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En Bloc Resection of Thoracic and Upper Lumbar Spinal Tumors Using a Novel Rotation-Reversion Technique through Posterior-Only Approach

Ming Lu, MD*,†, Changhe Hou, MD†, Wei Chen, MD†, Zixiong Lei, MD†, Shuangwu Dai, MD†, Shaohua Du, MD†, Qinglin Jin, MD†, Dadi Jin, MD†, Haomiao Li, MD†

*Department of Orthopedic Surgery, The First Affiliated Hospital of Jinan University, Guangzhou, †Department of Musculoskeletal Oncology, Center for Orthopedic Surgery, The Third Affiliated Hospital of Southern Medical University, Guangzhou, China

Background: En bloc resection is recommended for the treatment of malignant and aggressive benign spinal tumors; however, it often requires a combined anterior-posterior approach, which is usually accompanied by longer surgical duration, increased blood loss, larger trauma, and surgical complexity. The present study describes a novel rotation-reversion technique for en bloc resection of the thoracic and upper lumbar spinal tumors using a posterior-only approach and evaluate its safety and efficacy.

Methods: Thirteen patients with thoracic and upper lumbar (L1-L3) spinal tumors were treated with en bloc resection using the rotation-reversion technique through a posterior-only approach at our institution between 2015 and 2023. The clinical characteristics and surgical results of the patients were reviewed and analyzed.

Results: Posterior-only en bloc resection was performed successfully in all 13 patients using the rotation-reversion technique, with a median follow-up of 30.4 months (range, 6–74 months). The average maximum size of these 13 tumors was 5.7 × 5.8 × 4.8 cm. The mean operation time and blood loss were 458.5 minutes (range, 220–880 minutes) and 3,146.2 mL (range, 1,000–6,000 mL), respectively, with 4 of the 13 patients (30.8%) experiencing perioperative complications. Negative margins were achieved in all the 13 patients (100%). One patient experienced local recurrence (7.7%) and 1 patient experienced instrumentation failures. Interbody fusion was confirmed in 11 of the 13 patients (84.6%), with a median fusion time of 6.9 months. All of the 13 patients experienced varying degrees of mild postoperative neurological deficits owing to resection of the nerve roots affected by tumor invasion of the vertebrae. No vessel injury or postoperative neurological paralysis occurred, except 1 patient who had been completely paralyzed before surgery.

Conclusions: The rotation-reversion technique is an effective procedure for en bloc resection of selected thoracic and upper lumbar spinal tumors through the posterior-only approach.

Keywords: *Spinal tumor, Surgical resection, En bloc resection, Surgical margin, Surgical technique*

Nowadays, en bloc resection is recognized as the gold standard technique for treating malignant and aggressive benign spinal tumors based on the Enneking staging and Weinstein-Boriani-Biagini (WBB) classification, which define the margin of excision according to the tumor location and extension and propose standard surgical procedures.[1,2] Combined anterior-posterior approaches and sometimes even additional lateral approaches are needed in en bloc resection of spinal tumors in standard surgical

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Correspondence to: Haomiao Li, MD
Department of Musculoskeletal Oncology, Center for Orthopedic Surgery, The Third Affiliated Hospital of Southern Medical University, No.183, Zhongshan Ave, Tianhe Distract, Guangzhou 510630, China
Tel: +86-20-6278-4550, Fax: +86-20-6278-4550
E-mail: lihaomiao1977@hotmail.com
Ming Lu and Changhe Hou contributed equally to this work as co-first authors.

procedures.[3,4] Total en bloc spondylectomy (TES), which resects the involved vertebrae in 2 major blocs by using the transpedicular osteotomy technique as proposed by Tomita et al. in 1994,[5] can be performed successfully in the thoracic and upper lumbar spine (L1-L3) through the posterior-only approach, which is conducive to decreasing surgical complexity and reducing operation wound.[6] However, it has been criticized for potential tumor contamination intraoperatively due to the transpedicular osteotomy in Tomita 3–6 type spinal tumors, in which tumor invasion not only extends to the vertebral body but also involves the pedicle and posterior arches.[6,7]

The lower lumbar spine segments (L4-L5) are surrounded by vital and complicated anatomies including major vessels, lumbosacral plexus nerves, psoas, iliac muscles, and the osseous obstruction of bilateral iliac wings that limits the space required for resection of the tumor from the posterior-only approach. In contrast, the anatomical position of the vital structures in the thoracic and upper lumbar spine (L1-L3) like major vessels (thoracic/abdominal aorta and inferior vena cava) are relatively stable and lack surrounding anatomical barriers over the surface of the vertebrae in these segments. In our opinion, en bloc resection of spinal tumors in the thoracic and upper lumbar segments based on the Enneking staging and WBB classification is feasible through the posterior-only approach, with the guarantee that at least 1 side of the pedicle and posterior arches are not invaded by the tumor. Here, we present a novel rotation-reversion technique for en bloc resection of the thoracic and upper lumbar spinal tumors using a posterior-only approach and demonstrate its safety and efficacy.

METHODS

This study protocol was approved by the Ethics Committee at The Third Affiliated Hospital of Southern Medical University (IRB No. 2022-008), and written informed consent was obtained from all patients.

Study Participants

From 2015 to 2023, 13 consecutive patients with primary malignant or aggressive benign thoracic and upper lumbar spinal tumors were treated with en bloc resection by using the rotation-reversion technique through the posterior-only approach at our institution (Table 1). There were 6 female and 7 male patients, with an average age of 33.2 years (range, 15–56 years). The tumor pathological types included osteosarcoma (3 cases), giant cell tumor (3 cases), chondrosarcoma (2 cases), Ewing's sarcoma (2 cases), embryonal rhabdomyosarcoma (1 case), chordoma (1 case), and malignant peripheral nerve sheath tumor (1 case). The WBB classification grades were S3 (3 cases), IB (3 cases), IIA (1 case), and IIB (6 cases). Three patients were recurrent tumor revision cases including 1 case of osteosarcoma, 1 case of embryonal rhabdomyosarcoma, and 1 case of chondrosarcoma. Tumors involved 1 level in 6 patients, 2 levels in 1 patient, 3 levels in 4 patients, and 4 levels in 2 patients. One patient underwent sagittal en bloc resection with a safe margin, while preserving the integrity of the spinal column.

Treatment Strategy Determination

All patients underwent radiography, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography/CT examinations preoperatively. A core needle biopsy was performed and histological diagnosis was made in all patients preoperatively. Selective arterial embolization was performed to embolize the blood supply vessels of the affected vertebrae 1 day before surgery in all cases. Tumor stage and surgical margins were assessed and determined according to the Enneking staging and WBB classifications.

Surgical Technique

Fig. 1 illustrates the en bloc resection technique performed using the one-stage posterior approach. Patients who underwent one-stage posterior en bloc resection using the rotation-reversion technique were placed in the prone position. All structures surrounding the posterior arch of the diseased vertebrae were separated according to the designed margin, and transpedicular screws were inserted into segments adjacent to the affected vertebrae. Posterior reconstruction with at least 2 vertebral levels above and below should be fixed by pedicle screws for 1 or 2 levels of en bloc spinal column tumor resection. For en bloc resections of more than 2 levels, at least 3 vertebral levels above and below should be fixed by pedicle screws and this should be combined with the satellite rod technique to yield strong 3-dimensional reconstruction and reduce the risk of rod breakage postoperatively. After bilateral costotransversectomy, the great vessels and structures surrounding the ventral side of the vertebrae were carefully dissected using a spatula and the surgeon's fingers at the upper and lower disc levels of the affected vertebrae that were not infiltrated by the tumor, and 2 dissectors were installed in the above dissected levels to block the great vessels and mediastinal structures (Fig. 2). A safe window was opened at the posterior arch of the vertebrae invaded by the tumor after piecemeal excision of the laminae and

Table 1. Clinical Characteristics of the Patients in This Study

No.	Age (yr)	Sex	Histology	Levels involved	Max-diameter (cm)	Enneking stage	WBB classification	Previous surgery	Preoperative chemo	Preoperative radiation	Operation time (min)	Blood loss (mL)	Reconstruction method	Complication	Margin	Follow-up (mo)	LR	Metastasis	Oncological status	Interbody fusion (mo)
1	20	M	OS	T6-T7	5.1 × 3.4 × 4.7	IIB	5-1/A-D	+	+	–	600	5,000	TM/PS	-	Marginal	4	–	+ (Lung)	DOD	-
2	22	M	ES	L2	4.2 × 5.1 × 2.3	IIA	4-9/B-C	–	+	–	350	4,000	EC/PS	Cage subsidence	Wide	72	–	–	NED	11
3	34	F	CHS	T2-T5	14.2 × 10.8 × 11.4	IB	1-7/A-D	–	–	–	880	5,500	TM/PS	Pneumonia	Marginal	28	–	+ (Lung)	DOD	-
4	22	F	GCT	T9-T11	6.0 × 6.3 × 5.0	S3	3-10/A-D	–	–	–	560	5,200	AV/PS	Pneumonia	Marginal	74	–	–	NED	6
5	30	F	GCT	T4	3.8 × 4.2 × 2.0	S3	3-9/B-D	–	–	–	350	6,000	TM/PS	-	Marginal	53	–	–	NED	7
6	17	F	ERMS	T4-T6	3.8 × 3.7 × 5.9	IIB	9-10/A-D (SEBR)	+	+	–	420	1,500	AV/PS	-	Marginal	38	–	–	NED	6
7	47	F	MPNST	T12	5.0 × 4.6 × 3.6	IIB	4-10/A-D	–	+	–	220	2,200	AV/PS	Pneumonia, IF	Marginal	27	+	+ (Lung, spine)	DOD	7
8	56	M	CHO	T6-T9	8.2 × 7.7 × 8.7	IB	3-10/A-D	–	–	–	420	2,500	AV/PS	-	Marginal	27	–	–	NED	6
9	25	M	GCT	T5-T7	6.0 × 7.2 × 6.2	S3	4-12/A-D	–	–	–	480	2,500	AV/PS	Pneumonia	Marginal	26	–	–	NED	8
10	43	M	CHS	T5-T7	4.5 × 6.4 × 4.7	IB	5-12/A-D	+	–	–	420	2,500	AV/PS	-	Marginal	21	–	–	NED	6
11	51	M	OS	L2	5.0 × 6.5 × 2.4	IIB	3-10/A-D	–	+	–	360	1,000	AV/PS	-	Marginal	11	–	–	NED	7
12	49	M	OS	T8	3.5 × 4.0 × 2.2	IIB	4-7/A-D	–	+	–	420	1,500	AV/PS	-	Marginal	8	–	–	NED	6
13	15	F	ES	T2	5.3 × 5.1 × 3.5	IIB	10-7/A-D	–	+	–	480	1,500	AV/PS	-	Marginal	6	–	–	NED	6

WBB: Weinstein-Boriani-Biagini, Chemo: chemotherapy, LR: local recurrence, OS: osteosarcoma, TM: titanium mesh, PS: pedicle screw, DOD: died of disease, ES: Ewing's sarcoma, EC: expandable cage, NED: no evidence of disease, CHS: chondrosarcoma, GCT: giant cell tumor, AV: artificial vertebrae, ERMS: embryonal rhabdomyosarcoma, SEBR: sagittal en bloc resection, MPNST: malignant peripheral nerve sheath tumor, IF: instrumentation failure, CHO: chordoma.

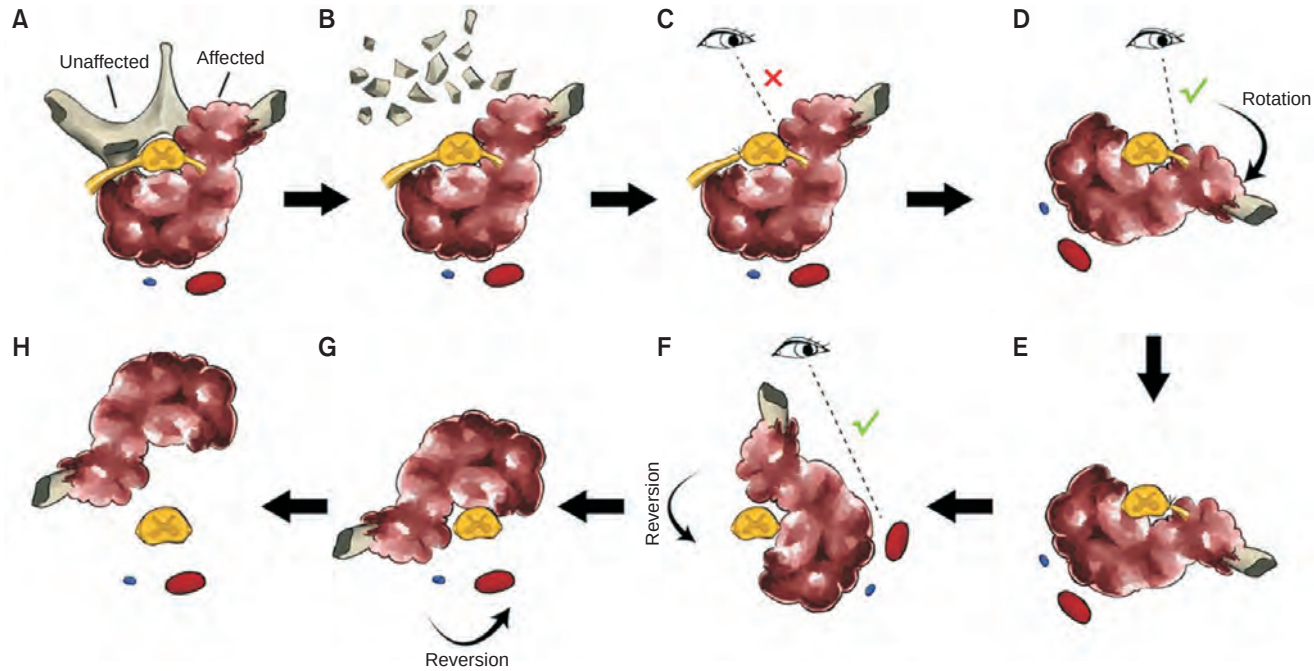

Fig. 1. Illustration of en bloc resection of a spinal tumor using the rotation-reversion technique through a single posterior approach. (A) A thoracic spinal tumor with intracanal and paraspinal invasion. (B) A safe window was opened at the posterior arch by piecemeal excision of the healthy laminae and pedicle on the unaffected side. (C) Nerve root on the unaffected side was sectioned, but the nerve root and dura on the affected side, which were covered by the tumor, could not be safely released from the tumor due to the lack of directional visualization. (D) The dura on the affected side was separated from the lesion under direct visualization by the rotation technique. (E) The nerve root on the affected side covered by the tumor was sectioned under direct visualization. (F) The great vessels and surrounding structures on the ventral side of the tumor-invaded vertebra were dissected under direct visualization using the reversion technique with the posterior approach. (G) Reversion of the entire mass was continued until it was completely released posteriorly. (H) The entire mass was removed posteriorly.

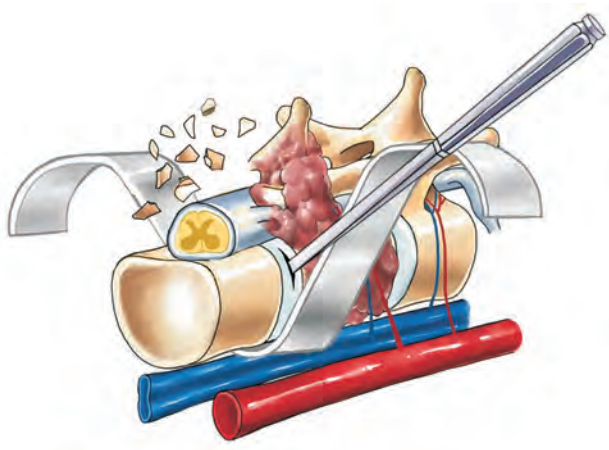

Fig. 2. Illustration of vertebral osteotomy at the planned cranial and caudal disc levels of the affected vertebra by using a sharp osteotome.

pedicle that was not infiltrated by the tumor, allowing entry into the spinal canal and section of the nerve roots on the unaffected side (Fig. 1B). Owing to tumor invasion of the lamina and pedicle, the nerve roots and dura on the affected side were covered by the tumor and could not be safely released from the tumor, as no directional visualization could be provided in a posterior approach (Fig. 1C). Hence, vertebral osteotomy was performed at the planned cranial and caudal disc levels using a sharp osteotome (Fig. 2). A temporary rod was fixed only on the unaffected side for stabilizing the spine to avoid spinal cord injury during osteotomy, which did not obstruct the space and surgical field of the affected side. After vertebral osteotomy, the specimen was rotated around the longitudinal axis to the affected side, enabling direct visualization of the dorsal structures of the spinal column (Fig. 1D). This allowed the dura to be separated from the tumor and the nerve roots to be sectioned without breaching the tumor capsule on the affected side (Fig. 1E). Next, using the reversion technique, the great vessels and surrounding structures on the ventral side of the tumor-invaded vertebrae could be reversibly rotated, providing directional visualization of the anterior vertebral column (Fig. 1F), allowing dissection to be carefully performed under direct visualization from the posterior approach, thereby avoiding great vessel damage

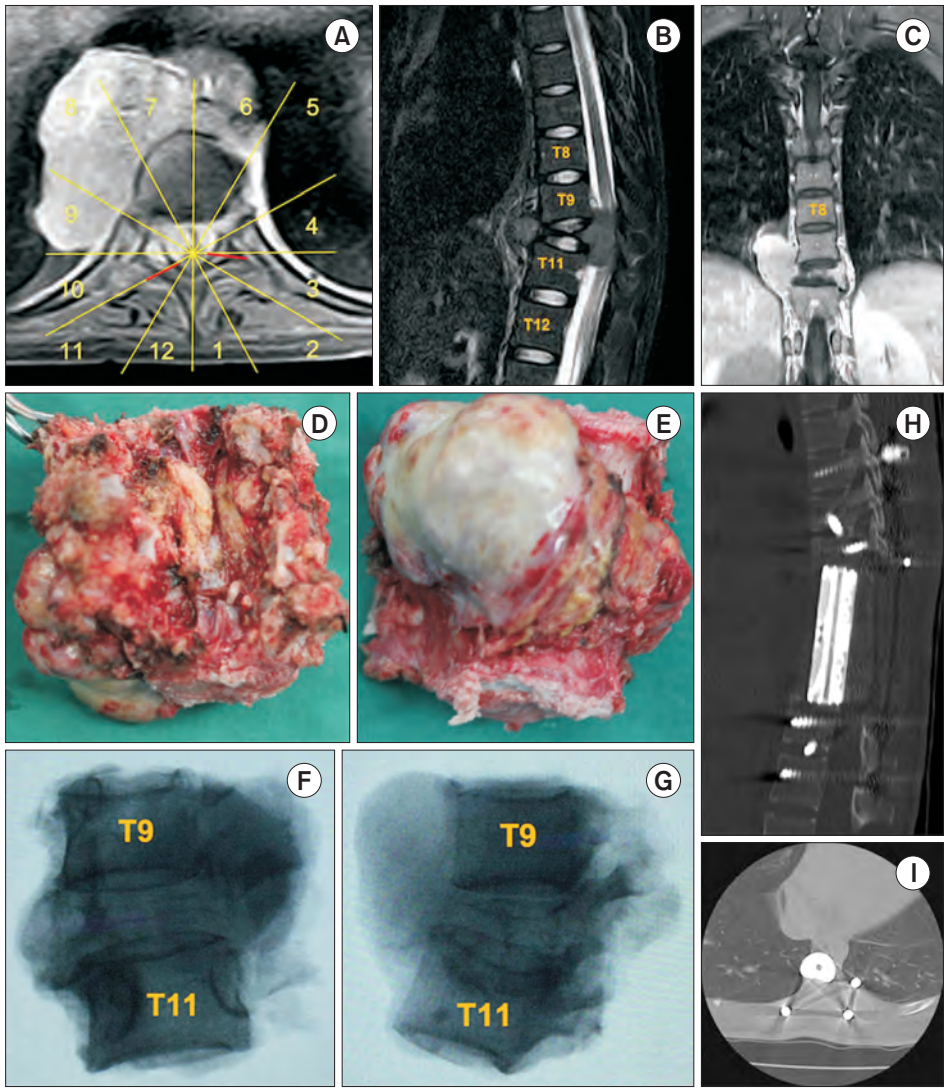

Fig. 3. A case of T9-T11 giant cell tumor that underwent one-stage posterior en bloc resection using the rotation-reversion technique. (A-C) Preoperative magnetic resonance imaging (the red line represents the safe window zone opened at the posterior arch). (D) Appearance on the dorsal side of the resected tumor-invaded vertebrae. (E) Appearance on the ventral side of the resected tumor-invaded vertebrae. (F, G) X-ray images of the excised specimen. (H, I) Postoperative computed tomography scan imaging.

and intraoperative tumor contamination. Finally, the entire mass was removed posteriorly using a reverse maneuver (Fig. 1G and H). The anterior defect was reconstructed, and pedicle screws were fixated using the posterior approach. Based on our experience, the angle of rotation generally does not exceed 90°, while the angle of reversion can reach up to 180° after circumspinal column dissection is completed. Fig. 3 illustrates the en bloc resection of the thoracic spinal tumor performed in 1 of these patients.

Follow-up

A regular follow-up was performed after the patient had been discharged from the hospital. Radiographs, CT scans, and MRI scans were performed during follow-up for all patients. Oncological and functional results were evaluated based on the clinical manifestations and imaging findings.

RESULTS

Oncological Results

En bloc resection was successfully performed, and negative margins, including 12 marginal and 1 wide margin, were obtained in all 13 patients (Table 1). According to the McDonnell classification,[8] 4 patients (30.8%) experienced minor complications (mostly pneumonia), while no major complications occurred. One patient (patient 7) experienced local recurrence associated with lung and spinal metastases 12 months after surgery. The patient had undergone an en bloc resection of T12 malignant peripheral nerve sheath tumor with marginal margins. Although proton radiation therapy was subsequently administered, the patient died 27 months after surgery. Two other patients (patients 1 and 3) died of lung metastases at 4 and 28 months postoperatively, respectively, without local re-

currence at the time of death.

Functional Results

All of the 13 patients experienced varying degrees of mild postoperative neurological deficits owing to resection of the nerve roots of the vertebrae affected by tumor invasion. No vessel injury or postoperative neurological paralysis occurred. Seven patients could walk normally (Frankel E), and 5 were able to walk with crutches (Frankel D) at the last follow-up time. One patient (patient 3), who had complete paralysis (Frankel B) preoperatively, did not experience any significant improvement in motor function during follow-up. Interbody fusion was observed in 11 of the 13 patients (84.6%), with a median fusion time of 6.9 months. One patient experienced instrumentation failure and neurological deficits due to tumor recurrence and adjacent vertebral metastasis (patient 7). Revision surgery was performed with normal spinal alignment maintained for this patient. Cage subsidence was observed in 1 patient during the follow-up, with no clinical symptoms.

DISCUSSION

There are many technical challenges encountered during en bloc resection of spinal tumors performed using a posterior-only approach as follows: (1) circumspinal decompression by separating the dura mater and nerve roots from the posterior longitudinal ligament and the posterior part of the affected vertebral body cannot be easily completed with the posterior approach, especially when tumor extension protrudes into the spinal canal; (2) the dissection of the great vessels from the anterior margin of the affected vertebral body, which solely relies on the surgeon's fingertips and vertebral spatula, is not safe enough. As the above operation processes cannot be performed under direct vision from a conventional posterior approach surgery, posterior-only en bloc resection is a great risk.[9,10] Taking all these challenges into account, a combined anterior release and posterior resection and reconstruction procedure is usually recommended, but it implies a longer surgical duration, more blood loss, and increased operation wound. Despite these difficulties, we still tried to find feasible solutions for en bloc resection of spinal tumors in the thoracic and upper lumbar segments through the posterior-only approach, and we believe these technical challenges may be resolved by the rotation-reversion technique.

In this technique, we focused on the safe margin and operation security, which are the 2 most important concerns during en bloc resection. Rather than resecting the diseased vertebrae into 2 major blocks by TES, en bloc resection based on the Enneking staging and WBB classification was completed in a single posterior approach using the rotation-reversion technique in this study, which fulfilled all the criteria of surgical margins and the principles of tumor excision for the removal of spinal tumors. Unlike the operation sequence mentioned by TES, by which circumspinal column dissection including separating the anterior great vessels and releasing the dura mater and roots in the canal is first achieved before discotomy, we first perform discotomy at the upper and lower discs of the diseased vertebrae and then release the dura and great vessels by rotating and reversing the diseased vertebrae, respectively. The reason why we adopt this different surgical sequence is that mediastinal structures such as the segment artery, aorta, and esophagus are sometimes difficult to safely separate from the affected vertebrae by the surgeon's fingertips or spatula, especially in the case of tumor extraosseous extension in the ventral region of the spinal column with the above important structures invaded. This is also the reason why a combined anterior release procedure is often required. In this study, we only needed to separate the mediastinal structures from the healthy vertebrae at the upper and lower disc levels of the diseased vertebrae, where there was no tumor invasion and no segmental vascular distribution; thus, it is easy for safe separation by the surgeon's fingertips. After discotomy at the above separation levels, using the rotation-reversion technique, the dura mater, nerve roots, and mediastinal structures were safely separated from the affected vertebrae under direct observation throughout the entire process, reducing the risk of damaging large blood vessels and safe margins.

Another theoretical advantage of this technique is that it avoids squeezing the tumor during the release of the anterior margin along the ventral side of the affected vertebrae when a single posterior approach is adopted. A potential risk factor for poor prognosis after resection of a malignant tumor may be squeezing and grasping the tumor prior to ligation of the surrounding vessels during the release and resection, as this may cause tumor cells to be released, increasing the risk of shedding tumor cells into the paravertebral vessels and deteriorating the prognosis.[11,12] Unlike the previous routine procedure, in which the mediastinal structures were pushed forward from the tumor by the surgeon's fingertips meeting each other anterior to the affected vertebrae from both sides,[5] we release the anterior margin by reversing the affected vertebrae to a direct field of view, without squeezing the affected vertebrae during the release procedure, which is more in line

with the principle of "no-touch isolation technique" advocated in the strategy to prevent the spread of tumor cells.[13]

The core concept of this newly designed operation sequence and technique is the operation procedure of circumspinal column dissection during rotation or reversion. At least a space demanding 60° to 90° of clock panel radiating zones of the healthy pedicle and posterior arches on the transverse plane defined by the WBB staging system is mandatory for a safe window opening to enter into the canal. Otherwise, the dura mater tube could not be completely separated from the vertebral canal wall even by rotating the affected vertebrae, which may increase the risk of spinal cord injury during processing of the affected vertebrae. Owing to the limited safe window opening into the canal and the reserved posterior arch blockage, it is difficult to perform discotomy using the surgical T-saw described by TES.[5] Instead, we used a sharp osteotome to cut the intervertebral disc from posterior to anterior under the protection of a dissector installed in the ventral vertebrae to block away the great vessels and mediastinal structures. After discotomy, the specimen was rotated or reversed around the spinal cord. Care should be taken to avoid damaging the vessels and spinal cord when rotating or reversing a specimen. Separation and rotation/reversion procedures must be carried out simultaneously as synchronous cooperation between the chief surgeon and assistants is quite important. Do not rotate or reverse excessively before the separation is completed.

Negative margins obtained in en bloc resection have been recognized as the most crucial factor associated with successful prognosis in aggressive benign and malignant tumors.[14] This novel "Rotation-Reversion" technique strictly complies with the safe surgical margin defined by Enneking staging and WBB classification, which have been verified as commonly accepted standards to enhance cure and reduce local recurrence.[15-18] Wide or marginal surgical margins, confirmed by postoperative CT scan imaging and histopathologic evaluation, were obtained in all of the patients in our study, which guarantees excellent results of this novel technique.

This study has several limitations. First, the sample size was insufficient, and the follow-up time was relatively short. Second, this was a single-center retrospective study, which might have led to case selection and surgical treatment strategy biases. Third, this study was limited by the surgical efficacy of spinal tumors. Other adjuvant therapies that might affect tumor prognosis, such as radiotherapy and chemotherapy, were not included in this study, warranting further investigation. Despite these limitations, this study proposes a new technique for en bloc resection of thoracic and upper lumbar spinal tumors through a posterior-only approach. The rotation-reversion technique presented here may help the development of optimal surgical strategies for treatment of spinal tumors. Posterior-only approach en bloc resection of spinal tumors in the thoracic and upper lumbar segments can be performed successfully by using the novel rotation-reversion technique with good results and limited complications.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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ORCID

Ming Lu https://orcid.org/0000-0002-1701-9133
Changhe Hou https://orcid.org/0000-0001-7994-3754
Wei Chen https://orcid.org/0009-0003-9326-2666
Zixiong Lei https://orcid.org/0009-0000-8608-4361
Shuangwu Dai https://orcid.org/0000-0003-1329-0345
Shaohua Du https://orcid.org/0000-0002-0543-4487
Qinglin Jin https://orcid.org/0000-0001-5728-2684
Dadi Jin https://orcid.org/0000-0002-9448-2615
Haomiao Li https://orcid.org/0000-0001-9629-790X

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