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Comparation of tumor-free margin or intralesional spondylectomy for chondrosarcoma in mobile spine: a retrospective study of surgery management, complications and prognosis

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Abstract

Study design Retrospective Cohort Study.

Objectives Chondrosarcoma of mobile spine is a rare aggressive malignant tumor and postsurgical local recurrence rates remain high. En bloc resection is currently the preferred treatment. Resection that achieves tumor-free margin removal of the tumor may enable more complete removal of tumor tissue but significantly increases the complexity and risk of surgery and results in more postoperative complications. We sought to compare surgical outcomes, complications, and prognoses between patients who underwent en bloc resection with and without intralesional removal of the tumor.

Methods We reviewed 56 patients with spinal chondrosarcoma who underwent en bloc tumor resection and reconstructive surgery at our center between 2000 and 2024 with a minimum postoperative follow-up of 1 year. We collected and analyzed data regarding surgical procedures, complication characteristics, and local tumor control and recurrence.

Results We included 56 patients. Of these, 36 patients underwent the first surgery, and 20 experienced recurrences. All patients underwent en bloc tumor resection; 36 and 20 underwent intralesional and tumor-free margin resections, respectively. We recorded 83 complications; the incidence and the number of major complications were significantly higher in the tumor-free margin surgery group. Thirty patients experienced tumor recurrence and 26 patients died.

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Tumor-free margin en bloc resection and conventional-type chondrosarcoma were predictive factors for reduced long-term postoperative recurrence and mortality risk.

Conclusions Tumor-free margin resection carries higher risks and is associated with a greater number of perioperative complications, but reduces the risk of local tumor recurrence and prolongs recurrence-free survival and overall survival, providing patients with better prognoses.

Keywords Chondrosarcoma, Mobile spine, En bloc spondylectomy, Surgical margin, Complication, Prognosis

Introduction

Chondrosarcoma of the spine is a rare malignant tumor, accounting for approximately 2–12% of all chondrosarcomas [1–3]. Non-surgical treatments, such as chemotherapy and radiotherapy, are ineffective in controlling local tumor growth and invasion. Consequently, en bloc resection is the preferred treatment for spinal chondrosarcoma [3–8]. This surgical approach involves the removal of the affected bone and soft tissue at one time, aiming to minimize local recurrence and distant metastasis. En bloc resection can be categorized into intralesional surgery, which invades the tumor, and tumor-free margin surgery, which avoids passing through the tumor and includes marginal and wide-margin resections [9–11]. Retrospective studies of patients with refractory recurrent spinal chondrosarcoma have demonstrated that achieving wide surgical margins significantly improves recurrence-free survival (RFS) and overall survival (OS) [12].

En bloc resection that achieves tumor-free margin removal of the tumor enables a more complete removal of tumor tissue, leading to higher OS rates, improved tumor control, and reduced local recurrence rates. However, the anatomical structure of the spine is complex and wider surgical margins are necessary for tumor-free margin procedures—that is, a larger scope of resection—while also avoiding damage to critical structures such as the spinal cord and nerves. This significantly increases the complexity and risk of surgery and results in more postoperative complications [13–18]. Regardless of whether a posterior-only approach or a combined approach is employed for en bloc resection, the surgical risks are high, and perioperative management faces significant challenges.

Due to the rarity of spinal chondrosarcoma, few studies have been published comparing en bloc resections with different surgical margins for this condition. Our institution, as one of the largest spinal tumor centers in China, has accumulated a substantial number of primary spinal chondrosarcoma cases. Through a retrospective analysis of these cases, we sought to evaluate diagnostic and therapeutic strategies, compare surgical outcomes, complications, and prognoses between patients who underwent en bloc resection with and without intralesional removal of the tumor, and provide additional insights for the diagnosis and treatment of spinal chondrosarcoma.

Materials and methods

General information

This study was approved by the Ethics Committee of our university hospital (IRB00006761-M2023022) and its implementation adhered to the Declaration of Helsinki. The requirement for informed consent was waived because of the retrospective nature of the study.

Between January 1, 2000, and May 31, 2024, our spinal surgery team treated a total of 58 patients with spinal chondrosarcoma, as determined by reviewing our center's spinal tumor case data. Two patients who received early treatment were lost to follow-up due to incomplete electronic records and changes in contact information. Therefore, a total of 56 patients with confirmed diagnoses who underwent en bloc tumor resection and reconstructive surgery in our department were included in this retrospective study. Inclusion criteria were: primary spinal chondrosarcoma confirmed by final histological diagnosis; no distant visceral metastasis as indicated by preoperative imaging or intraoperative findings; and postoperative follow-up of at least 12 months with available imaging data. Exclusion criteria included: postoperative pathological diagnosis results with other tumors instead of chondrosarcoma; patients with metastatic tumors originating outside the spine; and those who underwent surgeries other than en bloc resection.

The retrospective evaluation included patients' electronic medical records, surgical records, anesthesia records, pathology reports, and imaging information. Data collected comprised patients' age, gender, clinical presentations, neurological function, tumor involvement of vertebral bodies and associated structures, surgical methods, operation time, estimated intraoperative blood loss, postoperative pathology, length of hospital stay, and treatment-related complications. Additionally, the pathological classification of chondrosarcoma in postoperative specimens was documented. Neurological function was assessed using the modified Frankel grading system. Enneking staging was determined based on imaging findings.

Imaging and biopsy

All patients routinely underwent anteroposterior and lateral spinal radiographs, computed tomography (CT), and magnetic resonance imaging (MRI). Bone scans and

positron emission tomography-CT were performed when necessary to exclude systemic metastasis. CT angiography was conducted if tumors were anatomically closely associated with major vascular structures. For patients undergoing initial surgery, CT-guided percutaneous tumor biopsy was routinely performed, while patients with recurrent tumors following previous resection do not require additional pathological confirmation.

Treatment protocol

In clinical practice, the management of spinal chondrosarcoma begins with assessing the patient's clinical presentation. Emergency surgical treatment is performed if the patient experiences acute worsening of neurological symptoms—such as pain, sensory and motor disturbances—or even complete loss of neurological function. If the patient's condition is stable with slowly progressing symptoms, a CT-guided percutaneous biopsy is routinely conducted to confirm the diagnosis and to further determine the treatment and surgical plan. Surgical decisions are made through multidisciplinary team (MDT) collaboration [19], involving spine surgeons, general surgeons, thoracic surgeons, interventional vascular surgeons, anesthesiologists, radiologists, pathologists, and others.

En bloc resection is indicated for spinal chondrosarcomas originating from extradural spinal osseous tissue without distant visceral metastasis. The surgical plan, including the choice of surgical approach, was determined based on tumor location, size, extent of involvement, the patient's overall health status, and the results of MDT discussions, with reference to the Weinstein-Boriani-Biagini (WBB) staging system [11, 20]. Routine preoperative embolization of the tumor's feeding arteries was performed before tumor-free margin surgeries to reduce surgical difficulty and risk by occluding the tumor's blood supply and inhibiting its growth [21]. Following resection, spinal reconstruction was typically achieved using 3D-printed artificial vertebral bodies or titanium mesh in combination with titanium plates, pedicle screws, and bone graft fusion with internal fixation.

Pathological examination is the gold standard for diagnosing chondrosarcoma. To better analyze this cohort of en bloc resection cases, we defined en bloc resection as the complete removal of the tumor along with a layer of surrounding healthy tissue.

Surgeries were classified into tumor-free margin en bloc resections and intralesional en bloc resections based on the surgical protocol. All cases with tumor-free margin underwent postoperative pathological verification, while cases with positive tumor margins or those without pathological verification were categorized as intralesional resections. For patients undergoing intralesional en bloc resection, postoperative localized stereotactic radiotherapy of 40–50 Gy was administered.

Perioperative complications were classified according to McDonnell's criteria as major or minor complications, based on whether they significantly affected patient recovery [22].

Table 1 Demographic and clinical characteristics

Items	Intralesional, *n* (%)	Tumor-free margin, *n* (%)	Total	*P*-value
Male, n (%)	18(50.0)	10(50.0)	28(50.0)	1.000
Age (years), Mean ± SD	44.5 ± 14.9	43.1 ± 12.7	44.0 ± 14.0	0.714
Hospital stay (days), Median (IQR)	15.0(14.0)	16.5(13.0)	15.5(13.0)	0.973
Recurrent, n (%)	16(44.4)	4(20.0)	20(35.7)	0.067
Preoperative neurological function, n (%)				
Frankel A	0(0)	2(10.0)	2(3.6)	0.039*
Frankel B	3(8.3)	0(0)	3(5.4)	
Frankel C	6(16.7)	0(0)	6(10.8)	
Frankel D	10(27.8)	4(20.0)	14(25.0)	
Frankel E	17(47.2)	14(70.0)	31(55.4)	

The results are presented as the mean ± standard deviation, median (InterQuartile Range), number (percentage), or number only

Abbreviations: SD: standard deviation; IQR: InterQuartile Range. *: P-value less than 0.05

Follow-up

After discharge, patients were required to undergo imaging examinations at 3, 6, and, 12 months postoperatively, and annually thereafter. CT or MRI scans were performed at each follow-up visit. If patients exhibited symptoms suggestive of local recurrence, immediate CT or MRI examinations were conducted. The minimum follow-up duration was 12 months.

Statistical analysis

All collected data were analyzed using SPSS Statistics v.27.0 (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was employed to assess the normality of data distributions. Quantitative variables were expressed as means ± standard deviations (SD) for normally distributed data, or as medians with ranges (minimum to maximum) for non-normally distributed data. Differences between groups were evaluated using Student's t-test for normally distributed data and the Mann-Whitney U-test for non-normally distributed data. Categorical variables are presented as percentages and compared using the chi-squared test or Fisher's exact test. Survival analyses were conducted using Kaplan-Meier curves and the Cox proportional hazards model. A p-value < 0.05 was considered statistically significant.

Results

Demographic and clinical characteristics

This study included 56 patients, consisting of 28 men and 28 women (Table 1). The mean age at diagnosis was 44.0 years (range 14–71 years). All patients exhibited symptoms of mechanical compression or neurological deficits caused by spinal chondrosarcoma; additionally, 36 patients experienced spinal or limb pain. A total of 24 patients developed spinal cord injury symptoms due to tumor growth, classified according to the Frankel grading system as follows: Grade A (2 patients), Grade B (3 patients), Grade C (6 patients), and Grade D (14 patients). The average duration from symptom onset to surgery was 20.2 months (range 1–120 months). Thirty-six patients had primary tumors, while the remaining 20 patients had recurrences after previous tumor resection.

In this study, cases were grouped based on whether the surgical margins transgressed the tumor during surgery. Among the 56 patients, 36 underwent intralesional en bloc resection (Figs. 1, 2 and 3), while the remaining 20 underwent tumor-free margin resection (Fig. 4). The baseline characteristics—including gender, age, length of hospital stay, and whether the tumor was a primary occurrence—were evenly distributed between the two

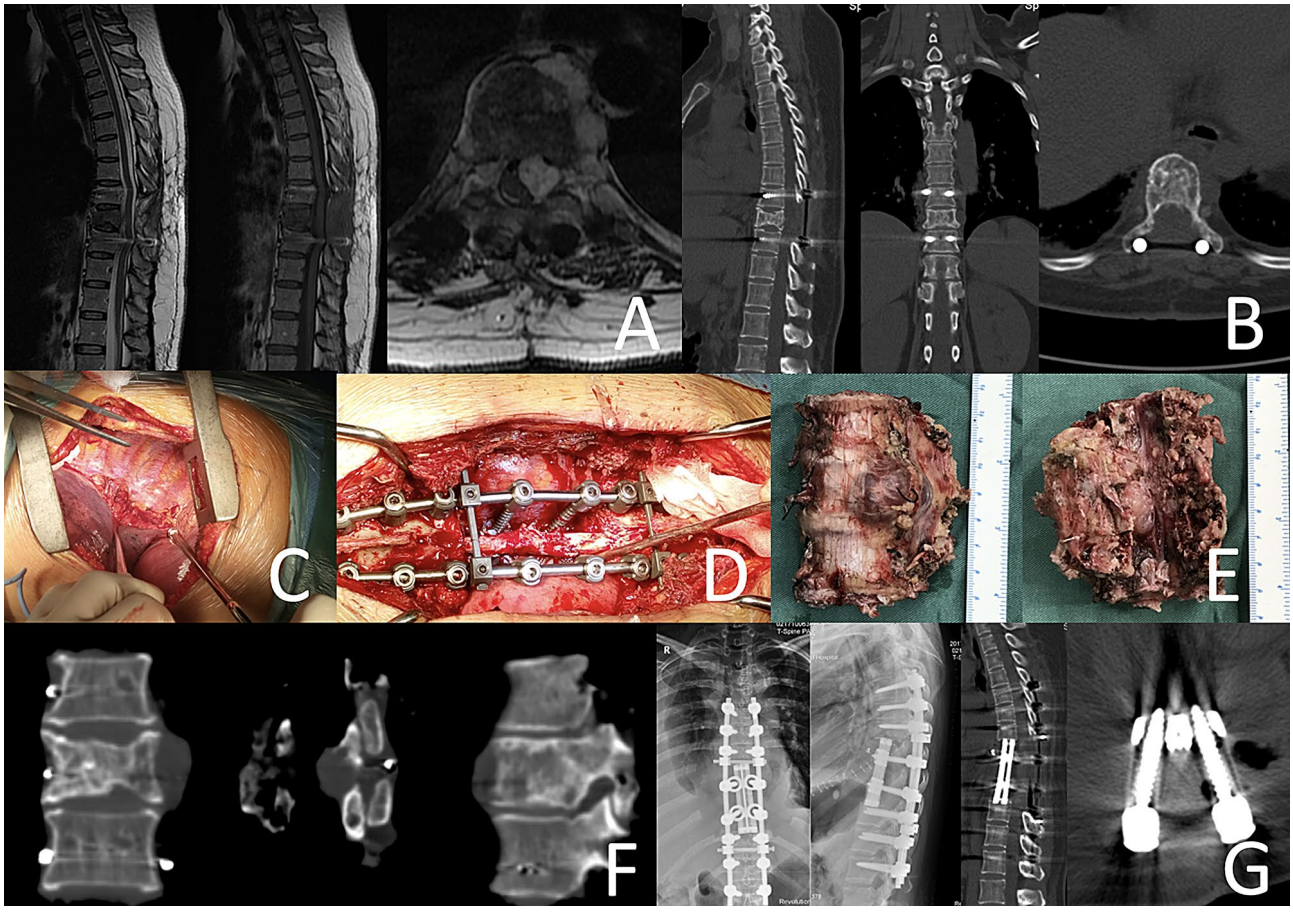

Fig. 1 This case involves a 40-year-old female patient with a T9 chondrosarcoma, classified under the WBB staging system as T9 3–10 A-D. In July 2017, the patient underwent a "posterior approach thoracic tumor resection, decompression, bone grafting, and internal fixation surgery" at a local hospital. Postoperative pathology indicated a "mucinous chondrosarcoma." After receiving postoperative radiotherapy and chemotherapy, the patient was discharged. Two months later, due to residual tumor, the patient was transferred to our hospital seeking further treatment. Upon admission, embolization of the bilateral segmental arteries of T8, T9, and T10 was performed, followed by a staged lateral-posterior approach surgery. The postoperative pathology revealed a high to moderately differentiated chondrosarcoma, and no tumor cells were found in the scar tissue on the surface of the dura mater, achieving an en bloc resection of the tumor without traversing it. The patient received adjuvant radiotherapy postoperatively and, during a two-year follow-up, no local recurrence was observed. **A** and **B**: Preoperative MRI and CT images indicated that the tumor involved the T9-10 intervertebral foramina and the medial side of the T10 pedicles. **C**: In the first stage, a lateral approach was used, preserving the pleura on the tumor surface as a safety margin. **D**: In the second stage, a posterior approach was used. During surgery, several tears in the dura mater occurred due to scar tissue, all of which were repaired. **E**: Postoperative specimen. **F**: Postoperative specimen X-ray images. **G**: The postoperative specimen CT scans, including coronal vertebral sections, coronal spinal canal sections, and sagittal intervertebral foramen sections, revealed tumor involvement of the T9-10 intervertebral foramina. **H**: The postoperative specimen CT showed a complete resection while preserving the left attachments. I: Postoperative X-ray and CT images indicate complete tumor resection and satisfactory internal fixation

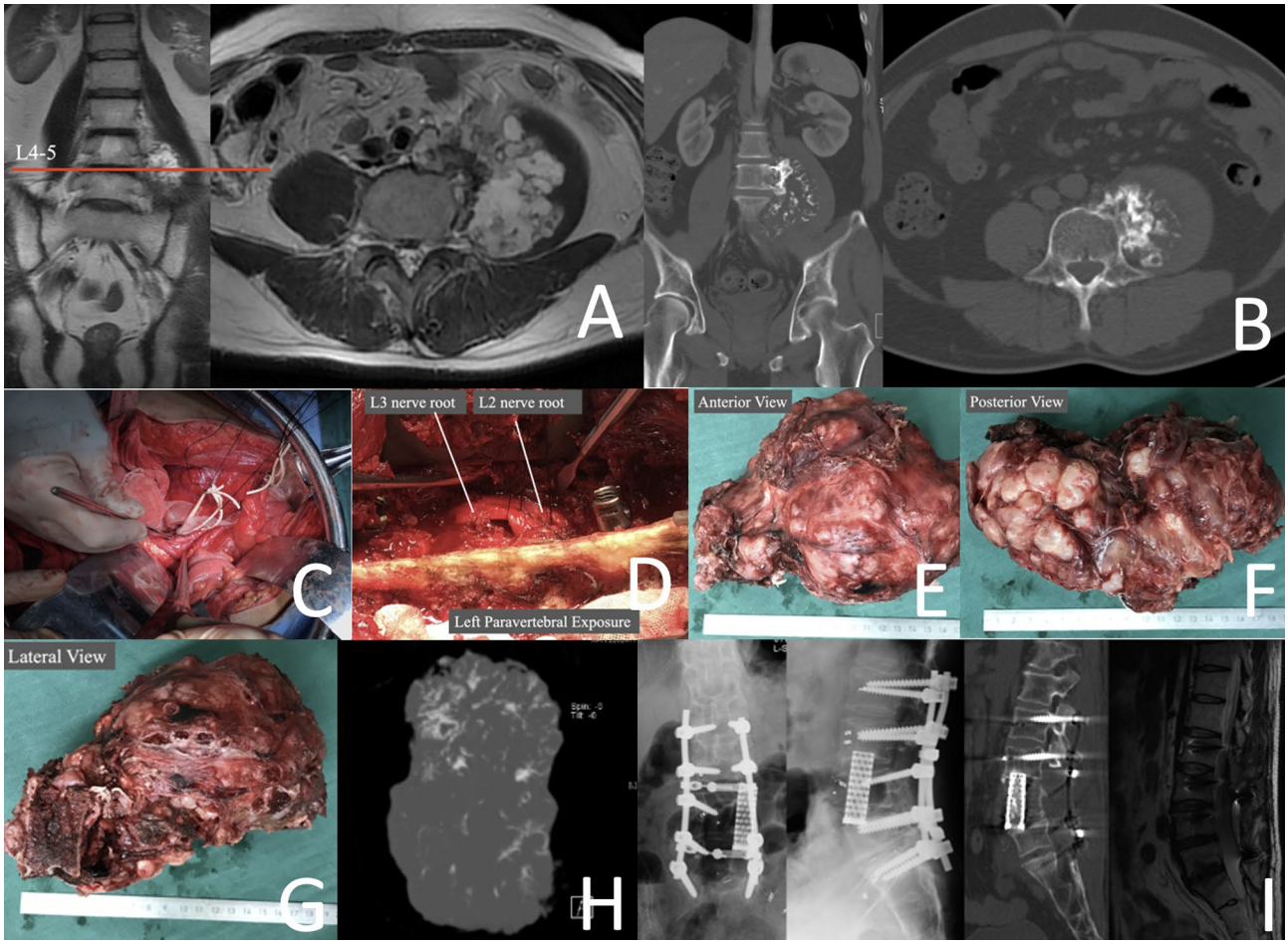

Fig. 2 This case involves a 38-year-old male patient with a L4 chondrosarcoma, classified under the WBB staging system as L4 4–6 A-B. The patient was admitted to the general surgery department with a large retroperitoneal mass due to chronic constipation. Upon admission, examinations revealed that the tumor originated from the L4 vertebral body, and the neurological examination was normal. A CT-guided biopsy resulted in a diagnosis of well-differentiated chondrosarcoma. After embolization of the segmental arteries, a one-stage en bloc resection surgery was performed using a combined anterior midline-posterior midline-lateral approach without traversing the tumor. Postoperative pathology confirmed a well-differentiated chondrosarcoma (Grade I). The patient received adjuvant radiotherapy and chemotherapy after surgery. During a one-year follow-up, bone fusion was satisfactory, and there was no tumor recurrence. **A** and **B**: Preoperative MRI and CT images indicated that the tumor originated from the L4 vertebral body. **C**: An anterior midline approach was used to separate and isolate the tumor from the ureters and iliac vessels up to the front of the vertebral body. The L3-4 and L5-S1 intervertebral discs were resected. **D**: A posterior midline approach was used to resect the L4 and L5 posterior elements, separate the nerve roots, remove the L3-4 and L5-S1 intervertebral discs, perform sagittal osteotomies of L4 and L5, and carry out pedicle screw fixation and fusion. **E**: A lateral approach was used to separate the lateral aspect of the tumor and remove it en bloc, followed by intervertebral fusion from L3 to S1. **F**, **G** and **H**: Surgical resection specimen. **I**: The postoperative specimen CT shows significant destruction of the vertebral bone, with punctate, patchy, and arc-shaped calcifications visible internally. The lesion boundaries remain relatively clear. **J**: Postoperative X-ray and CT images indicate good bone fusion and no tumor recurrence

groups, with no statistically significant differences. However, a significant difference was observed in preoperative neurological function between the two groups.

Surgical resection method

All patients underwent surgical treatment at our center and were confirmed by postoperative pathological diagnosis to have spinal chondrosarcoma. The tumor locations were distributed as follows: 17 cases in the cervical spine, seven in the cervicothoracic spine, 23 in the thoracic spine, one in the thoracolumbar spine, and eight in the lumbar spine. Regarding surgical approaches, two patients underwent anterior-only resection, 27 underwent posterior-only resection, 22 underwent one-stage combined anterior-posterior approach surgery, and five underwent staged combined anterior-posterior approach surgery. The median total operative time was 357.5 min (range 107–1,154 min), the median intraoperative blood loss was 1,000 mL (range 70–5250 mL), and the median intraoperative blood transfusion volume was 1,100 mL (range 0–6900 mL). In terms of comprehensive postoperative treatments, among patients whose resected margins transgressed the tumor (intralesional resection), 24 received postoperative radiotherapy and nine received

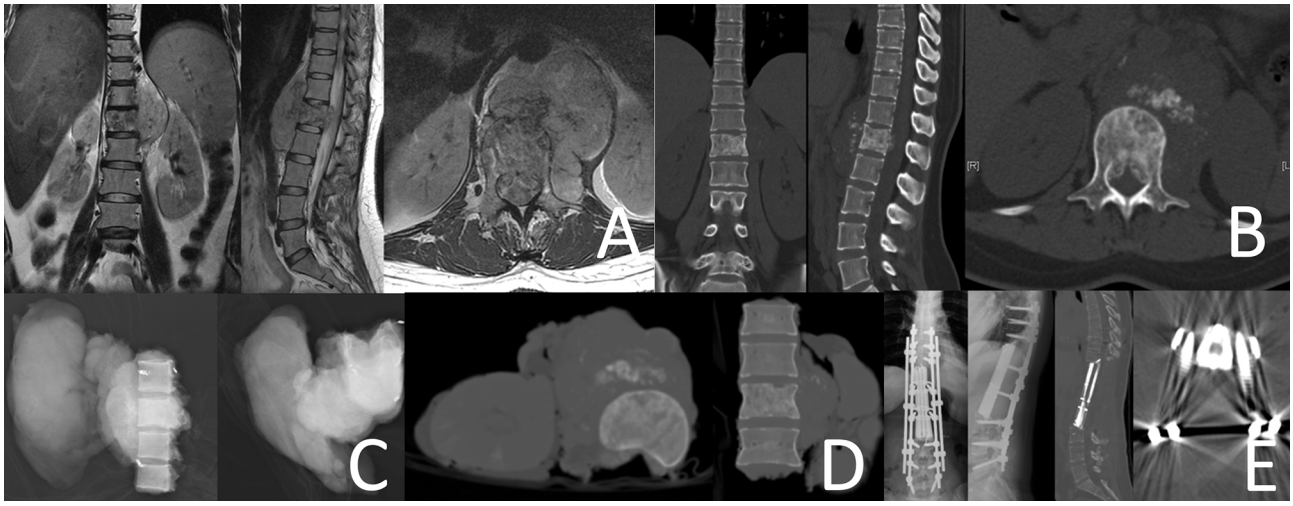

Fig. 3 This case involves a 29-year-old female patient with a T11-L2 chondrosarcoma, classified under the WBB staging system as L1 3–9 A-D. The patient primarily presented with dull and aching pain in the lower back for seven months. An examination at a local hospital revealed a lumbar vertebral tumor, and the neurological examination was normal. A biopsy via puncture diagnosed mesenchymal chondrosarcoma. After undergoing three courses of chemotherapy with IE, VAC, and IE regimens, the patient underwent staged anterior-posterior combined approach surgery at our hospital. This surgery involved en bloc resection of the entire vertebrae from T11 to L2 along with left nephrectomy, achieving tumor removal without traversing the tumor. Postoperative pathology confirmed mesenchymal chondrosarcoma (Grade II-III). The patient received adjuvant chemotherapy and local radiotherapy after surgery. During a three-year follow-up, no tumor recurrence was observed, and the internal fixation remained stable. **A** and **B**: Preoperative MRI and CT images indicated that the tumor did not shrink after chemotherapy, with spinal involvement from T11 to L2. **C**: CT revealed the formation of a tumor thrombus within the left renal vein. **D**: 3D tumor model and surgical planning for osteotomy sites at each segment. **E**: Surgical specimen X-ray images. **F**: Surgical specimen CT images. **G**: Postoperative X-ray and CT images indicate complete tumor resection and satisfactory internal fixation

postoperative chemotherapy. Among patients whose margins did not transgress the tumor (tumor-free margin resection), six received postoperative radiotherapy and one received postoperative chemotherapy.

En bloc resection of chondrosarcoma requires a large surgical field and extended operation time, resulting in significant damage to surrounding organs and tissues. Whether the resection transgresses the tumor significantly impacts perioperative management. To elucidate differences between en bloc resections with different surgical margins, we compared tumor characteristics, preoperative preparation, surgical approaches, intraoperative conditions, and postoperative radiotherapy and chemotherapy in patients undergoing intralesional versus tumor-free margin surgeries (Table 2).

Comparative analysis of the two groups revealed significant differences between intralesional and tumor-free margin surgeries in terms of preoperative tumor arterial embolization, total operative time, and postoperative radiotherapy. No statistically significant differences were observed between the groups regarding tumor segment distribution, number of vertebral bodies resected, or surgical approach, indicating a balanced distribution between the groups. Additionally, no significant differences were found in total intraoperative blood loss, total intraoperative blood transfusion volume, or postoperative chemotherapy rate between the two groups.

Seven patients (12.5%) experienced dural tears during surgery, resulting in cerebrospinal fluid (CSF) leakage. Larger tears were repaired intraoperatively, and all healed after conservative postoperative treatment. In cases of large chondrosarcomas, especially those involving the thoracic spine, adhesion of the tumor mass to the parietal pleura or penetration of the visceral pleura led to tears or damage to the parietal or full-thickness pleura in 11 patients (19.6%) during surgery. Among these, one patient had lung tissue damage. All injuries were promptly repaired by the surgeon or thoracic surgery team.

Perioperative complications

During the study period, a total of 83 perioperative complications were recorded among 56 patients with spinal chondrosarcoma (Table 3), averaging 1.48 complications per patient. Forty-two patients (75.0%) experienced at least one perioperative complication. Specifically, 17 patients (30.4%) had one complication, 16 patients (28.6%) had two complications, and nine patients (16.1%) had three or more complications. These complications included 57 major and 26 minor events. Thirty-four patients (60.7%) had major complications, and no perioperative deaths were reported.

Intraoperative vascular injuries occurred in 16 cases (28.6%), involving the vertebral artery, epidural venous plexus, bone tissue, and intraspinal venous plexus. All

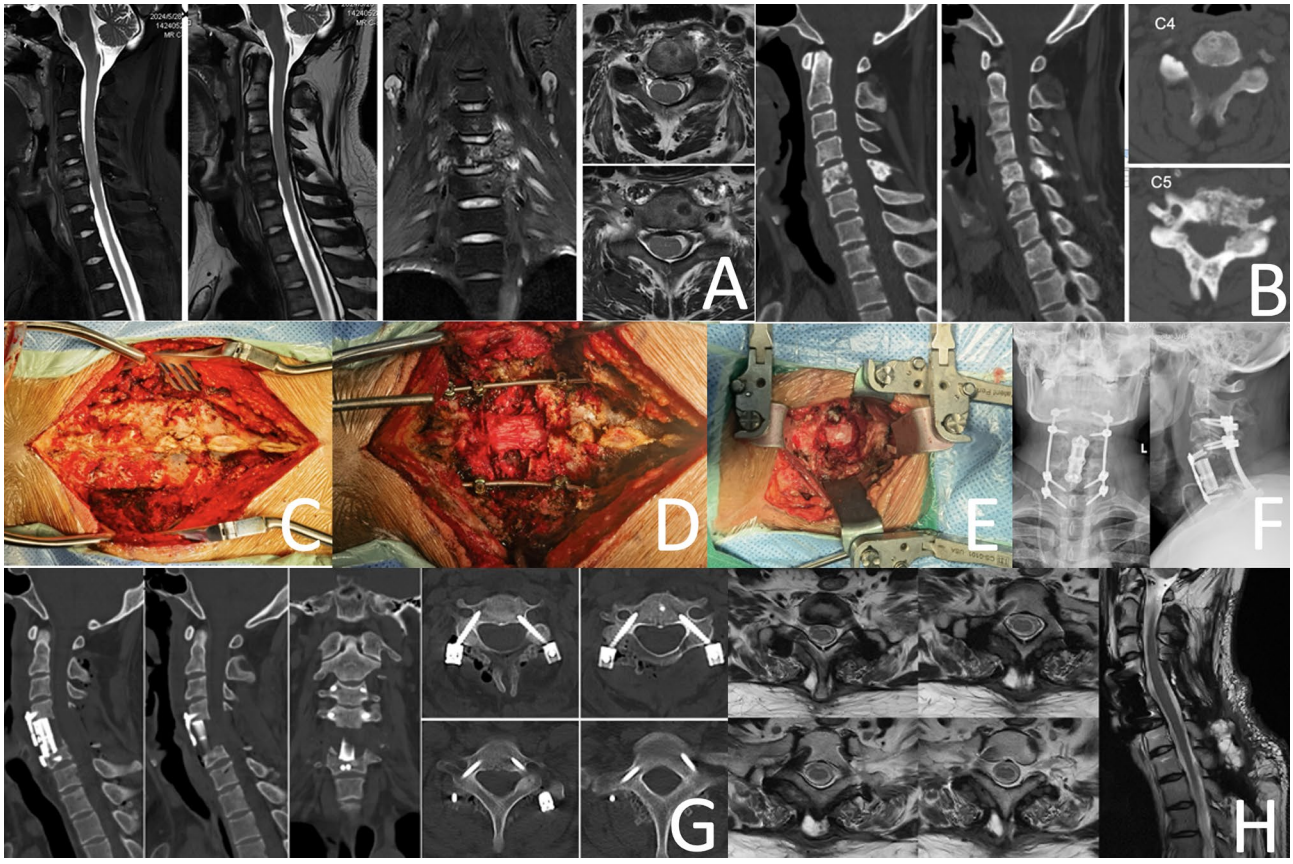

Fig. 4 This case involves a 36-year-old male patient with a C5 chondrosarcoma, classified under the WBB staging system as C5 1–12 A-C. The patient primarily presented with neck pain accompanied by pain, numbness, and weakness in the left upper limb for nine months and was diagnosed with chondrosarcoma over five months prior to admission. A puncture biopsy revealed a high-grade sarcoma, with dedifferentiated chondrosarcoma being the most likely diagnosis. After undergoing four courses of neoadjuvant chemotherapy, the patient underwent a staged posterior-anterior combined C5 total en bloc spondylectomy at our hospital, achieving extracapsular en bloc resection of the tumor. Postoperative pathology indicated an undifferentiated pleomorphic sarcoma. After discharge, the patient received local radiotherapy and began chemotherapy one month postoperatively. **A** and **B**: Preoperative MRI and CT images indicated that the neck soft tissue mass had slightly decreased in size following chemotherapy compared to prior measurements. **C** and **D**: A posterior approach was used to resect the C5 lamina and bilateral facet joints. **E**: A cervical anterior approach was used to achieve resection of the C5 vertebral body and bilateral facet joints. **F**: Postoperative MRI images. **G**: Postoperative X-ray shows good internal fixation. **H**: Postoperative CT images show en bloc resection of the tumor. **I**: Four months after follow-up, a repeat cervical spine MRI revealed high T2 signals in the soft tissues near the posterior margins of the C7-T1 facets and spinous processes. Pathological biopsy confirmed local recurrence

cases received immediate vascular suturing. In these patients, the median operative time for tumor-free margin surgery was 463 min, significantly longer than the 308 min for intralesional surgery ($p = 0.007$). Although no significant difference was observed in intraoperative bleeding and blood loss between the two surgical methods, hemostasis and vascular repair still required substantial time. Dural tears with CSF leakage occurred in seven cases (12.5%), and pleural injuries occurred in 11 cases (19.6%). The incidence of pleural injury was significantly higher in tumor-free margin resection than in intralesional resection ($p = 0.031$). All dural and pleural injuries were immediately repaired during surgery.

Regarding early postoperative complications, neurological function deterioration occurred in 12 patients (18.7%). Postoperative manifestations included paralysis, unexpected decreases in limb muscle strength or hypoesthesia, and band-like sensations. The most severe cases exhibited muscle strength of grade 0–1 in both lower limbs, which had not fully recovered by discharge. In two cases, planned intraoperative ligation of lumbar nerves led to decreased muscle strength in the lower limbs. In one case, stimulation of the recurrent laryngeal nerve during surgery resulted in postoperative hoarseness.

Fourteen patients (25.0%) developed pleural effusion, requiring thoracentesis, closed thoracic drainage, or long-term thoracic drainage (>7 days). All patients showed improvement after puncture or drainage. Postoperative pneumonia occurred in four cases (7.1%), which resolved after anti-infection treatment and oxygen therapy. Five patients (8.9%) experienced postoperative anemia and received blood transfusion therapy.

Table 2 Comparison between trans-tumoral and non-trans-tumoral surgeries

Items		Intralesional, *n* (%)	Tumor-free margin, *n* (%)	Total	*P*-value
Location of tumor, n (%)	Cervical	14	3	17	0.099
	Cervicothoracic	6	1	7	
	Thoracic	12	11	23	
	Thoracolumbar	0	1	1	
	Lumbar	4	4	8	
Number of resected vertebral bodies, Median (IQR)		2.0(1.0)	2.5(2.0)	2.0(2.0)	0.081
Whether there was dural sac preoperative compression dural sac, n (%)		27(75.0)	14(70.0)	37(73.2)	0.888
Preoperative embolization, n (%)		8(22.2)	14(70.0)	22(39.3)	0.001***
Surgical approach, n (%)	Anterior-only	2	0	2	0.587
	Posterior-only	17	10	27	
	One-stage combined anterior-posterior	13	9	22	
	Staged combined anterior-posterior	4	1	5	
Total operative time (mins), Median (IQR)		308(255)	463(451)	357.5(327)	0.007**
Intraoperative blood loss (ml), Median (IQR)		1000(1275)	800(2600)	1000(1575)	0.911
Intraoperative blood transfusion (ml), Median (IQR)		1100(1200)	800(2737)	1100(1200)	0.884
Postoperative radiotherapy, n (%)		24(66.7)	6(30.0)	30(53.6)	0.008**
Postoperative chemotherapy, n (%)		9(25.0)	1(5.0)	10(17.9)	0.061

The results are presented as the median (InterQuartile Range), number (percentage), or number only

Abbreviations: IQR: InterQuartile Range. **: P-value less than 0.01; ***: P-value less than 0.001

Table 3 Perioperative complications

Perioperative complications		Intralesional, *n* (%)	Tumor-free margin, *n* (%)	Total, *n* (%)	*P*-value
Major vascular injury		9(25.0)	7(35.0)	16(28.6)	0.427
Dural tear with CSF leakage		4(11.1)	3(15.0)	7(12.5)	0.673
Pleural injury		4(11.1)	7(35.0)	11(19.6)	0.031*
Neurological deterioration	Paraplegia	3(8.3)	3(15.0)	6(10.7)	0.440
	Decreased muscle strength or hypesthesia	4(11.1)	2(10.0)	6(10.7)	0.898
Pleural effusion		6(16.7)	8(40.0)	14(25.0)	0.053
Respiratory complications		1(2.8)	3(15.0)	4(7.1)	0.089
Urinary complications		1(2.8)	1(5.0)	2(3.6)	0.668
Digestive complications		1(2.8)	1(5.0)	2(3.6)	0.668
Wound healing problems		3(8.3)	1(5.0)	4(7.1)	0.643
Deep venous thrombosis		0(0)	2(10.0)	2(3.6)	0.053
Anemia		3(8.3)	2(10.0)	5(8.9)	0.834
Improper internal fixation		1(2.8)	1(5.0)	2(3.6)	0.668
Chylous leakage		1(2.8)	1(5.0)	2(3.6)	0.668

The results are presented as number (percentage), or number only. Abbreviations: CSF: cerebrospinal fluid. *: P-value less than 0.05

Four patients (7.1%) required debridement due to poor wound healing. Among them, one patient had a recurrent cervical chondrosarcoma after surgery at another hospital and underwent intralesional resection at our hospital in 2000. Postoperative wound healing was poor, and the patient still requires intermittent wound dressing changes during follow-up. In one case, intraoperative pleural damage was initially treated conservatively; after tumor resection, plastic surgeons repaired a large muscle defect. On the first postoperative day, wound dehiscence occurred and was managed by the plastic surgery team with debridement and suturing. Two patients (3.6%) developed deep vein thrombosis of the lower limbs, which improved after anticoagulant therapy without other complications such as embolism.

Postoperative imaging revealed that in one patient (1.8%), X-ray and CT scans showed slight rightward deviation of the 3D-printed artificial vertebral body, necessitating surgical adjustment. On the eighth postoperative day, the patient underwent wound exploration via a posterior lumbar approach, nerve root exploration, and adjustment of the artificial vertebral body. Postoperative

Table 4 Comparation of the incidence of perioperative complications between intralesional and tumor-free margin surgeries

	Major complications(*n*)	Minor complications(*n*)	Total(*n*)
Intralesional	18	15	25
Tumor-free margin	16	8	17
Total	34	23	42
P-value	0.028*	0.903	0.198

n: The number of cases with corresponding types of complications was recorded. *: P-value less than 0.05

Table 5 Comparation of the number of perioperative complications between intralesional and tumor-free margin surgeries

	Major complications (Median)	Minor complications (Median)	Total (Median)
Intralesional	0.5	0	1.0
Tumor-free margin	1.0	0	1.5
Total	1.0	0	1.0
P-value	0.011*	0.898	0.077

Median: The median number of specific types of complications in the respective groups. *: P-value less than 0.05

internal fixation was satisfactory. Additionally, two patients (3.6%) developed postoperative chylothorax, and symptoms gradually disappeared after thoracic drainage, dietary control, and parenteral nutritional support.

We compared the perioperative complications between intralesional and tumor-free margin en bloc tumor resection surgeries (Tables 4 and 5). In the intralesional surgery group, 25 patients experienced a total of 42 complications, while in the tumor-free margin surgery group, 17 patients experienced a total of 41 complications. Statistical analysis revealed that the incidence of major complications was significantly higher in the tumor-free margin surgery group compared to the intralesional surgery group ($p = 0.028$), indicating a statistically significant difference. Although no significant difference was found in the overall complication rate, the number of complications in the tumor-free margin surgery group was significantly higher than that in the intralesional surgery group ($p = 0.011$). These findings suggest that tumor-free margin en bloc resection of spinal chondrosarcoma, which requires complete and thorough removal of the tumor and surrounding tissues, entails higher surgical difficulty and is associated with more numerous, complex, and severe perioperative complications.

Follow-up and late complications

Among the 56 patients, 7 died of tumor recurrence within 1 year postoperatively. The remaining patients were followed for at least 1 year, with an average follow-up duration of 48.1 months.

One patient experienced internal fixation failure 38 months after surgery due to fracture of the titanium alloy fixation rod, necessitating revision surgery. This patient was followed-up for a total of 132 months after the first surgery, with no local tumor recurrence.

Local tumor control

An analysis was conducted on the 56 patients with available follow-up data. Of these, 30 patients experienced tumor recurrence, yielding a recurrence rate of 53.6% (30/56). The mean time to recurrence was 24.8 months (SD = 29.6), and the median time to recurrence was 13.0 months (IQR = 29.0 months). Among the 36 patients who underwent intralesional resection, 25 experienced recurrence, and 24 of these had died by the time of follow-up. In contrast, among the 20 patients who underwent tumor-free margin resection, 4 experienced recurrence, and 2 of these had died by the time of follow-up.

Comparing postoperative local recurrence rates and mortality rates between the intralesional and tumor-free margin en bloc resection groups, the tumor-free margin group exhibited a significantly lower postoperative local recurrence rate (20.0% vs. 69.4%) and a markedly lower mortality rate at the final postoperative follow-up (15.0% vs. 52.8%). The RFS was further extended in the tumor-free margin group, with a median RFS of 27 months and a median OS of 33.5 months. In comparison, the intralesional resection group had a median RFS of 18.5 months and a median OS of 41 months.

Incorporating variables such as gender, age, the surgical resection margin, tumor pathological type, recurrence after previous resection, preoperative arterial embolization, total surgery time, total intraoperative blood loss, number of perioperative complications, tumor involvement of spinal segments, vertebral bodies, accessory structures, and pedicles, a univariate analysis was conducted to assess postoperative recurrence (Table 6). The results indicated that five factors—intralesional en bloc resection, age over 40 at the time of surgery, unconventional (dedifferentiated and mesenchymal) pathological types, recurrence after previous resection, and an increased number of perioperative complications—were associated with an elevated risk of postoperative recurrence ($p < 0.2$). Following a multivariate regression analysis using the Cox proportional hazards model on these factors, it was further determined that tumor-free margin en bloc resection ($p = 0.048$), conventional chondrosarcomas ($p = 0.030$), and first surgical resection ($p = 0.014$) were independent predictors of a reduced long-term risk of recurrence in spinal chondrosarcoma.

Additionally, concerning postoperative mortality, the same analytical approach revealed that six

Table 6 Univariate survival analysis and multivariate Cox regression analysis on predictive factors for tumor prognosis

		Univariate *P*-value of recurrence	Multivariate *P*-value of recurrence	Univariate *P*-value of survival	Multivariate *P*-value of survival
Male, n (%)	18(50.0)	0.642		0.824	
Age (years), Mean ± SD	44.0 ± 14.0	0.142	0.266	0.079	0.296
Unconventional pathological types, n (%)	19(33.9)	0.022*	0.030*	0.027*	0.041*
Intralesional, n (%)	20(35.7)	0.012*	0.048*	0.028*	0.199
Recurrence after previous resection, n (%)	20(35.7)	0.003**	0.014*	0.009**	0.041*
Preoperative arterial embolization, n (%)	22(39.3)	0.594		0.517	
Total operative time (mins), Median (IQR)	357.5(327)	0.479		0.169	0.280
Intraoperative blood loss (ml), Median (IQR)	1000(1575)	0.438		0.691	
1 complication, n (%)	17(30.4)	0.544		0.126	0.123
2 complications, n (%)	16(28.6)	0.066	0.235	0.120	0.718
Over 3 complications, n (%)	9(16.1)	0.442		0.240	0.568
Vertebral bodies involved, n (%)	39(69.6)	0.473		0.811	
Vertebral accessory structures involved, n (%)	46(82.1)	0.745		0.377	
Vertebral Pedicles, n (%)	35(62.5)	0.514		0.296	
Cervical vertebra, n (%)	24(42.9)	0.206		0.237	
Thoracic vertebra, n (%)	29(51.8)	0.253		0.802	
Lumbosacral vertebra, n (%)	9(16.1)	0.236		0.752	

The results are presented as the mean ± standard deviation, median (InterQuartile Range), number (percentage), or number only

Abbreviations: SD: standard deviation; IQR: InterQuartile Range. *: P-value less than 0.05; **: P-value less than 0.01

Table 7 Stratified analysis of prognostic differences between tumor-free margin and intralesional En bloc resection

		P-value of recurrence	*P*-value of survival
The number of surgeries	First surgery	0.220	0.276
	Recurrence after previous resection	0.124	0.085
Tumor pathological type	Conventional	0.101	0.022*
	Dedifferentiated and mesenchymal	0.051	0.749

*: P-value less than 0.05

factors—intralesional en bloc resection, age over 40 at the time of surgery, unconventional pathological types, recurrence after previous resection, longer total surgery time, and an increased number of perioperative complications—were associated with an elevated risk of postoperative mortality ($p < 0.2$). Conventional chondrosarcomas ($p = 0.041$) and first surgical resection ($p = 0.026$) were identified as independent predictors of a reduced long-term risk of mortality in spinal chondrosarcoma.

Further stratification based on independent predictors, such as tumor pathological type and recurrence status, was performed to analyze the impact of en bloc resection margin involvement on tumor prognosis (Table 7). The results showed that in spinal chondrosarcomas with unconventional pathological types, tumor-free margin en bloc resection could reduce the risk of postoperative recurrence ($p = 0.051$). Conversely, in tumors with conventional pathological types, tumor-free margin en bloc resection could reduce the risk of long-term postoperative mortality ($p = 0.022$).

Discussion

Spinal chondrosarcoma is a malignant tumor originating from cartilaginous matrix, accounting for approximately 20–27% of all malignant bone tumors [9, 10]. The annual incidence of spinal chondrosarcoma is approximately one per million population. Primary spinal chondrosarcoma is relatively rare, representing approximately 2–12% of all chondrosarcomas [1–3], and predominantly occurs in adults aged 40 to 60 years; it is uncommon in children and adolescents. Most spinal chondrosarcomas are not sensitive to radiotherapy and chemotherapy, although some agents (such as bisphosphonates and denosumab) have been used in treatment; therefore, surgical resection remains the preferred treatment option [7, 22–25].

En bloc resection surgery has evolved through different surgical techniques. Both tumor-free margin and intralesional en bloc resection can be achieved through the WBB resection and total en bloc spondylectomy. Schwab et al. reported on a team that treated 24 patients with primary spinal chondrosarcoma who underwent surgery [26]. Among these patients, 17 achieved negative surgical margins (wide resection). Of these 17 patients, three (18%) died by the last follow-up. In contrast, among seven patients with positive surgical margins (marginal and intralesional resection), three (43%) died by the last follow-up.

In a 2000 study by Boriani and colleagues comparing piecemeal and en bloc resection of spinal chondrosarcoma [8], the authors suggested that en bloc resection can effectively prolong postoperative survival time and reduce the risk of local recurrence. Between 2011 and 2016, Wei Xu et al. described 15 cases of tumor-free margin en bloc resection of paraspinal chondrosarcoma [27]. Five cases exhibited local recurrence, with an average postoperative recurrence time of 22 months. Yue Zhang et al. reviewed 49 cases of refractory recurrent spinal chondrosarcoma between 2001 and 2017, comparing prognoses between intralesional and tumor-free margin resections [12], showing that patients who underwent tumor-free margin surgery had significantly higher RFS and OS compared to those who underwent intralesional surgery. However, in 2018, Nisson et al. conducted a systematic review comparing the recurrence and prognosis of 11 tumor-free margin surgery patients and 22 intralesional ones for primary spinal chondrosarcoma [28]. No statistically significant differences were observed in recurrence rates and mortality between the two groups.

As a result, the relationship among resection methods, treatment efficacy, postoperative outcomes, and complications has not been clearly established through large-scale studies: whether achieving a tumor-free margin should be the goal remains inconclusive.

Perioperative complications

In our study, 75% of patients experienced perioperative complications, which is comparable to results reported in previous research, with Demura et al. [15] and Bandiera et al. [18] reporting postoperative complication rates of 67% and 50%, respectively.

Regarding the incidence and number of major perioperative complications, the intralesional resection group had significantly lower rates than the tumor-free margin resection cohort, indicating that the surgical safety of intralesional resection is relatively higher than that of tumor-free margin resection.

Major vascular injury is the most common intraoperative complication in en bloc resection of spinal chondrosarcoma, involving the vertebral artery, azygos vein, and paravertebral venous plexus. However, the incidence of such injuries after intralesional and tumor-free margin resections (25% and 35%, respectively) showed no significant difference. We believe the main reasons are as follows: First, due to the rich distribution of venous plexuses anterior to the vertebral body, the extensive resection scope during en bloc tumor removal and the difficulty of separating anterior vertebral tissues via the posterior approach, there is a similar risk of major vascular injury regardless of whether the resection margins transgress the tumor. Second, up to 70% of tumor-free margin surgeries involved preoperative embolization of the tumor's feeding arteries—a proportion significantly higher than that in intralesional surgeries, indirectly reducing the risk of major vascular injury caused by surgical manipulation. All patients achieved adequate hemostasis intraoperatively through vascular repair, packing, or electrocoagulation, and no cases of postoperative bleeding occurred.

Postoperatively, 12 patients (21.4%) experienced neurological function deterioration, including 6 patients in the intralesional group and 6 in the tumor-free margin group. Six patients had unilateral or bilateral nerve roots of the corresponding segments severed and ligated during surgery, causing decreased muscle strength or paralysis of the lower limbs. Tumors resected via both intralesional and tumor-free margin surgeries may involve nerve roots; therefore, the incidence of postoperative neurological dysfunction was similar between the two groups, with relatively favorable prognoses. In three patients, postoperative neurological function did not improve, and they remained paraplegic after rehabilitation training, possibly due to delayed spinal cord ischemia. In other cases, muscle strength and sensory function improved or returned to normal at discharge.

Pleural effusion is a common postoperative complication, especially after surgery for thoracic spinal chondrosarcoma. In our study, the incidence of pleural effusion was 16.7% in the intralesional group and 40.0% in the tumor-free margin group. Indeed, pleural injuries were significantly more frequent in the tumor-free margin group ($p = 0.031$). This higher incidence may be due to more thorough and complete tumor removal, which increases the likelihood of pleural damage during thoracic tumor resection and extended resection margins. The perioperative management of such cases is critical, and closed thoracic drainage is essential. All patients had ceased drainage by the time of discharge, and the effusion gradually resolved.

CSF leakage is more common in surgeries for intradural tumors or during revision surgeries for tumor recurrence. The risk of dural tearing is unavoidable when the tumor adheres to the dura mater, regardless of whether the surgery is intralesional or not. In this study, intraoperative dural tears with postoperative CSF leakage occurred in four cases (11.1%) in the intralesional group and three cases (15.0%) in the tumor-free margin group. All cases were successfully repaired and healed after conservative treatments such as bed rest and fluid replacement.

In summary, compared with intralesional surgery, tumor-free margin resection surgery for spinal chondrosarcoma was associated with a higher number of major complications. This suggests that tumor-free margin surgery, while achieving a wider resection margin, may cause more trauma to surrounding organs and tissues, leading to an increase in the total number of perioperative complications.

Local control

Previous studies have fully confirmed that en bloc resection can significantly reduce local recurrence of spinal chondrosarcoma. Fisher et al. [29] analyzing a cohort of 111 spinal chondrosarcoma cases from 1987 to 2011, concluded that Enneking appropriate surgery is associated with a reduced risk of local recurrence but not with OS. In 2023, Abunimer et al. [30] based on a cohort of 72 patients, indicated that total en bloc resection of spinal chondrosarcoma is associated with local recurrence-free outcomes and improved OS. Xing-hai Yang et al. [31] further refined these conclusions, revealing the positive impact of en bloc resection on the prognosis of cervical and cervicothoracic chondrosarcoma. Huabin Yin et al. [32] conducted a retrospective study of 98 cases of spinal chondrosarcoma, emphasizing that total spondylectomy significantly reduces the risk of recurrence and distant metastasis while improving OS.

Our study results indicated that tumor-free margin en bloc resection of spinal chondrosarcoma can reduce local tumor recurrence and extend RFS periods for patients. Although the tumor-free margin surgery carries higher risks and more complications, choosing a more thorough resection without transgressing the tumor is necessary and valuable for achieving better therapeutic effects and prognosis. Based on tumor pathological type and whether the surgery was initial or for recurrence, stratified analysis was conducted. Compared to conventional spinal chondrosarcoma, tumors such as dedifferentiated and mesenchymal types had significantly higher postoperative recurrence rates. Therefore, tumor-free margin en bloc resection should be performed to further reduce tumor recurrence and improve prognosis.

On the other hand, since tumor-free margin en bloc resection has been applied in recent years with new surgical techniques, the number of cases is smaller, and the follow-up period is obviously shorter compared to intralesional surgery. The currently reported median survival time is also shorter, which may not fully reflect the survival situation after tumor-free margin en bloc resection. However, from short-term analyses, it can still be concluded that en bloc resection with tumor-free margins can reduce mortality caused by tumor recurrence and extend the OS of patients with spinal chondrosarcoma. Further stratification analysis showed that for conventional spinal chondrosarcoma, tumor-free margin en bloc resection could significantly reduce the risk of mortality. This may be due to the lower postoperative mortality rate of conventional tumors in the absence of recurrence and metastasis. Therefore, tumor-free margin en bloc resection should be performed to reduce the risk of postoperative recurrence and achieve longer and satisfactory overall survival.

Limitations

This study was a single-center, retrospective analysis and had certain limitations. First, spinal chondrosarcoma is relatively rare, making it challenging to obtain a large sample size for the case cohort. Additionally, due to the poor prognosis of patients with malignant tumors, the overall follow-up duration (over 12 months) was relatively short. Second, the surgical cases included in this study span a period of 24 years. With the accumulation of surgical techniques and experience, and the advancement of materials and medical technology over time, ensuring consistency in treatment is very difficult. Consequently, when comparing cases from different periods, it is also challenging to eliminate the impact of this factor.

Conclusion

To achieve complete resection of spinal chondrosarcoma and reduce local recurrence, en bloc tumor resection is the preferred treatment. Regarding resection margins, although tumor-free margin resection is more difficult and carries higher risks, and is associated with a greater number of perioperative complications, it can reduce the risk of local tumor recurrence, prolong RFS and OS, and provide patients with better prognoses. Therefore, when the condition and general health of patients with spinal chondrosarcoma permit, we recommend tumor-free margin en bloc tumor resection surgery.

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Author contributions

Fangzhi Liu and Ben Wang contributed equally as co-first author.Conceived and designed the researches: Feng Wei, Zhongjun Liu.Performed the researches: Fangzhi Liu, Ben Wang.Data analysis: Fangzhi Liu, Ben Wang, Feng Wei. Contributed materials/analysis tools: Fangzhi Liu, Ben Wang.Supervision: Feng Wei, Zhongjun Liu, Xiaoguang Liu.Wrote the paper: Fangzhi Liu, Ben Wang, Feng Wei. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the institutional research ethics committee ((IRB00006761-M2023022), according to the principles of the Declaration of Helsinki. The institutional review board granted a waiver of informed consent because of the retrospective nature of the study.

Consent for publication

All participants provided written consent for the publication of the results of this study.

Competing interests

The authors declare no competing interests.

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