Single-stage multi-level construct design incorporating ribs and chest wall reconstruction after en bloc resection of spinal tumour

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Abstract

Purpose Multi-level reconstruction incorporating the chest wall and ribs is technically demanding after multi-segmental total en bloc spondylectomy (TES) of thoracic spinal tumours. Few surgical techniques are reported for effective reconstruction. A novel and straightforward technical reconstruction through posterior-lateral approach was presented to solve the extensive chest wall defect and prevent occurrences of severe respiratory dysfunctions after performing TES. The preliminary outcomes of surgery were reviewed.

Methods Multi-level TES was performed for five patients with primary or recurrent thoracic spinal malignancies through posterior-lateral approach. The involved ribs and chest wall were removed to achieve tumour-free margin. Then titanium mesh with allograft bone and pedicle screw-rod system were adopted for the circumferential spinal reconstruction routinely. Titanium rods were modified accordingly to attach to the screw-rod system proximally, and the distal end of rods was dynamically inserted into the ribs.

Results The mean surgery time was 6.7 hours (range 5–8), with the average blood loss of 3260 ml (range 2300–4500). No severe neurological complications were reported while three patients had complaints of slight numbness of chest skin (no. 1, 3, and 5). No severe respiratory complications occurred during peri-operative period. No implant failure and no local recurrence or distant metastases were observed with an average follow-up of 12.5 months.

Conclusions The single-stage reconstructions incorporating spine and chest wall are straightforward and easy to perform. The preliminary outcomes of co-reconstructions are promising and favourable. More studies and longer follow-up are required to validate this technique.

Keywords Reconstruction · Thoracic spinal tumour · Chest wall defect · Complications · Multi-segmental total en bloc spondylectomy

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Introduction

Multi-segmental total en bloc spondylectomy (TES) has been reported challenging but rewarding in spinal tumours due to its efficacy in achieving a safe tumour-free margin, decreasing recurrence rate, and prolonging survival [1–5]. Generally, TES usually means specific surgical techniques applied in oncology to perform en bloc laminectomy and vertebrectomy in single or two stages [6, 7]. In addition, an en bloc resection with a margin of ≥ 4 cm is recommended for primary malignant tumours [8]. However, high peri-operative complication rate of this surgical procedure was reported in previous studies, including the increasing risk of dura and neurological damage, adjacent vascular injury, excessive bleeding due to the vertebral veins and epidural venous plexus, hardware failure,

systemic cardiac, renal and respiratory dysfunction, and hypercoagulate state, especially in those cases with multi-segmental involvements [6, 9]. Also, combined one-stage posterior and anterior approach or even re-operations are needed for such cases [10, 11]. For patients with multi-level thoracic spinal tumours involving huge rib cage, chest wall defects are a common sacrifice [11, 12]. Severe respiratory complications (such as paradoxical chest wall movement, even respiratory failure) cannot be neglected and always lead to a devastating consequence when more than three ribs (rib length > 10 cm [13] or a flail segment of the chest wall is greater than 5 cm [14, 15]). However, few studies reported the effective techniques to reconstruct the spine and chest wall defect in a straightforward way. And because of the absence of costovertebral joints which can be used as the anchor points, the available rigid or non-rigid prostheses applied in thoracic surgeries cannot be used after TES. To the best of knowledge, for spine surgeons, this is the first-reported and straightforward technical note focusing on the single-stage multi-segmental construct design incorporating ribs and chest wall reconstruction after en bloc resection of spinal tumour.

Patients and methods

Between January 2016 to January 2017, five consecutive patients with primary or recurrent multi-level spinal tumours underwent en bloc resections and single-stage co-reconstructions in our department. A database of these five patients was reviewed comprehensively. All the details (including potential benefits as well as risks and complications) regarding the surgical procedure were introduced to the patients and their family members, then informed consents were obtained from all patients. The study protocol was approved by the Institutional Review Board of the hospital prior to initiation of the study. The inclusion criteria was as follows: (1) spinal malignancy deriving from thoracic vertebrae; (2) more than three spinal columns were involved; and (3) more than three ribs (rib length > 10 cm) needed to be removed together. The exclusion criteria included the following: (1) patients with metastatic lesions, (2) less than three segments involvements, and (3) skip malignancy across the spinal column. All patients underwent surgical procedures within three days after the histological diagnosis of spinal malignancy (computed tomography (CT)-guided biopsy for pathological diagnosis (please see the specific information in Table 1), positron emission tomography-computed tomography (PET-CT) for detecting the potential metastases).

The follow-up strategy was defined from the first day after surgery to October 31, 2017. All patients were followed up every month for the first three months and every three months for the next 12 months through outpatient way, clinical condition and radiographic examination were obtained to evaluate the prognosis.

Table 1 Characteristics and outcomes of five patients with multi-segmental spinal tumours

No.	Age/sex	DOS	Pre-VAS	Pre-FS	Tumour status	Level	DM	Sur. time	Blood loss	Ribs	Pathology	LR	DM	Post-VAS	Post-FS	Follow-up
1	52/M	12 months	8	C	Primary	T4–7	No	7 h	3500 ml	4	Chondrosarcoma	No	No	4	D	15.0 months
2	30/M	12 months	9	C	Recurrent	T4–6	No	7.5 h	3500 ml	3	Osteosarcoma	No	No	7	D	11.0 months
3	25/F	2 months	8	B	Primary	T1–3	No	8 h	4500 ml	3	Chondrosarcoma	No	No	3	C	14.0 months
4	54/M	12 months	7	C	Recurrent	T7–10	No	5 h	2300 ml	4	Fibrosarcoma	No	No	4	C	13.5 months
5	64/M	6 months	8	B	Recurrent	T5–7	No	6 h	2500 ml	3	Chondrosarcoma	No	No	4	D	9.0 months

DOS: duration of symptoms; pre-VAS: pre-operative visual analogue scale; pre-FS: pre-operative Frankel score; DM: distant metastases; Sur. time: surgery time; LR: local recurrence; post: post-operative;

Surgical technique presentation

Before making surgical protocols, all patients received magnetic resonance imaging (MRI) and CT with contrast examinations. Three-dimension (3D) printed models (ratio 1:1) based on the CT angiography and MRI were conducted in order to achieve tumour-free margin intra-operatively. PET-CT was used to detect the potential lesions outside the spinal column (Fig. 1). Then a comprehensive evaluation was performed to assess the vertebral destructions, the relationship between the tumour and the surrounding musculoskeletal structures including spinal cord, nerve roots, ribs, pleura, blood vessels, and soft tissues.

One of the biggest problems for spinal surgeons was how to balance the tumour-resected extent and the relevant sacrifice. After detailed negotiations with patients and their families, en bloc resections through posterior-lateral approach were adopted. Incisions were designed through posterior approach via pre-operative 3D-printed model and intra-operative C-arm X-ray equipment. Pedicle screw implantation was performed bilaterally after routine exposure and the left titanium rod was fixed transiently for protecting spinal cord. The laminae were resected regularly via the use of piezosurgery. Nerve roots were ligated using non-absorbable suture (1#) and cut off by scalpel (Fig. 2a). Paravertebral muscles were protected using medical gauze (immersed in the normal saline in advance) and retractor for better muscle strength preserving and wound healing (Fig. 2b–c). The involved thoracic nerves, ribs, and chest wall were resected for a total tumour removal (Fig. 2d–e). Then the pleura defect was sutured using artificial membrane.

Routinely, all the patients (except no. 1) underwent single-stage co-reconstructions after combined en bloc resection of the involved spine column and chest wall. The specific co-reconstruction is as follows: (1) firstly regular spinal

reconstruction (pedicle screw-rod system and titanium mesh filled with allograft bone for circumferential reconstruction) was performed. The diameters of screws were 3.5–4.0 mm for T1–T5 segment, 4.0–5.0 mm for T6–T10 segment, and 5.5–6.0 mm for T11–T12 level. Also, the length of the screws ranged from 35 to 40 mm according to the sagittal diameter of the spinal column and intra-operative X-ray. The diameters of titanium mesh were 14 and 16 mm for upper and lower thoracic spine, respectively. According to our experience, the three adjacent thoracic vertebrae needed to be at least fused above and below the titanium mesh. Compression ought to be exerted on the mesh by compressing the screw-rod system. (2) Then we fashioned the titanium rod via specific clamp (length: according to the resected ribs, diameter 5.5 mm) to the contour of the ribs. (3) And we inserted the distal end of each rod into the end of the rib (inserted depth 30–40 mm). The proximal end of rods was attached to the posterior fixation via transverse connection as the artificial costovertebral joint (Fig. 2f). Thus, the proximal side of rod was rigid as crosslink device to prevent excessive rotation of the spine. The rod body was capable of preventing the collapse of chest wall, while the distal side was fixed dynamically to allow the thoracic cavity to expand in a certain extent. Notably, the fashioned rods are required to be inserted with proper depth (30–40 mm), otherwise fracture might occur at the stress-concentrating spot of the rods.

Then cis-platinum (1:1 with distilled water) was adopted for local infiltrated chemotherapy in cases that the thecal sac was unbroken. After suturing the wound layer by layer, all patients received vacuum sealing drainage (VSD) post-operatively. The tumor specimens were sent immediately to the pathologists. Then more detailed pathological examinations of the tumour were performed within the following seven to ten days. The post-operative radiotherapy was not recommended unless recurrence was suspected from the re-examinations.

Fig. 1 Pre-operative PET-CT image and 3D-printed model of a typical patient. **a** The PET-CT indicated no metastatic lesions outside the primary site. **b** The typical image of 3D-printed model was based on the pre-operative computed tomographic angiography (CTA) and magnetic resonance imaging (MRI)

Fig. 2 Description of important details of the surgical technique. **a** The left titanium rod was fixed transiently with T1–3 and T8–10 pedicle screws for spinal cord protection, and the involved nerve roots were ligated. **b–c** The medical gauzes were used to protect the paravertebral muscles to broaden surgical horizon for better tumour en bloc excision.

d–e The whole specimen of resected tumour and the X-ray fluoroscopy of resected tumour. **f** The titanium rods were modified for the curvature of the ribs via bent plier, then comprehensive spine and chest wall reconstructions were finally performed as the intra-operative image showed

Actually, for the first time in treating the patient (no. 1), since we just performed the regular spinal reconstruction without tackling the ribs and chest wall defect at the first surgery, the patient suffered severe paradoxical chest wall movement with unsatisfied blood oxygen saturation and could only be supported by mechanical ventilation. Thus, we performed the second surgery as illustrated above the next day. Fortunately, after using titanium rods as the rigid support for the chest wall defect, the patient separated himself from ventilator support and breathed on his own without respiratory failure.

Results

Characteristics of patients

Four male and one female patients were enrolled in our current study, with age ranging from 25 to 64 years old (mean 45). Two patients had primary lesion for the first operation, while three needed revisions because of the recurrent malignancy. The most common complaints included nocturnal increasing back pain, lower extremity numbness, and even paraplegia. The mean pre-operative visual analogue scale (VAS) was 8.0 (range 7–9), and Frankel score ranged from B to C.

Surgical outcomes

The mean surgery time was 6.7 hours (range 5–8), with the average blood loss of 3260 ml (range 2300–4500). The mean follow-up was 12.5 months (range 9.0–15.0). Patients received X-ray and CT re-examinations post-operatively to assess the

reconstructive system. Figure 3 shows the typical post-operative images of healed incision and reconstructions. The final pathological reports indicate chondrosarcoma in three patients (nos. 1, 3, and 5), osteosarcoma in one patient (no. 2), and fibrosarcoma in one patient (no. 4).

No severe neurological complications happened during the follow-up period, except three patients had slight complaints of chest skin numbness (nos. 1, 4, and 5). Four patients regained ambulatory status two months after the surgery, another one (no. 1) was able to walk without assistance in approximately 11 weeks after surgery. The post-operative Frankel score ranged from C to D with at least one-level upgrading. The mean post-operative VAS was 4.4 (range 3–7).

No patient died during the peri-operative period. One (no. 1) had flail-chest-related dyspnea after the first surgery due to the lack of effective rib reconstruction and recovered after undergoing the second operation. The other four patients recovered uneventfully with favourable wound healing. No pneumonia or other infections occurred during the peri-operative period and no one needed to be supported by mechanical ventilation. At the final point of follow-up, proper anatomical shape of the rib cage and favourable spinal reconstruction were obtained from the re-examination results. No hardware failure or local recurrence or distant metastases were observed at the latest follow-up. Details of patients' characteristic and outcomes were recorded in Table 1.

Discussions

TES has been proven challenging but rewarding in spinal oncology practice [1, 16–18]. In some multi-level cases

Fig. 3 Outcomes of posterior wound healing condition and co-reconstruction system. **a** The image of wound healing condition (1 month after surgery). **b** The post-operative X-ray image during the peri-operative period (3 days after surgery). **c** The CT reconstructive image of reconstruction system (3 months after surgery)

incorporating ribs and chest wall, ribs and chest wall need to be removed together to achieve a tumour-free margin. As a result, flail chest is a common fatal consequence which can result in paradoxical chest wall movement, altered respiratory mechanics, and followed by acute respiratory failure [19]. The respiratory complication rate after chest wall resection is reported as high as 24–27% [13, 20]. To the best of our knowledge, from the perspective of spine surgeon, few studies have focused on the effective reconstruction after en bloc resection of spinal tumour incorporating chest wall and ribs. Hereby, this technical note is devoted to delineate posterior-only approach to perform multi-segmental en bloc resection and an easy-to-operate way for comprehensive spine and rib reconstruction to avoid severe respiratory complications.

Surgical stabilization of flail chest has been demonstrated feasible and promising for reducing pneumonia rate, tracheostomy rate, duration of mechanical ventilation, and duration of intensive care unit stay [19]. For thoracic surgeons, rigid or non-rigid prostheses were usually used for chest wall reconstructions [20, 21]. However, the studies above all focus on the chest wall reconstruction from the point of thoracic surgeons with the existence of the whole or part vertebrae. From the perspective of spinal surgeons, these techniques might not be available especially in cases of spinal tumors. Since the fixation techniques above are all based on the existence of costovertebral joints, they can be used as the anchor points. Therefore, without the presence of fulcrums, the fixation techniques in the thoracic surgery could not be effective after combined resections of spinal tumours, ribs, and chest wall. From the point of spine surgeons, limited information was reported regarding addressing such huge chest wall defect. Table 2 illustrates the information of chest wall reconstructions from the related published studies [11, 15, 22, 23]. However, each study reported one case, respectively. The authors all performed the whole surgery with two or three stages, and the blood loss ranged from 3000 to 8700 ml (two did not provide specific blood loss). The material for chest wall reconstruction included MatrixRib and SILC fixation systems, polymethylmethacrylate

and polypropylene mesh, methylmethacrylate, and right eighth rib as well as Marlex mesh. Demura et al. [23] reported that the patient suffered subcutaneous recurrence one year after surgery and underwent successful excision subsequently. Also, the patient received revision surgery because of pseudarthrosis. However, the reported methods and material might not meet the demand in reconstructing the extensive chest wall defect of the patients in our study. In our reconstruction systems, one of the ends of the titanium rods is made as the artificial rigid fulcrums, and the other end is inserted into the rib along with thoracic expansion dynamically. Figure 4 shows the diagrammatic images of this reconstruction system. The chest wall collapse and paradoxical respiration can be avoided with titanium rod support. This technique is easy to handle and definitely practical in such clinical cases.

In addition, although one-stage combined posterior and anterior approach or even posterior-only approach has been reported safe and effective in treating most of multi-level spinal tumours [11, 24, 25], the radical excision might be tough unless the paravertebral muscles are cut off in cases with large paraspinal tumour mass. Therefore, we adopted posterolateral way to protect paravertebral muscles and resect tumours radically. We used gauzes to expose the paraspinal tumour mass below the muscles for reserving back strength maximally (Fig. 2a–b). It's convenient and practical. In addition, we believe it's also a contributor for post-VAS decreasing due to less injury during the operation.

Effective reconstruction after total spinal tumour removal remains a big challenge. To the best of knowledge, this is the novel study reporting this new technique from the perspective of spine surgeons. The preliminary outcomes of these comprehensive reconstructions are promising and favourable, including pain relief and neurological function improvement. No severe respiratory complications occurred during the peri-operative period. All the five patients have no delayed wound healing, local failure, or distant metastases. However, due to the challenging surgical skills and intra-operative blood loss as well as critical peri-operative management, the surgical

Table 2 Information of chest wall reconstruction from the related published studies

Year	Journal	Diagnosis	No. of cases	Approach	Involved segment	Chest wall reconstruction material	Blood loss (ml)	Complications	Follow-up (month)
2011	Eur Spine J	Pancoast tumour	1	Posterolateral	T2–4	MatrixRib and SILC fixation systems	–	Right arm and scapular pain	7
2011	Spine (Phila Pa 1976), Neurosurgery	Ewing Sarcoma	1	Anterior and posterior (two stages)	T8–9	Polymethylmethacrylate & polypropylene mesh	3000	None	24
2011	Neurosurgery	Chordoma	1	Posterior and bilateral (three stages)	T1–5	Methylmethacrylate	–	None	25
2011	Orthopedics	Giant cell tumor	1	Anterior and posterior (two stages)	T12	Right eighth rib & Marlex mesh	8700	subcutaneous recurrence & pseudarthrosis	84

Fig. 4 The diagrammatic image of co-reconstruction system

procedure ought to be performed by the dedicated team from spinal oncology. We also recommend that specific 3D-printed models (1:1) based on the thorough MRI and CT examinations need to be made for better pre-operative evaluation and surgical resection.

Although this is the first report focusing on the new technical co-reconstruction after combined excisions of spinal tumours, ribs, and chest wall, limitations do exist. Firstly, the cohort of patients is small. Secondly, the duration of follow-up is not long enough. Larger sample size and longer follow-up period are essential to prove the safety and effectiveness of this technique.

Conclusions

To weight the benefits and sacrifices, multi-level TES should be taken into decision-making process in treating primary or recurrent spinal tumours and should be performed by dedicated team of spinal oncology. The whole procedure can be performed only through posterior approach, which is straightforward and cost-effective. The preliminary outcomes of comprehensive spine and chest wall reconstructions using titanium are favourable and promising. More studies and longer follow-up are required to validate this technique.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Ethics approval and consent to participate The study had been approved by the Hospital Ethics Committee and written informed consents were obtained from the patients for publication of these case series and any related data. Copies of the written consent forms are available for review by the editorial board of this journal.

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