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Surgical strategies for radical resections in subaxial cervical spine tumors

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ABSTRACT

Background: Radical resection of subaxial cervical spine tumors is challenging. This study evaluates outcomes following these extensive procedures.
Methods: We retrospectively reviewed 24 patients (mean age 38.8 yrs) treated (2002–2022) for subaxial cervical tumors (8 benign, 10 primary malignant, 6 metastatic). Procedures included total en bloc spondylectomy (TES, n = 9), total piecemeal spondylectomy (TPS, n = 6), and en bloc tumor resection (ETR, n = 9). Outcomes assessed included radiographic fusion, functional status (Visual Analog Scale [VAS]/Neck Disability Index [NDI]), complications, local recurrence, and survival. Paired t-tests and Kaplan-Meier/log-rank tests were used for statistical analysis.
Results: Mean follow-up was 62 months. Benign tumor patients (ETR) experienced no recurrences or major complications and showed significant VAS/NDI improvement ($p < 0.05$). Primary malignant tumor patients (TES/TPS/ETR) had no local recurrence but suffered higher mortality (6/10 deaths; 4 disease-related) and complications (vertebral artery injury, cerebrospinal fluid leak, nerve injury), along with significant VAS/NDI improvement ($p < 0.05$). Metastatic tumor patients (TES/TPS) had no local recurrence or intraoperative complications; 50 % of these patients died from systemic disease. Significant VAS/NDI improvement was also achieved ($p < 0.05$). Radiographic fusion was confirmed in all the patients where bone grafts were applied (n = 21). Overall survival differed significantly by tumor type ($p = 0.0395$), with a significant trend across groups ($p = 0.0340$).
Conclusion: Radical resection for selected subaxial cervical tumors achieved high fusion rates, significant functional improvement, and excellent local tumor control. However, inherent risks of severe complications exist, particularly with malignant tumors. Survival varied significantly by histology. Current data preclude definitive conclusions on the comparative oncological efficacy of en bloc versus piecemeal techniques.

1. Introduction

Radical resection of an entire vertebra (spondylectomy) or en bloc resection of a tumor within the subaxial cervical spine are typically reserved for primary bone tumors and neurogenic extramedullary tumors, and less commonly for solitary metastases (Cohen et al., 2002; Rhines et al., 2005; Bailey et al., 2006; Wang et al., 2012; Boriani et al., 2006; Luzzati et al., 2021). Both benign and malignant primary bone tumors are rare in this region, whereas metastases predominate, similar to other spinal regions (Luzzati et al., 2021). Compared with the thoracolumbar region, operative treatment in the cervical spine is influenced by the presence of the vertebral arteries (VAs), which can sometimes be preserved but may as well require sacrifice to achieve oncological radicality. Total en bloc spondylectomy (TES) involving a subaxial cervical vertebra has been described in only two case reports (Stulik et al., 2015; Currier et al., 2007). Reports of total piecemeal spondylectomy (TPS) in the subaxial cervical spine are also rare (Molina et al., 2014) whereas reports of en bloc tumor resection (ETR), often multilevel, are numerous (Rhines et al., 2005; Bailey et al., 2006; Guppy et al., 2013; Cloyd et al., 2009; Xiao et al., 2016). Extensive surgical interventions in the cervical spine are associated with a higher rate of severe complications, including paralysis and death (Luzzati et al., 2021). Intralesional or partial resection compromises oncological radicality and typically leads to worse outcomes.

The aim of the present study was to evaluate the radiological and functional outcomes of patients following extensive resections of the

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subaxial cervical spine and to assess the efficacy of en bloc resections in this context.

2. Material and methods

From 2002 to 2022, a total of 39 consecutive patients underwent radical resection of cervical spine tumors at our institution. This included complete vertebral resections or en bloc resections of primary tumors and solitary metastases in the cervical spine region. After excluding tumors involving the upper cervical spine, the final study group comprised 24 patients with involvement of the subaxial cervical spine (C3-C7). The mean age of these patients was 38.8 years (range, 9–74).

There were 10 primary malignant tumors, 6 patients with metastatic disease and 8 patients with benign primary tumors of the subaxial cervical spine. Among these, there were two neurogenic tissue tumors: one meningioma (classified as benign) and one malignant schwannoma. The distribution of tumor types is presented in Table 1.

Primary tumors were assessed according to the Enneking (1986) and Wenstein-Boriani-Biagini (Boriani et al., 1997) (Figs. 1 and 2). For metastatic involvement of the vertebrae, we also used the Bilsky et al. Epidural Spinal Cord Compression (ESCC) scale (Bilsky et al., 2010) (Fig. 3), which helped guide the selection of the surgical approach. For both TPS and TES, surgery commenced with a posterior approach to stabilize the cervical spine, with the extent determined by the location of the pathology, planned extent of resection and bone quality. A representative case of Ewing's sarcoma (EWSA) is presented (Figs. 4–7). Subsequently, resection was completed via an anterior approach, followed by insertion of an interbody cage and placement of a bridging plate. Bone grafting was performed in 21 patients. Specifically, autografts from the iliac crest were used in 9 cases, while banked allografts were used in another 9 cases. In three patients, a combination of autograft and allograft was utilized. All patients were discussed at Tumor Board of our institution.

For en bloc tumor resection (ETR), the surgical approach was determined by the tumor's anatomical location, as classified by the Weinstein-Boriani-Biagini (WBB) classification system. The vertebral artery was preserved in 22 cases, while in 2 cases, it was sacrificed to achieve oncologically compete resection. Postoperatively, patients were immobilized with either a Philadelphia collar or a custom-fabricated rigid cervical orthosis for a minimum of 3 months. All surviving patients diagnosed with primary bone tumors or metastatic lesions were referred to the oncology department for adjuvant therapy tailored to their histopathological findings. Patients with benign tumors underwent stringent monitoring through a structured follow-up protocol in our outpatient department.

Patients attended follow-up appointments in the outpatient department at 6 and 12 weeks, 6 and 12 months, and subsequently at intervals of 6 months (for malignant tumors and metastases) or annually (for benign tumors). Immediate postoperative X-ray and CT scans were routinely performed to check the adequacy of resection, alignment, and instrumentation position. Repeat imaging was performed at approximately 4 months and one year postoperatively, and then as needed (Figs. 8 and 9).

Table 1
Surgical characteristics.

No.	Sex	Age	Level	Histology	Enneking	WBB (Bilsky)	Fusion level	Total time (min)	Total blood loss (mL)	Complications	Resection
Primary tumors											
1	M	56	C4	Plasmocytoma	II B	A-D/9-4	C0-C6	250.0	4500.0	None	TPS
3	M	24	C2-C3	Chordoma	II B	A-D/2-10	C0-C6	855.0	13500.0	Profuse bleeding	TES
4	F	16	C3	EWSA	II B	A-D/12-10	C2-C4	290.0	950.0	None	TES
5	M	9	C3	EWSA	II B	A-D/2-11	C2-C4	440.0	1050.0	None	TES
6	M	32	C7	OSA	II B	A-D/1-11	C4-T3	390.0	2800.0	None	TPS
13	F	13	C7-T1	Malign schwannoma	II B	A,E/3-7	C6-T2	180.0	300.0	None	ETR
14	M	74	C2-C4	Chordoma	II B	A-D/2-10	C0-T3	660.0	4400.0	None	TES
16	F	16	C7	OSA	II A	B-C/4-9	C4-T2	315.0	1000.0	None	TPS
23	M	62	C2-C4	Plasmocytoma	II B	A-D/1-12	C0-T2	630.0	6500.0	None	TES
24	M	43	C7	CHSA	II B	A-D/7-10	C4-T2	430.0	1200.0	None	TES
Metastases											
7	F	39	C7	Ca. Mammae	I B	A-D/3–11 (1b)	C4-T2	190.0	1900.0	None	TPS
8	F	39	C3	Ca. Mammae	II B	A-D/3–11 (1b)	C2-C5	240.0	800.0	None	TPS
9	F	58	C6-C7	Ca. Mammae	II B	A-D/2–8 (1c)	C4-T2	480.0	4800.0	None	TES
10	F	72	C3	Ca. Mammae	II B	A-D/4–11 (1a)	C2-C5	500.0	1750.0	None	TES
12	F	54	C7	Ca. Parotis	I B	B-C/12-3 (1c)	C4-T2	350.0	2500.0	None	TES
20	M	68	C7	Papilofolicular thyroid Ca.	II B	A-D/5–9 (1a)	C3-T2	390.0	3500.0	None	TPS
Benign tumors											
2	M	14	C4	Meningeoma	II B	A-D/4-11	C2-C6	435.0	400.0	Durotomy	TPS
11	M	17	C7	GCT	II B	A-D/7-2	C6-T1	320.0	2300.0	None	TPS
15	M	49	C2-C3	OO	I	B/2-4	C2-C4	120.0	1300.0	None	ETR
17	F	13	C6	OO	I	B/6-7	C6-C7	75.0	200.0	None	ETR
18	F	23	C6	Schwannoma	II B	A,E/9-11	C5-T1	110.0	1100.0	None	ETR
19	M	68	C4	OB	III	B-C/9-11	C2-C5	100.0	500.0	None	ETR
21	F	15	C4	OCH	III	B-C/2-4		45.0	50.0	None	ETR
22	F	57	C3	OO	I	B/2-3	C2-C4	90.0	50.0	None	ETR

Abbreviations: M-male, F- female, EWSA- Ewing's sarcoma, Ca.- carcinoma, OSA-osteosarcoma, CHSA-chondrosarcoma, GCT-giant cell tumor, OO- osteoid osteoma, OB- osteoblastoma, OCH- osteochondroma, TPS- total piece meal spondylectomy, TES- total *en bloc* spondylectomy, ETR-*en bloc* tumor resection.

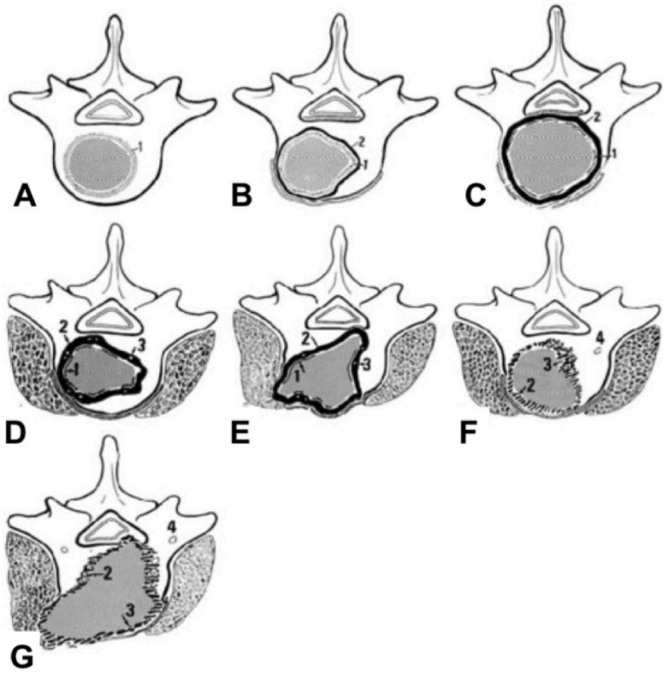

Fig. 1. The Enneking classification of primary tumor staging: (A–C) Benign tumors (D–G) Malignant tumors (1) Tumor capsule (2) Tissue reaction (3) Island of tumor within reactive zone (4) Skip metastasis (Choi, Crockard Review of metastatic spine tumour classification Eur Spine J 2010).

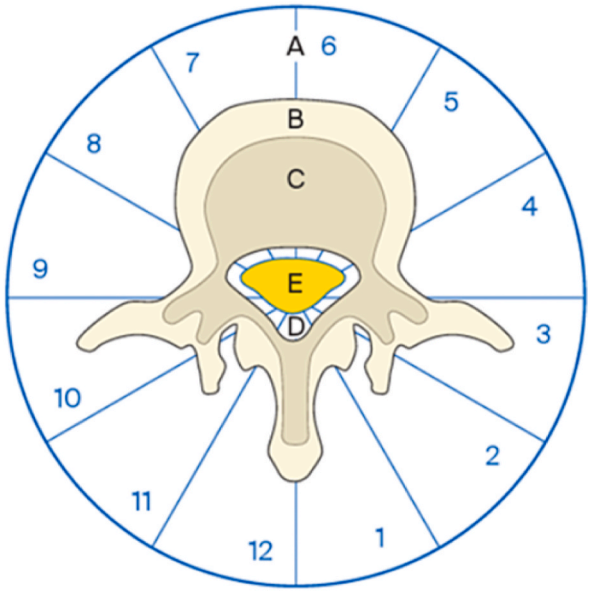

Fig. 2. WBB (Weinstein-Boriani-Biagini) classification: (A) Soft Tissue (B) Intraosseous superficial (C) Intraosseous deep (D) Extradural (E) Intradural (F) Vertebral artery involvement (1–12) Zones of involvement in an axial plane (surgeryreference.aofoundation.org).

MRI examinations were performed regularly postoperatively and at intervals of 6 months (malignant tumors and metastases) or 1 year (benign tumors) to assess for local recurrence. Distant metastases were assessed during standard oncologic follow up (PET/CT, Bone scintigraphy).

The cohort was evaluated based on patient age and gender, tumor grade and stage, tumor size, patient preoperative neurological status, the type of surgical procedure performed, extent of fixation, evidence of bone fusion and stability of the cervical spine construct, tumor recurrence, functional outcome (VAS and NDI scores), complications, and patient survival (Table 2).

Changes in clinical parameters (VAS and NDI) over time were statistically evaluated using the paired two-sample Student's t-test for means. P-values less than 0.05 were considered statistically significant. Kaplan-Meier analysis was used to estimate and compare survival rates among the three tumor groups. The log-rank test assessed significant differences in overall survival between the groups. Additionally, the log-rank test for trend assessed the presence of a trend in overall survival across the tumor types (Fig. 10). All statistical analyses were conducted using GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts USA).

3. Results

The mean follow-up duration was 80.3 months (range, 38–195) for surviving patients and 31.7 months (range, 1–156) for the entire patient cohort.

The benign tumor group comprised 8 patients (4 female) with a mean age of 32 years (range, 13–68), all treated by ETR. No tumor recurrence or major complications occurred, and all patients were alive at the final follow-up. The mean neck pain VAS score decreased from 5.9 preoperatively to 4.7 at three months postoperatively, 1.2 at one year postoperatively, and 0.9 at the final follow-up. The mean NDI score also improved significantly, decreasing from 27.6 preoperatively to 5.3 at the final follow-up. CT examinations performed between 3 and 6 months postoperatively confirmed bone fusion in all 7 patients where bone grafts were applied.

The primary malignant tumor group included 10 patients (3 female) with a mean age of 34.5 years (range, 9–74), treated by ETR (n = 1), TPS (n = 3), or TES (n = 6). No local tumor recurrence was observed in this group. Six patients died: one died immediately postoperatively due to uncontrolled diffuse bleeding from the anterior surgical wound, one died from a stroke 10 months postoperatively, and four died due to systemic disease progression (plasmocytoma, n = 1; osteosarcoma, n = 2; malignant schwannoma, n = 1). The mean postoperative survival for these four patients who died of disease progression was 55.3 months. In these four cases, disease progression manifested as distant metastases and related complications. Intraoperative complications in this group included vertebral artery injury (n = 2), cerebrospinal fluid (CSF) leakage (n = 1), and recurrent laryngeal nerve injury (n = 1). CT examinations performed between 3 and 6 months confirmed bone fusion in all 8 surviving patients evaluated at that time point (two patients without bone grafts). The mean neck pain VAS score decreased significantly from 7.3 preoperatively to 3.9 at three months, 2.3 at one year, and 1.2 at the final follow-up. Similarly, the mean NDI score improved significantly from 26.2 preoperatively to 5.3 at the final follow-up.

The metastatic tumor group consisted of 6 patients (5 female) with a mean age of 55 years (range, 39–72), treated by TES (n = 3) or TPS (n = 3). No local tumor recurrence was identified in any of these patients; however, 3 patients died from systemic disease generalization at a mean of 18.3 months postoperatively (breast carcinoma, n = 2; parotid gland carcinoma, n = 1). No intraoperative complications were recorded in this group. The mean neck pain VAS score decreased significantly from 5.7 preoperatively to 3.4 at three months, 1.7 at one year, and 0.8 at the final follow-up. Similarly, the mean NDI score improved significantly from 22.7 preoperatively to 4.7 at the final follow-up. CT examinations performed between 3 and 6 months confirmed bone fusion in all 6 patients. CT scans were independently evaluated by a senior musculoskeletal radiologist with expertise in neuroimaging, who was blinded to all demographic and clinical data, including the pathology reports.

The Kaplan-Meier survival curves for each tumor type (Fig. 6) demonstrate varying patterns of overall survival. The log-rank test revealed statistically significant differences in overall survival among the three tumor types ($\chi^2 = 6.261$, df = 2, p = 0.0437). The log-rank test

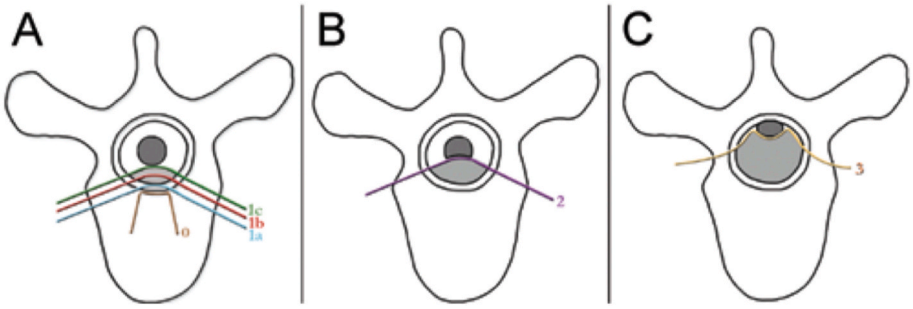

Fig. 3. ESCC scale (Epidural Spinal Cord Compression Scale): (A) 0 bone only disease, 1a Epidural impingement without thecal sac deformation, 1b deformation of thecal sac, without spinal cord abutment, 1c deformation of the thecal sac with spinal cord abutment without compression (B) 2 Spinal cord compression, but CSF visible around the cord (C) 3 Spinal cord compression, no CSF visible around the cord. (Bilsky Reliability analysis of the epidural spinal cord compression scale J Neurosurg Spine, 2010).

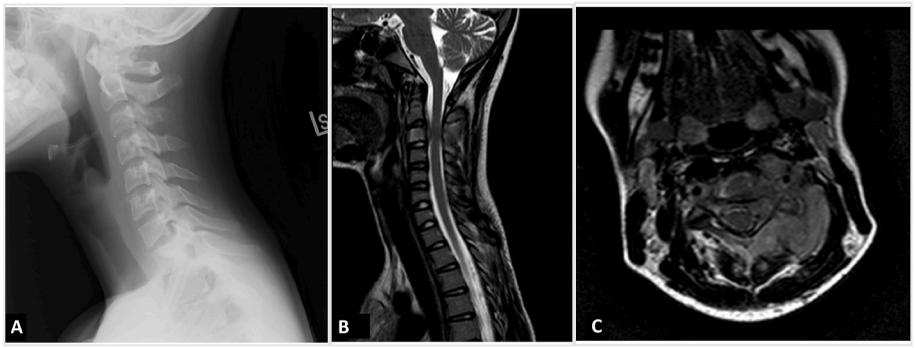

Fig. 4. Radiological findings of EWSA of C3 prior to neo-adjuvant chemotherapy: (A) Lateral radiograph (B) MRI sagittal view (C) MRI axial view.

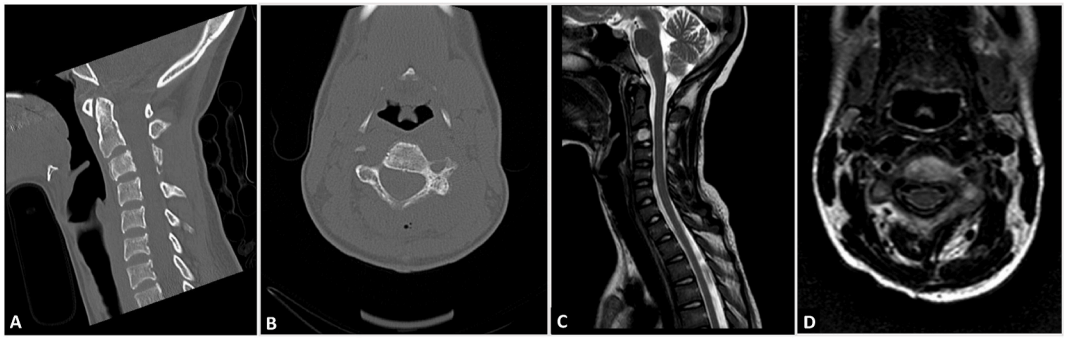

Fig. 5. Preoperative examination of EWSA C3 after neo-adjuvant chemotherapy: (A) CT sagittal reconstruction(B) CT Axial view (C) MRI sagittal reconstruction (D) MRI axial view.

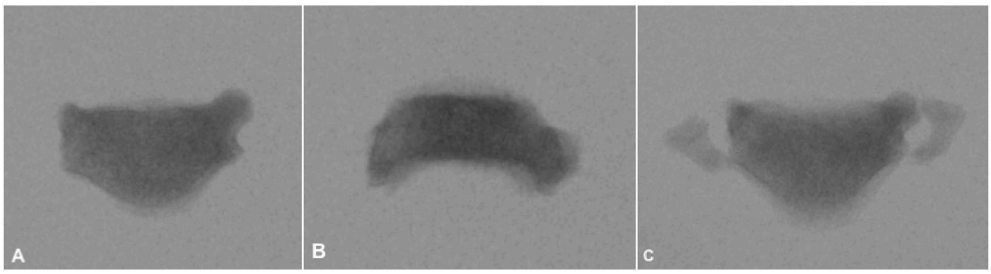

Fig. 6. Intraoperative radiograph of the resected C3 vertebral body: (A) View of the upper endplate (B) View of the lower endplate (C) Detailed view to the osteotomy of the transverse foramen bilaterally.

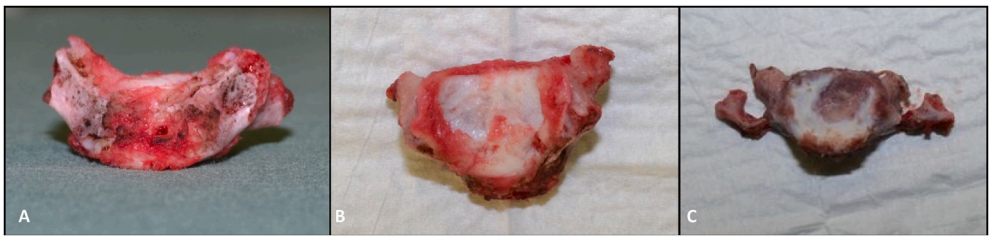

Fig. 7. Intraoperative view of anterior en bloc spondylectomy of C3: (A) Coronal view (B) View of the inferior endplate (C) View of the upper endplate with detail on transvers foramen osteotomy.

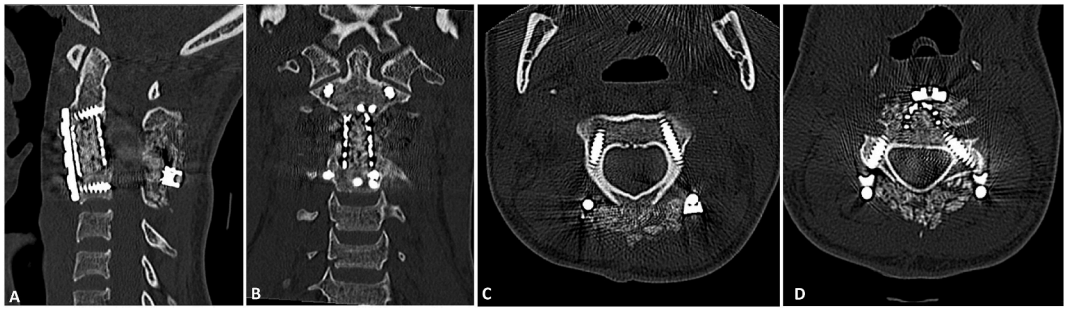

Fig. 8. Postoperative examination (2nd postop day after anterior resection): (A) CT sagittal reconstruction (B) CT coronal reconstruction (C) CT Axial image of C2 with pedicle screws inserted following Goel's technique (D) CT Axial reconstruction of C4 with pedicle screws placed using Abumi's technique.

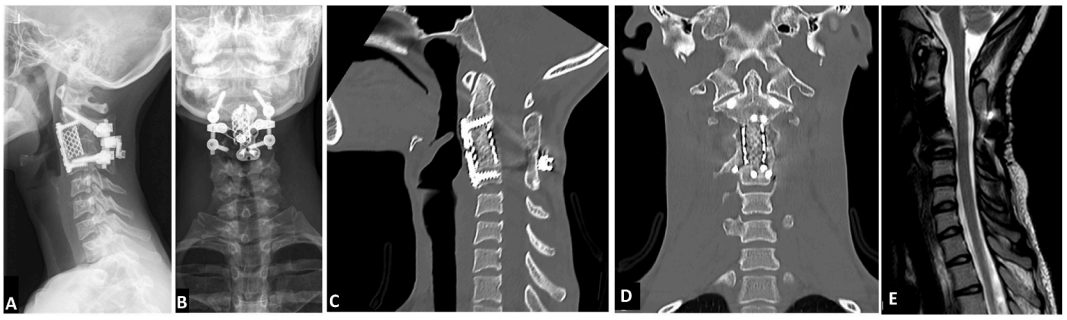

Fig. 9. Follow Up at 10years: (A) Lateral radiograph, (B) AP radiograph, (C) CT sagittal reconstruction, (D) CT coronal reconstruction, (E) MRI sagittal image.

for trend indicated a significant trend towards poorer overall survival progressing from benign to primary malignant tumors to metastatic tumors ($\chi^2 = 4.563$, df = 1, p = 0.0327). The primary malignancy group had a median survival of 92 months, while the secondary malignancy group had a median survival of 60.5 months, reflecting poorer outcomes in patients with metastatic disease.

4. Discussion

This study demonstrates the feasibility of performing extensive radical resections (TES, TPS, ETR) for various tumors involving the subaxial cervical spine in a cohort of 24 patients. Our key findings indicate that radical tumor resection can be considered a definitive treatment for benign tumors with excellent outcomes. For primary malignancies and especially metastatic cases, surgery should be integrated into a multidisciplinary approach, with the recognition that systemic disease burden ultimately limits survival. Nonetheless, the survival achieved in some metastatic cases suggests that radical resection can contribute to prolonged survival in selected patients, beyond its role in palliation or local tumor control. In our cohort of patients, no local tumor recurrences observed during a mean follow-up of 62 months. Furthermore, patients experienced statistically significant improvements in both neck pain (VAS) and functional disability (NDI) across all tumor types.

Extensive resection procedures in the subaxial cervical spine have been repeatedly described in the literature, typically in smaller series or case reports (Cohen et al., 2002; Rhines et al., 2005; Cloyd et al., 2009; Chou et al., 2009). Luzzati et al. (2021) recently published a series of 30 patients with primary cervical spine tumors treated by radical resection. Our finding of no local recurrence supports the principle of radical resection achieving adequate oncologic margins, a concept emphasized particularly for primary malignant bone tumors where en bloc resection in the thoracolumbar spine has been shown to improve survival (Boriani et al., 2006; Abe et al., 2000; Marmor et al., 2001; Tomita et al., 1997). However, total en bloc spondylectomy (TES) in the subaxial cervical spine remains exceptionally rare. The technical challenges posed by the vertebral arteries (VAs) in the C1-C6 region often necessitate piecemeal dissection even during procedures intended to be en bloc (e.g., TPS), making true TES difficult (Wang et al., 2012). Our experience mirrors this, with VA preservation being possible in most cases (22/24) but requiring deliberate sacrifice in two cases to achieve oncological radicality. This aligns with recommendations, such as those by Westbroek et al. (2020), who suggest considering VA resection when circumferential involvement exceeds 180°. Ultimately, the choice of an adequate operative technique depends on multiple factors, including the extent of the pathological process, involvement of vertebral arteries and nerve

Table 2
Clinical characteristics and follow up information.

						VAS		NDI				
No.	Sex	Age	Level	Histology	Symptoms	preop	postop	preop	postop	FU	Symptoms post	Result
Primary tumors												
1	M	56	C4	Plasmocytoma	Neck pain	5	1	19	2	156	Occipital hypestesia	DOD
3	M	24	C2-C3	Chordoma	Quadriparestesis	7	N/A	20	N/A	1	N/A	DOD
4	F	16	C3	EWSA	Neck pain	3	0	11	0	153		NED
5	M	9	C3	EWSA	Neck pain, nocturnal pain	10	0	10	0	130		NED
6	M	32	C7	OSA	Upper limbs parestesia, apraxia	8	3	41	16	18		DOD
13	F	13	C7-T1	Malign schwannoma	None	3	1	27	8	28		DOD
14	M	74	C2-C4	Chordoma	Neck pain	8	4	40	19	10	Right shoulder pain	DOD
16	F	16	C7	OSA	Neck pain, right shoulder pain, paraparesis	10	N/A	27	N/A	19		DOD
23	M	62	C2-C4	Plasmocytoma	Quadriparesis	10	0	38	0	40		NED
24	M	43	C7	CHSA	Neck pain, left upper limb parestesia	9	3	29	8	38	RLN paresis	NED
Metastases												
7	F	39	C7	Ca. Mammae	Neck pain	5	0	29	0	28		DOD
8	F	39	C3	Ca. Mammae	Upper limbs parestesia	7	2	32	10	12		DOD
9	F	58	C6-C7	Ca. Mammae	C7-C8 radiculopathy	8	0	37	3	93		NED
10	F	72	C3	Ca. Mammae	None	4	0	10	0	92		NED
12	F	54	C7	Ca. Parotis	Neck pain, right shoulder pain	10	3	28	15	13		DOD
20	M	68	C7	Papilofolicular thyroid Ca.	None	0	0	0	0	51		NED
Benign tumors												
2	M	14	C4	Meningeoma	Neck pain, quadriparesis	10	2	50	20	195		NED
11	M	17	C7	GCT	Neck pain, upper limbs parestesia	6	0	28	5	91		NED
15	M	49	C2-C3	OO	Left upper limb weakness	8	2	36	6	60		NED
17	F	13	C6	OO	Neck pain	8	0	42	0	58		NED
18	F	23	C6	Schwannoma	None	0	0	0	0	57		NED
19	M	68	C4	OB	Neck pain, upper limbs pareshesia	5	2	37	11	52		NED
21	F	15	C4	OCH	None	0	0	0	0	51		NED
22	F	57	C3	OO	Neck pain	10	1	28	0	44		NED

Abbreviations: M-male, F- female, EWSA- Ewing's sarcoma, OSA-osteosarcoma, CHSA-chondrosarcoma, Ca.- carcinoma, GCT-giant cell tumor, OO- osteoid osteoma, OB- osteoblastoma, OCH- osteochondroma, DOD-death of disease, NED-no evidence of disease, RLN- recurrent laryngeal nerve.

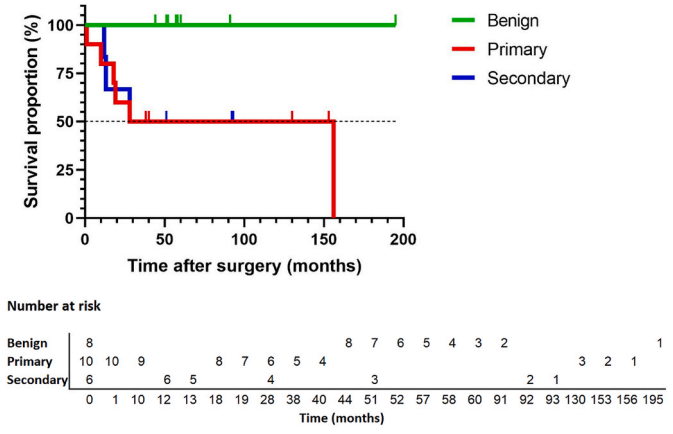

Fig. 10. Kaplan-Meier Survival Curves and Log-Rank Test of patients following radical cervical spine surgery showing significant differences in overall survival between benign, primary, and secondary tumors (P = 0.0437).

roots, bone quality, and the patient's overall health status.

A key question remains the relative efficacy of en bloc (TES/ETR) versus piecemeal (TPS) resection in the cervical spine. Total piecemeal spondylectomy (TPS) is perhaps the most frequently described technique for circumferential vertebral resection in the cervical spine due to the VA constraints (Cohen et al., 2002; Stulik et al., 2015; Simsek et al., 2009). It is often employed for tumors like chordoma, which, although typically slow growing, can have indistinct margins, making intralesional resection highly prone to local recurrence. Wang et al. (2012) reported outcomes for 14 patients after total 'intralesional' resection (likely meticulous piecemeal) for cervical chordoma, noting worse prognosis with upper cervical involvement, a finding echoed by Molina et al. (2014) who found better results for en bloc resections in the subaxial region compared to the upper cervical spine.

While our study included patients undergoing different approaches, particularly for malignant and metastatic disease, the heterogeneity of tumor types and the relatively small sample size within each subgroup preclude a statistically robust comparison of oncological outcomes (survival, recurrence) specifically between these techniques using our data alone. Larger, comparative studies are needed to definitively determine if one approach offers superior oncological outcomes in the subaxial cervical spine. Nevertheless, the absence of local recurrence in our entire cohort, regardless of the specific technique (TES, TPS, or ETR), underscores the importance of achieving complete tumor removal with clear (negative) surgical margins, which remains the primary surgical objective. The literature supports both meticulous piecemeal (Wang et al., 2012; Molina et al., 2014) and en bloc approaches (Cohen et al., 2002; Rhines et al., 2005; Guppy et al., 2013; Cloyd et al., 2009; Chou et al., 2009) when aiming for radicality, with the choice often dictated by the factors mentioned above.

En bloc tumor resection (ETR), often multilevel, is particularly applicable for tumors with significant extraosseous extension (Cohen et al., 2002; Rhines et al., 2005; Molina et al., 2014). Our preference for ETR, even in selected benign lesions (like the meningioma in our series) or tumors where adjacent destruction risks instability, reflects a strategy to minimize recurrence risk, although the incremental benefit compared

with less aggressive resection for clearly benign entities requires careful consideration. We concur regarding the avoidance of high-speed burrs near tumor margins whenever possible, owing to the theoretical risk of tumor cell dissemination and subsequent implantation metastases. True TES, preserving VAs and nerve roots, is feasible but rare, depending on favorable intraosseous tumor localization. Currier et al. (2007) described C5 TES requiring piecemeal burr removal around the VA, while Štulík et al. (Stulik et al., 2015) reported C3 TES achieving en bloc transverse process removal around the VA without a high-speed burr.

Consistent with most published strategies (Cohen et al., 2002; Stulik et al., 2015; Currier et al., 2007; Chou et al., 2009; Simsek et al., 2009; Chan et al., 2009; Pinter et al., 2022) and considering the instability created by extensive resections, we prioritized initial posterior stabilization using polyaxial screw-rod systems (Wang et al., 2012; Stulik et al., 2015; Guppy et al., 2013; Chou et al., 2009; Pinter et al., 2022). Only a few authors advocate an anterior-first approach in the subaxial region (Rhines et al., 2005). We believe accurate posterior fixation and fusion are paramount, striving to minimize instrumentation length where possible. We generally aimed for short-segment fixation where biomechanically feasible (Stulik et al., 2015; Tu et al., 2018), although the extent ultimately depends on resection type, tumor histology (e.g., chordoma often requires longer constructs), bone quality, and patient factors (Stulik et al., 2015; Xiao et al., 2016; Aoun et al., 2018). The anterior vertebral column was typically reconstructed using mesh or expandable titanium cages, bridged by an anterior cervical plate (Cohen et al., 2002; Rhines et al., 2005; Currier et al., 2007; Cloyd et al., 2009; Chou et al., 2009) or via a combination of a cage and plate construct (Simsek et al., 2009; Tu et al., 2018). PEEK and carbon fiber reinforced PEEK implants are also available alternatives. Our high fusion rates, achieved using cages and plates with bone graft (autografts or allografts), are encouraging, especially in contrast to some reports highlighting challenges with non-union, particularly after cervical chordoma resection (Hsieh et al., 2009). The use of vascularized fibular grafts (Pinter et al., 2022) for reconstruction following multi-segmental resection, remains an option for complex cases, although none were used in this series.

The significant complication rate documented in our series, especially in the primary malignant group, highlights the inherent risks associated with these extensive procedures, a finding also emphasized by Luzzati et al. (2021) in their series. The decision regarding VA sacrifice remains complex, with differing opinions regarding the necessity and utility of preoperative balloon occlusion testing (Ogungbemi et al., 2015). Some advocate for it as a safety measure against potential cerebral ischemia, while others deem it irrelevant given that ischemic events can manifest later.

5. Limitations

This study has several limitations. Firstly, its retrospective nature introduces potential biases in data collection and patient selection. Secondly, the sample size is relatively small and heterogeneous, encompassing benign, primary malignant, and metastatic tumors with varying histologies, which limits the statistical power for subgroup analyses and generalizability. Thirdly, being a single-center experience, our findings may not fully represent outcomes achievable elsewhere. Fourthly, while the mean follow-up is over 4 years, longer follow-up would be necessary to capture potential late recurrences, particularly for slower-growing tumors like chordoma. Finally, as previously stated, the study design and sample size did not allow for a direct, statistically valid comparison of the oncological efficacy between en bloc (TES/ETR) and piecemeal (TPS) resection techniques.

6. Conclusion

Radical resections of the subaxial cervical spine are effective for achieving local tumor control and providing significant functional improvement for selected primary and secondary tumors, as demonstrated by the absence of local recurrence and improved VAS/NDI scores in our cohort. High rates of successful spinal fusion can be expected. However, these remain high-risk procedures associated with potentially severe complications and mortality, particularly in patients with primary malignant disease. Survival is significantly influenced by tumor histology. Selection of the surgical approach (TES, TPS, ETR) depends on multiple factors including tumor characteristics and anatomical constraints. While radicality is paramount, the current data from this study does not allow definitive conclusions to be drawn regarding the superiority of a specific surgical approach (en bloc vs. piecemeal) in terms of long-term oncological outcomes. Oncological radicality should be pursued judiciously through interdisciplinary discussion, balancing the goal of long-term disease-free survival against the substantial procedural risks.

Conflict of interest

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

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