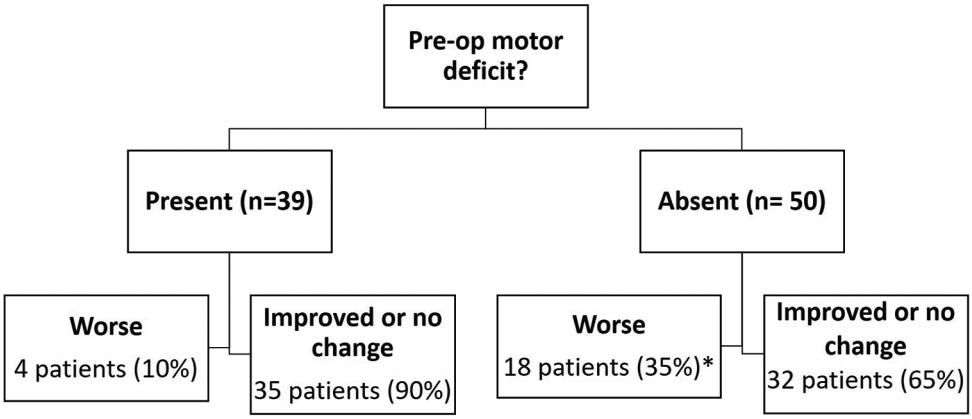

Figure 3: Postoperative motor outcome (third row) based on presence or absence of preoperative motor deficits. In the second row, "*n*" refers to number of tumors. *Among patients without preoperative motor deficit, the rate of motor decline decreased to 27% by 6 months after surgery.

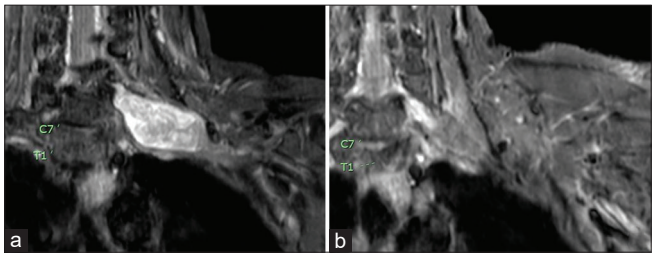

Figure 4: Preoperative magnetic resonance imaging (MRI) showing an enhancing 5-cm mass at the levels of C6-T1 with proximal extension toward the C7 foramen (a). Postoperative MRI 3 months after surgery shows near total resection of the lesion (b).

Table 3: Subgroup analyses.

	Postoperative motor score	
	Worsened	**Stable or improved**
Tumor type		
Benign	19	54
Malignant	3	11
Extent of resection		
GTR	15	51
STR	7	14
Age		
≥49	12	32
<49	10	34

GTR: Gross total resection, STR: Subtotal resection

malignant), extent of resection, genetic syndrome, gender, and age did not reach statistical significance.

Representative cases

Case 1

A 60-year-old female presented with an enlarging lump over the left clavicle associated with progressively worsening pain radiating to the back of the left hand. On examination, a Tinel's sign was present over a palpable supraclavicular mass. MRI of the brachial plexus with contrast showed a 5-cm enhancing mass within the left brachial plexus [Figure 4a]. A supraclavicular approach was performed for resection. The mass was noted to arise from middle trunk with proximal extension to the C7 foramen. Maximal safe debulking was performed. The poles of the tumor were isolated, and direct electrical stimulation did not elicit any motor activity. The inferior pole was sectioned, and remaining tumor superiorly was coagulated and cut as proximal as possible within the exposure. No cerebrospinal fluid leak was encountered. Remaining capsule was not aggressively dissected. Pathology was consistent with schwannoma. Postoperative MRI showed near total resection of the lesion [Figure 4b]. Following surgery, the patient's preoperative arm pain resolved. Her strength remained full. Postoperative MRI 3 months after surgery showed significant interval resection with small residual extending medially into the left C7 neural foramen.

Case 2

A 70-year-old female presented with progressively worsening right upper extremity paresthesias and a severe band-like sensation around the right thumb. She had normal sensory and motor function on examination. MRI of the brachial plexus showed a 6-cm lesion compressing the lateral cord of the brachial plexus [Figure 5]. An infraclavicular approach with an incision in the deltopectoral groove was performed for resection. Neuromonitoring was used to identify a region of the capsule that was free of neural elements. The capsule was opened sharply, and the tumor was debulked. At the end of the tumor resection, the brachial plexus was in normal orientation and free of compression. Pathology was consistent with lipoma. At 10-month follow-up, the patient reported resolution of her preoperative symptoms.

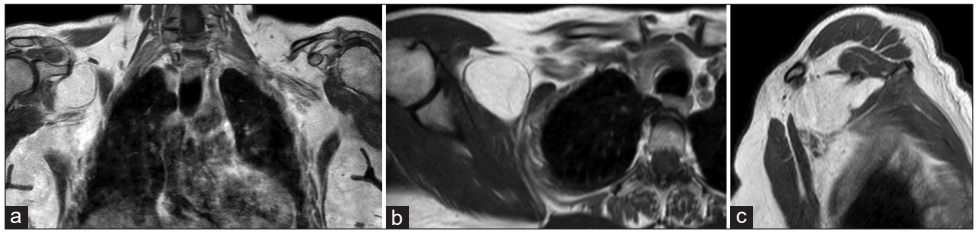

Figure 5: Preoperative magnetic resonance imaging showing a 6-cm non-enhancing lobulated mass in the right infraclavicular/axillary region. On coronal (a), axial (b), and sagittal (c) T1-weighted sequences, the mass is hyperintense; it has low signal on fat-suppressed T2-weighted images.

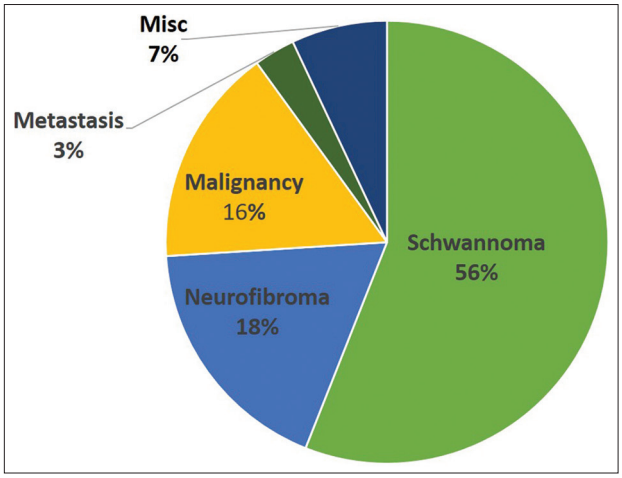

Figure 6: Tumor types in the literature, as listed in Table 3. Ganju, Binder, Jia, and Go *et al.*[1,5,6,10,] did not include patients with metastases at presentation. Desai *et al.*[3] was excluded, as the study only evaluated benign nerve sheath tumors.

DISCUSSION

We present one of the largest recent series of brachial plexus region tumors by a single surgeon at a single academic institution. Our report is unique in that it is an extension of a prior study[9] published in 2004 by the same surgical team documenting a prior case series of brachial plexus tumors one decade before the start of the current series. Whereas many series examine peripheral nerve tumors in general[13,14] or a variety of non-oncologic lesions of the brachial plexus,[12] we focus specifically on tumors of the brachial plexus itself and non-neural tumors in the region adjacent to the brachial plexus with the objective of identifying patterns of presentation and outcome that may aid in prognosis and management. We compare our findings with those of similar studies in the literature over time [Table 4].

Overall, the distribution of preoperative patient and tumor characteristics in our study is similar to other case series. Most patients undergoing surgery were middle aged, and there was no clear gender predilection. A palpable mass was the most common presenting symptom, which occurred in 90% or more of patients in selected series.[3,6,10,11] Pain was the next most common presentation; it was noted in all patients in one series in which pain at presentation included tenderness to palpation.[3] Whereas 8% of patients complained of weakness, a motor deficit was detected on clinical examination in 40% of patients. This rate is more consistent with rates of 12–62% for motor weakness in similar studies [Table 4]. These findings suggest that patients more commonly report a palpable and sometimes painful mass but may less frequently appreciate a motor deficit, which should be screened for by the clinician on neurological examination. The number of patients with NF-1 in our series (17%) was midway in the range of reported values (9–32%) for other series of brachial plexus tumors [Table 4]. Surgical approach reflected the distribution of tumor [Figure 1]. The majority of tumors (78%) were benign NSTs. This finding is similar to other comparable studies in the literature [Figure 6]. Unlike our prior series in which benign NSTs were comprised of 55% neurofibromas and 45% schwannomas, the current series had a predominance of schwannomas (66%) over neurofibromas (35%).[9] Schwannomas were the more common benign NST in multiple series.[1,3,5,6,10,18] The rate of schwannoma was reported to be higher in the more recent series of brachial plexus tumors operated on at Louisiana State University Health Sciences Center from 1986-1998 (32%) compared to their earlier experience from 1969-1986 (14%).[2,5,15] Rates of primary malignancy, metastases, and other non-neural lesions of the brachial plexus region were variable. Our rates of malignancy (6%) were similar to Jia *et al.*,[10] but they were lower than those previously reported by our group (18%) and other case series.[5,9,18]

A special emphasis was placed on motor and pain outcomes in this case series. For patients with a pre-existing preoperative motor deficit, the rate of the motor deficit worsening postoperatively was low (10%). The regression results showing that the presence of a preoperative motor deficit was associated with improved postoperative motor function suggest that motor deficits, possibly related to neural compression, are likely to improve after surgery for tumor removal. For those without a pre-existing motor deficit, the chance of motor function worsening was higher (35%). This rate of decline is likely attributed to the

Table 4: Comparison of selected brachial plexus region tumor case series listed in chronological order.

Authors	Yr	N	Age (mean, range, years); Gender	NF-1 stat-us	Pathology (Sch, NF, met, malig, misc)	Sensory change	Motor deficit	Pain	Palpable mass	Postoperative pain or sensory change (improved or unchanged)	Postoperative motor function (improved or unchanged)	FU (mo.)	GTR
Ganju *et al.*, 2001[5]	1986–1998	111	39 (6–70); 51% F, 49% M	23%	62% benign NST (52% Sch, 48% NF), 26% malig, 0% mets, 12% misc	22%	60%	59%	52%	78% Sch (among those with preoperative pain) 91% NF (among those with preoperative pain)	44% NF (among those with preoperative weakness) 69% Sch (among those with weakness preoperative)	38 (benign NSTs)	69%
Huang *et al.*, 2003[9]	1990–2001	42	43, 16–71; NA	14%	46% benign NST (45% Sch, 55% NF), 18% malig, 20% mets, 16% misc	61%	52%	70%	30%	87% Sch 82% NF 59% malig and met	78% Sch 73% NF 35% malig	NA	NA
Binder *et al.*, 2004[1]	1992–2003	25	47 (19–71); 25% F. 75% M	32%	80% benign NST (75% Sch, 25% NF), 16% malig, 0% mets, 4% misc	44%	12%	60%	60%	NA	NA	NA	64%
Desai *et al.*, 2012[3]	2000–2009	115	48 (39–60); 68% F, 32% M	9%	100% benign NST (61% Sch, 39% NF)	100%	12%	100%	93%	5%	96%	30	64%
Siqueira *et al.*, 2009[18]	2001–2006	18	31 (9–60); 61% F, 39% M	11 %	44% benign NST (88% Sch and 12% NF, 28% malig, 11% met, 17% misc	54%	33%	67%	83%	100% pain, 72% sensory	83%	17	78%
Jia *et al.*, 2016[10]	2001–2012	143	48 (19–76); 45% F 55% M	NA	92% benign NST (91% Sch, 9% NF), 8% malig	48%	8%	36%	90%	NA	NA	>1 yr	90%
Go *et al.*, 2012[6]	2002–2011	23	39 (16–66); 50% F, 50% M	14%	90% benign NST (75% Sch, 20% NF), 9% malig, 5% misc	55%	41%	23%	77–95%	91%	83%	14	73%

(Contd...)

Table 4: *(Continued)*.

Authors	Yr	N	Age (mean, range, years); Gender	NF-1 stat-us	Pathology (Sch, NF, met, malig, misc)	Sensory change	Motor deficit	Pain	Palpable mass	Postoperative pain or sensory change (improved or unchanged)	Postoperative motor function (improved or unchanged)	FU (mo.)	GTR
Jung *et al*., 2018[11]	2010–2017	18	51 (24–80); 56% F, 44% M	NA	83% benign NST (73% Sch, 27% NF), 6% malig, 6% met, 5% misc	44%	22%	56%	94%	100%	94%	20	89%
Current series	2001–2016	103	47 (3–85), 50% F, 50% M	17%	68% benign NST (66% Sch, 34%), 6% malig, 7% met, 19% misc	71%	40%	85%	90%	82%	75%	10	76%

Benign NST: Benign nerve sheath tumor, F: Female, FU: Follow-up, GTR: Gross total resection, M: Male, malig: Primary malignancy, met: Metastasis, misc: Miscellaneous, mo.: Month, N: Number of tumors under study, NA: Not available, NF: Neurofibroma, NF-1: Neurofibromatosis type 1, Sch: Schwannoma. Primary malignancy includes MPNST, chondrosarcoma, Ewing's sarcoma, and chordoma. Sensory change refers to sensory deficit, paresthesias, or numbness. Y: years, which refers to dates of patient enrollment

conservative definition of weakness used for the study, which was a one-point decrease in MRC scale for muscle strength. For instance, among the 35% of patients with a decline in strength, half of the patients had 4/5 strength in the weakest muscle tested. Furthermore, among patients without a preoperative motor deficit, the rate of postoperative motor decline decreased from 35% to 27% when the patients were followed for longer than 6 months. This finding supports a gradual improvement in motor function that is likely to occur over time and is consistent with clinical experience. These factors likely account for the lack of a difference in motor outcomes between patients with benign versus malignant brachial plexus tumors. Other groups have shown the rates of postoperative decline to be lower among patients with non-malignant tumors. For example, in our earlier series, the rates of motor decline for schwannoma, neurofibroma, and MPNST resection were 22%, 27%, and 64%, respectively.[9] Overall, our rate of postoperative motor decline (25%) is similar to other series and lower than others [Table 4]. The postoperative rate of worsened pain was roughly equivalent regardless of the presence or absence of pain at presentation and was 18% in our series. These findings were transient in the majority of cases. These findings are similar to the rates of postoperative pain found in other cases series [Table 4]. Ideally, patients should be followed for several years postoperatively, since motor and pain changes improve over time with slow regeneration of nerves; however, it is our experience that asymptomatic patients or those doing well clinically less commonly agree to return for follow-up.

In addition to motor score, pain, and sensory function, several additional outcomes were examined. Serious complications were infrequent in our series and in related studies. We experienced vascular injury at a low rate comparable to Binder *et al*. in which one subclavian artery injury occurred during tumor mobilization in a series of 25 primary brachial plexus tumor cases.[1] Similarly, Ganju *et al*. report two additional cases of vascular injury.[5] Complications such as phrenic nerve injury are infrequent, generally asymptomatic, and usually transient. The 72% rate of GTR in our series is similar to the rate reported in the literature, which ranges from 64% to 90% and is dependent on the tumor pathologies included, with case series of predominantly BNSTs associated with higher rates of GTR. In our series, motor outcomes were no different among patients undergoing GTR or STR. It is possible that GTR may result in more manipulation of the nerve or intentional sacrifice of functioning fascicles in the case of malignancy. An additional consideration is that tumor capsule or pseudocapsule may be intentionally left behind after resection of a nerve sheath tumor. This remnant capsule plus scar tissue may be interpreted as residual or recurrent tumor on postoperative studies. For this reason, we only

included in our definition of recurrence those tumors that showed radiographic growth for which the patient underwent subsequent treatment. Motor outcome was also no different between patients above or below the median age of all subjects, suggesting that age may not be a major factor in predicting motor outcome after brachial plexus region tumor resection. Jung *et al*. assessed age in relation to tumor size, finding that larger tumors tended to occur in younger patients, but they did not evaluate motor outcomes.[11]

This study has several limitations. First, the study is retrospective in nature and follow-up is limited. For instance, some patients with MPNSTs are listed as not having recurred or received adjuvant therapy, which is due to lack of long-term follow-up for all patients. Due to the high number of patients included over a 15-year period, additional prospective follow-up was not feasible. Furthermore, survival analysis was not included for this reason. Whereas we included all tumors of the brachial plexus region to be as inclusive as possible and to increase the number of tumors included for analysis, the broad inclusion criteria may also be viewed as a limitation in that several outcome measures represent pooled findings for various tumor pathologies. Whenever the number of cases permitted, subgroup analyses were performed. Similar to other case series, our study focused on motor, pain, and sensory outcomes in relation to preoperative status; future studies will include patient-reported quality of life measures as well.

CONCLUSION

We describe a series of 103 brachial plexus region tumors operated on by a single surgeon at a single institution over a 15-year period with a special emphasis on motor and pain outcomes and a comparison with similar series over time. Comparable overall trends were noted between case series over time, with a palpable mass and associated tenderness being the most common presentation. Schwannoma was the most common tumor pathology in our study. For prognostic purposes, motor strength was unlikely to change following surgery. Those without preoperative motor deficits had a higher chance of a decline in motor strength after surgery, although this rate decreased over time. Conversely, the presence of a preoperative motor deficit was predictive of motor improvement after surgery.

Declaration of patient consent

The Institutional Review Board (IRB) permission obtained for the study.

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Conflicts of interest

There are no conflicts of interest.

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