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ORIGINAL ARTICLE

An improved total en bloc spondylectomy for L5 vertebral giant cell tumor through a single-stage posterior approach

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Abstract

Purpose Although total en bloc spondylectomy (TES) is strongly recommended for spinal giant cell tumor (GCT), it is extremely difficult to excise a L5 neoplasm intactly through the single-stage posterior approach. Given the risk of neurological and vascular injury, intralesional curettage (IC) is usually recommended for the treatment of L5 GCT. In this study, we presented our experience with the use of an improved TES to treat L5 GCT through the single-stage posterior approach.
Methods This study included 20 patients with L5 GCT who received surgical treatment in our department between September 2010 and April 2021. Of them, seven patients received improved TES without iliac osteotomy, and the other 13 patients received IC ($n=8$), sagittal en bloc resection ($n=1$), TES with iliac osteotomy ($n=3$), and TES with radicotomy ($n=1$) as control.
Results The mean operative time was 331.43 ± 92.95 min for improved TES group and 365.77 ± 85.17 min for the control group ($p=0.415$), with the mean blood loss of 1142.86 ± 340.87 ml *vs.* 1969.23 ± 563.30 ml ($p=0.002$). Postoperative treatment included bisphosphonates in nine patients and denosumab in 12 patients including one patient who changed from bisphosphonates to denosumab. Three patients who received IC experienced local recurrence, and no relapse was observed in improved TES group.
Conclusion Single-stage posterior TES for L5 GCT was previously considered impossible. In this study, we presented our experience with the use of an improved surgical technique for L5 TES through the single-stage posterior approach, which has proved to be superior to the conventional procedures in terms of blood loss control and complication and recurrence rates.
Level of Evidence IV.

Keywords Total en bloc spondylectomy · Intralesional curettage · Giant cell tumor · Fifth lumbar vertebra · Surgical approach

Introduction

Giant cell tumor (GCT) of the bone is a locally aggressive and rarely metastasizing tumor, accounting for about 22% of all benign bone tumors [1, 2]. The incidence of GCT in spinal motion segments ranges from 1.4 to 9.4% [3], with a relatively high postoperative recurrence rate of 25–50% [4, 5]. According to its benign and invasive behavior in nature, intralesional curettage (IC) and adjuvant therapy with the use of denosumab or bisphosphonates are common treatments for spinal GCT (SGCT). Total en bloc spondylectomy (TES) is appropriate for patients with primary malignant tumors, aggressive benign tumors, or isolated metastasis. To date, there is strong evidence supporting TES for spinal SGCT due to lower local recurrence than other treatment methods [2, 6–10].

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TES is technically feasible for vertebral tumors between T1-L3 [11], but only a few articles have reported its use in lower lumbar spinal tumors through a single-stage posterior approach [12–16]. The L4 and L5 vertebral bodies are the largest of the spinal vertebrae located at the deepest point of lumbar lordosis. In addition, L5 surgery through a posterior-only approach is extremely challenging due to the complex surrounding anatomies such as the abdominal aorta, inferior vena cava (IVC), lumbosacral plexus nerves, together with the obstruction caused by the bilateral iliac wings. Therefore, a combined posterior and anterior approach to achieve TES for the lower lumbar tumors is recommended as the preferred approach in the literature [12].

In recent 3 years, we have applied a novel technique to perform a posterior approach only TES for L5 spinal tumors via fully dissection of L4 and L5 nerve roots and restoring lumbar lordosis, without iliac osteotomy. In this study, we elaborated the technical key points and made a comparison between our improved total en bloc spondylectomy via the single-stage posterior approach and conventional surgical procedures reported in the literature.

Materials and methods

The study was performed in the Department of Orthopedic Oncology of Changzheng Hospital (Shanghai, China). From September 2010 to April 2021, 256 SGCT patients were admitted and received surgical treatment in our department, including 62 patients with GCT in the lumbar spine. Of them, 20 patients had the tumor in the L5 vertebra, accounting for 7.8% of all SGCT cases. Meanwhile, these patients with GCT in L5 accounted for 13.6% of 147 patients with L5 tumor who were surgically treated in our department during the same period. The study was approved by the hospital ethics committee, and written informed consent was obtained from all patients. The flowchart of the enrolled patients with L5 GCT is presented in Fig. 1.

The diagnosis of SGCT was confirmed by needle biopsy in 14 of the 20 patients before surgical resection, and the other six patients received emergence surgery without doing needle biopsy because of severe neurologic dysfunction or unbearable pain. All 20 patients received intraoperative fast pathological examination, and the diagnosis of GCT was confirmed by two specialist pathologists of orthopedic oncology. The preoperative neurologic status was recorded according to the Japanese Orthopedic Association (JOA) score [17]. Tumor extension was described according to the Weinstein–Boriani–Biagini (WBB) system and Tomita classification based on CT and MRI. The target population of the improved TES for L5 GCT included patients with type 1–4 or some type 5 lesions according to the Tomita classification, without major vascular involvement. Similarly, this novel surgical technique could be applied in patients without a large mass in layers A and sectors 6–7 based on WBB system for avoiding damage to the vascular structures. Selective arterial embolization was performed to decrease

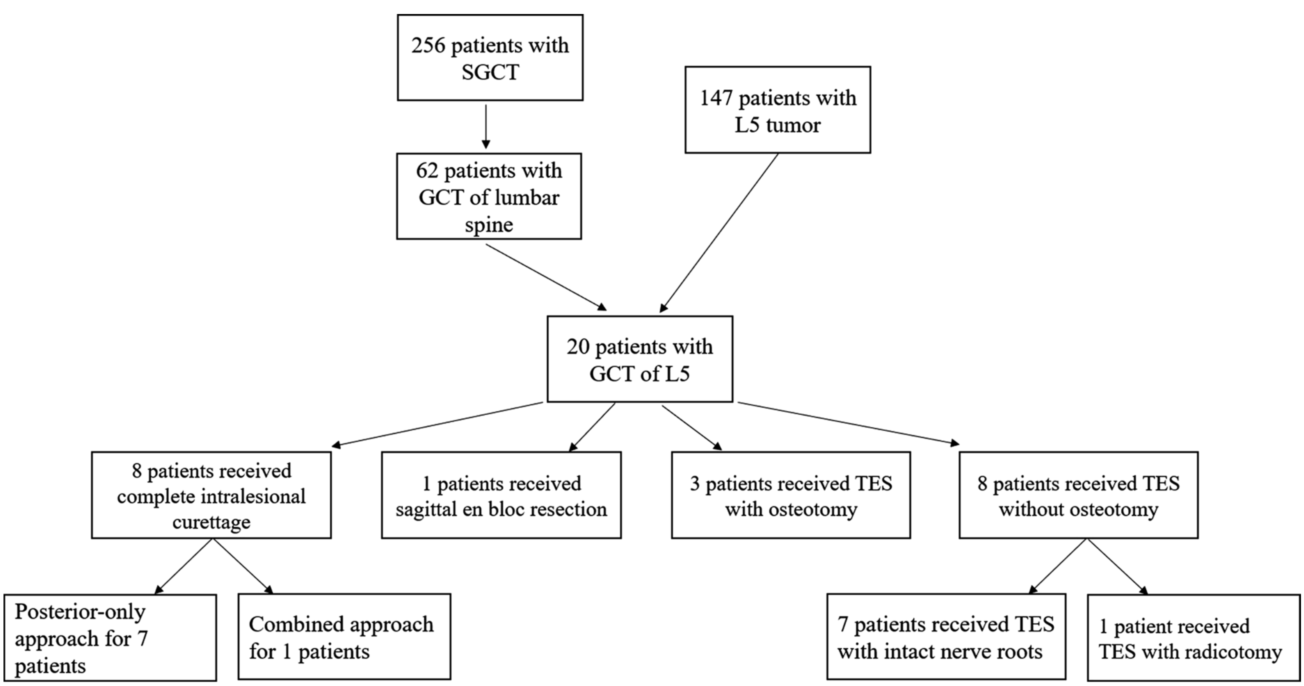

Fig. 1 Flowchart of enrolled patients with L5 GCT

intraoperative bleeding in 19 patients, including one patient who was also implanted with an abdominal aortic balloon. To maintain spinal stability and balance, a screw-rod system allying with the artificial vertebral body or titanium mesh was used for reconstruction in all patients.

The recurrence status was confirmed based on the clinical manifestations and imaging findings on the outpatient follow-up basis. Regular assessment was performed at 3, 6, and 12 months after surgery, every 6 months for the next 2 years, and annually for life thereafter. Follow-up data were obtained from outpatient clinic visits and telephone interviews. In the first three months after surgery, neural function was re-evaluated based on the JOA score and the recovery rate calculated using the equation: recovery rate (%) = (postoperative score − preoperative score)/(29 − preoperative score) × 100 [17]. Spinopelvic alignment parameters including lumbar lordosis (L1-S1 and L4-S1), pelvic incidence (PI), and pelvic tilt (PT) were measured and analyzed based on preoperative and postoperative lateral radiograms of the spine. The follow-up period was defined as the interval from the date of surgery to death, or until April 2022 for surviving patients.

Statistical analyses were performed with SPSS, version 22.0 (Chicago, Illinois, USA). Continuous data are described as the mean and standard deviation (SD) and compared by Student's t test. $p < 0.05$ was considered statistically significant.

Surgical procedures of the improved TES

TES aided by iliac osteotomy was performed as previously described in Case 4, 7 and 8 [12]. The right L5 nerve root was cut in Case 10 because of tumor erosion and the vertebral body was rotated out successfully. TES via the novel surgical procedure was performed in Case 13–17, 19 and 20.

Step 1. The patient was placed prone on the operating table after general anesthesia. A common straight midline incision was made from L3 to S2. The muscles and other soft tissues were dissected from the spinous process, the lamina and transverse process. Eight suitable pedicle screws were implanted into L3, L4, S1 and S2 routinely. With the paraspinal tissues retracted laterally, the supraspinous and interspinous ligaments were dissected. Part of the L4 and the whole L5 spinous process and lamina were removed to expose the spinal canal with the osteotome technique. The neighboring articular processes, as well as the L5 pedicles, were osteotomized and removed. As the spinal canal space is often invaded by the tumor in SGCT, the dura mater should be dissected carefully and freed up circumferentially.

Step 2. The titanium rod was bent into the appropriate curvature and fixed to the bilateral screws. Then, unilateral L4 and S1 screws were lifted alternately to restore the degree of the lumbosacral spine lordosis. This procedure could reduce the influence from the blockage of iliac wings. Unilateral L4 and L5 nerve roots were dissected for adequate length caudally to achieve enough space for tumor rotation according to the size of the vertebral body. According to our experience, the appropriate length of dissection of the L4 and L5 nerve root was 3.5–4.0 cm. The psoas muscles and surrounding tissues were separated along the lateral vertebral wall to the ventral vertebral body using a blunt dissection technique by lance-shaped dissectors, which was key to avoid damage to the ventral vascular structures. The segmental vessels were identified and ligated in case they were injured. Several gauzes were filled in the interval between the vertebral body and major vessel to ensure the safety of cutting the L4/5 and L5/S1 disks and anterior longitudinal ligament. It is preferable to use the osteotome with a blunt edge for separation of the intervertebral space when the surgeon had a sensation of loosening in his hand. The nerve root retractors were used for gentle traction, and then the L4 and L5 nerve roots were mobilized and larger space was provided for rotation of the L5 vertebral body. When the vertebra was detached from the spinal column, radiographic examination was carried out to confirm the radiographic margins.

Step 3. After completion of L5 TES, circumferential reconstruction of the L5 vertebra was conducted. The residual vertebral disks were handled. An artificial vertebral body or titanium mesh filled with autologous or artificial bone grafts was used for L5 vertebral body reconstruction. Selection of gaskets' angles is according to total lumbar lordosis in the preoperative standing neutral position. It is conducive to the placement of artificial vertebral body between the vertebral bodies. Proper sagittal compression along the pedicle screws and rods could effectively prevent anterior slippage of the artificial vertebral body. Finally, a drain was placed and the wound was sutured routinely (Figs. 2, 3, 4; Supplementary Fig. 1).

Results

Of the 20 included patients, four were male and 16 were female with a mean age of 33.45 ± 14.42 (median 30, range 14–68) years, including 13 patients (65%) aged between 20 and 40 years. A single-stage posterior approach was employed in 19 patients, and a combined approach was selected in the remaining patient (Case 1). The patient in Case 6 had received IC in another hospital 6 months before this admission. Sagittal en bloc resection was performed in one patient (Case 18) to remove the right half vertebral body with an extended incisal margin; TES with iliac osteotomy was performed in three patients (Case 4, 7 and 8) [12]; TES with radicotomy was performed in one patient (Case 10); TES without osteotomy was performed in the

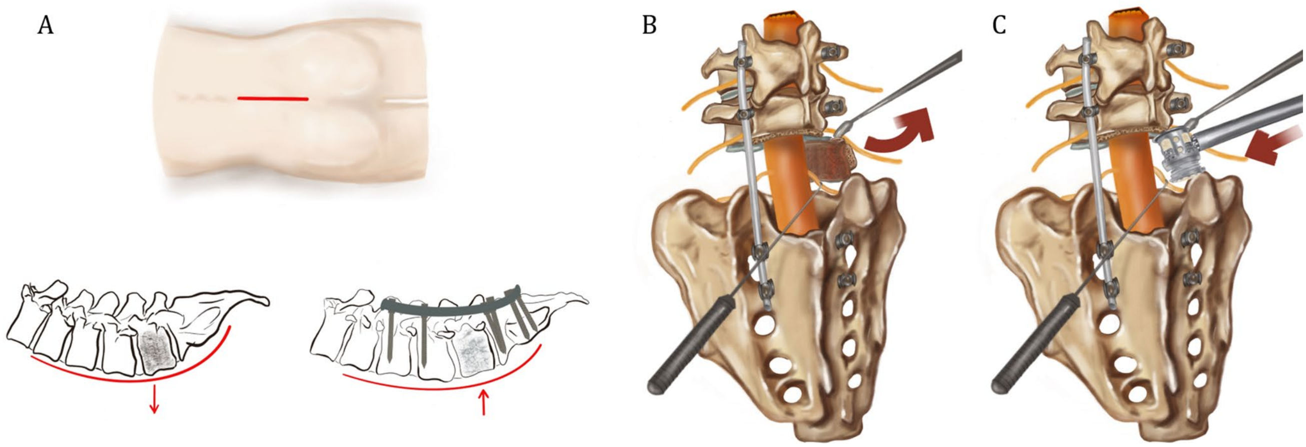

Fig. 2 Diagrammatic drawing of the new technique. **A** The patient was placed prone on the operating table after general anesthesia. Without stabilization by titanium rod, the degree of lumbosacral spine lordosis will increase in a prone-position lumbar surgery. With the help of titanium rod, unilateral L4 and S1 screws are lifted alternately. The degree of lumbosacral spine lordosis is restored. **B**, **C** Unilateral L4 and L5 nerve roots were dissected for adequate length caudally to achieve enough space for rotation of the L5 vertebral body. An artificial vertebral body or titanium mesh filled with autologous or artificial bone grafts was used for L5 vertebral body reconstruction subsequently

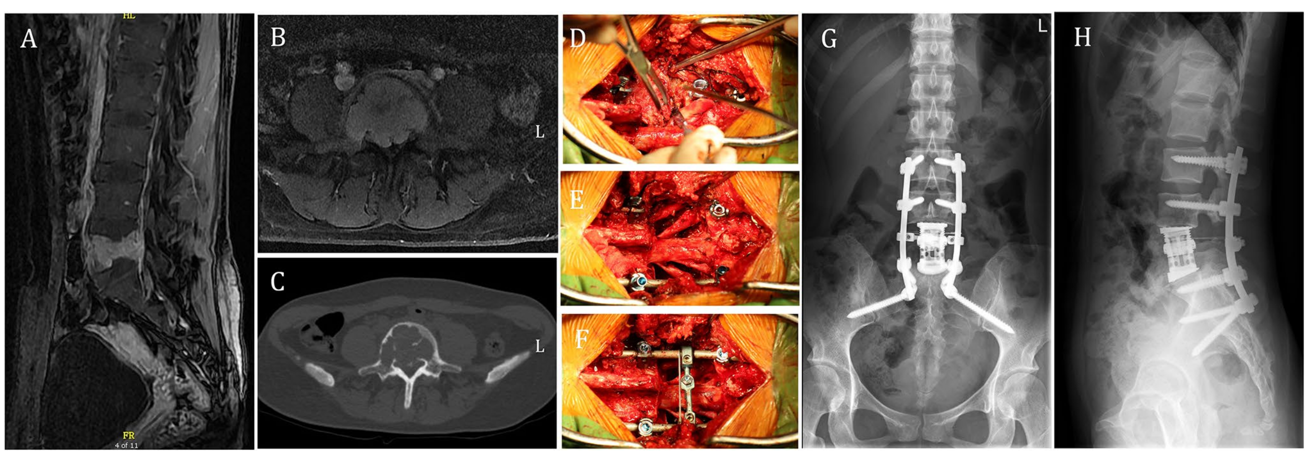

Fig. 3 Case 17 **A**–**C** Preoperative images revealed a vertebral neoplasm of the fifth lumbar L5 with compression fracture. **D**–**F** Intraoperative images showed the vertebral tumor was complete removed and titanium cables was used to limit displacement of artificial vertebra. **G**, **H** Postoperative X-ray

remaining seven patients. The mean surgical time in the seven patients who received the improved TES without osteotomy and other 13 patients via the single approach was 331.43 ± 92.95 min and 365.77 ± 85.17 min, respectively ($p = 0.415$), with a mean blood loss of 1142.86 ± 340.87 ml and 1969.23 ± 563.30 ml, respectively ($p = 0.002$).

Perioperative complications were observed in five patients, including incisional infection, delayed wound healing, numbness of the left lower limb and right foot drop after surgery. In Cases 1 and 6, the incisions were healed up gradually after continuous suction and intensive care. The traction injury of the left L4 and L5 nerves led to numbness of the left lower extremity in Case 8 and 14, which improved significantly in four weeks [12]. In Case 10, the right L5 nerve root was encased and eroded by the tumor, which had to be ligated intraoperatively. Early rehabilitation of the right limb and orthotics was conducive to relieve the symptoms of right foot drop. Neurologic symptoms were improved to varying degrees postoperatively. The pre- and postoperative JOA score was 8–23 (mean 14.6 ± 3.86) and 19–28 (mean 24.0 ± 2.75), respectively. The neurologic prognosis was excellent in 13 cases (> 60%), good in six cases (25 ~ 60%), unchanged in the remaining one (< 25%). No internal fixation failure

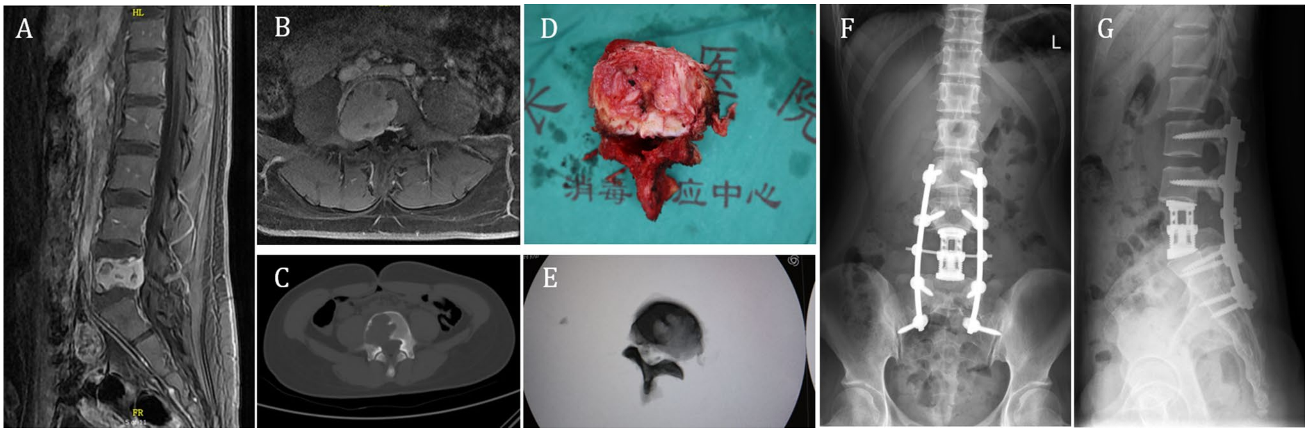

Fig.4 Case 19 **A**–**C** Preoperative images presented a vertebral tumor of L5. **D**, **E** The vertebral body involved with GCT was took out intactly. **F**, **G** Postoperative X-ray

was detected in our series. In the improved L5 TES group, pre- and postoperative lumbar lordosis was, respectively, 36.3 ± 7.20 and 31.0 ± 8.80 for L1-S1 ($p = 0.243$), and 28.6 ± 3.45 and 27.2 ± 7.21 for L4-S1 ($p = 0.655$). There was also no significant difference between preoperative and postoperative PI (42.0 ± 9.66 *vs.* 42.7 ± 10.9, $p = 0.909$) and PT (16.1 ± 5.05 *vs.* 14.0 ± 5.81, $p = 0.484$). Pathological evaluation showed negative surgical margins in all seven patients.The mean follow-up period was 49.20 ± 7.18 months. Unfortunately, three patients (15%) who received IC developed local recurrence during the follow-up period, for whom revision surgery was performed subsequently. At present, all the three patients are alive with no relapse, though pulmonary metastasis was detected in one patient (Case 1) about 3 months after the initial surgery. The initial surgical plan of Case 2 was TES. However, severe osteolytic damage was found in the L5 vertebral body during operation and the vertebra was fragmented during dissection and rotation. Therefore, TES was converted to IC and local recurrence developed 18 months after operation in this patient. All the 20 patients received adjuvant therapy postoperatively, including 9 patients with bisphosphonates and 12 patients with denosumab (bisphosphonates were changed to denosumab after the second operation in Case 2), and two patients also received radiotherapy after local relapse. The main clinical information is presented in Table 1.

Discussion

GCTB is one of the most common primary bone tumors with potentially aggressive behaviors [2]. This locally aggressive characteristic of GCTB may result in a high rate of local recurrence due to insufficient excision despite the postoperative adjuvant therapy with denosumab [18] or bisphosphonates [2, 7, 19]. En bloc resection was recommended by the Spine Oncology Study Group (SOSG) in 2009 [20]. Although it is technically feasible for T1-L3 vertebral tumors, it is extremely difficult to excise a L5 vertebral tumor intactly through the posterior-only approach [12, 13, 21]. In addition, the anatomical structure at the level of L5 are complex. The vertebral body of L5 is the widest of the spinal column, and the surrounding space is cramped and deep. Additionally, the tight ligament connection between L5 and the adjacent sacral structures needs to be released for total spondylectomy. The aortic bifurcation and venous confluence are usually located at the L4 to L5 level, but the operation performer should be highly alert to any possible variation in the anatomy of the iliolumbar vein. Therefore, TES of L5 tumor runs a high risk of causing major vascular injury during operation and neurologic deficits after operation [21–23].

So far only a few groups have successfully removed a L4/L5 vertebral tumor through the posterior-only approach [12–16]. Xiong et al. performed TES of the lumbar tumor via the paraspinal approach as first described by Wiltse et al. [14]. Compared with the conventional posterior midline approach, the paraspinal approach can provide a better view of the ventral aspect of the spine and reduce the risk of injury to the IVC and segmental vessels. In our previous study, we reported seven patients who underwent TES for the fifth lumbar tumors through the posterior-only approach with excellent outcomes [12]. Osteotomy of the iliac crest was carried out to eliminate the obstacles of the iliac wing. Based on the previous experience and autopsy research [12, 13, 16, 24], surgical strategies have further improved without osteotomy of the iliac crest. Dai et al.

Table 1 Detailed clinical data of the 20 patients

Case no	Age/Sex	WBB staging	Tomita classification	E/B	JOAS Pre	Approach	OT, min	BL, ml	Excision Model	Complications	AT	JOAS Post	JOA RR (%)	LR	Outcomes
1	25/F	5–11 A-D	5	E	18	P + A	410	2400	IC	II	Bp + RT	22	36.4	58 months Post	140 months/ AWD
2	25/F	3–10 B-D	4	N	17	P	240	1200	IC	None	Bp/ De + RT	19	16.7	18 months Post	85 months/ NED
3	51/F	6–12 A-D	5	E	10	P	345	2000	IC	None	Bp	28	94.7	None	83 months/ NED
4	30/F	7–10 B-C	2	E	17	P	400	3000	TES	None	De	23	50	None	78 months/ NED
5	40/M	4–9 A-D	5	E + B	10	P	260	3000	IC	None	Bp	26	84.2	None	75 months/ NED
6	26/F	3–10 A-D	5	E	12	P	290	1500	IC	DIH	Bp	22	58.8	12 months Post	69 months/ NED
7	37/M	2–5 B-C	1	E	21	P	335	1600	TES	None	De	27	75	None	59 months/ NED
8	68/M	4–9 B-C	1	E	15	P	320	1500	TES	NLL	De	27	85.7	None	53 months/ NED
9	41/M	4–9 B-D	4	E	13	P	570	2000	IC	None	Bp	21	50	None	47 months/ NED
10	65/F	2–10 A-D	5	E	16	P	415	1600	TES	RFD	De	21	38.5	None	45 months/ NED
11	21/F	2–11 A-D	5	E	12	P	390	2200	IC	None	Bp	23	64.7	None	44 months/ NED
12	41/F	4–9 B-D	4	E	15	P	420	1600	IC	None	Bp	21	42.9	None	36 months/ NED
13	30/F	4–10 A-D	5	E	10	P	330	800	TES	None	De	23	68.4	None	35 months/ NED
14	34/F	3–10 B-D	4	E	8	P	415	1600	TES	NLL	De	22	66.7	None	29 months/ NED
15	21/F	4–9 B-D	4	E	17	P	460	1000	TES	None	De	28	91.7	None	23 months/ NED
16	18/F	4–10 A-D	5	E	17	P	270	800	TES	None	Bp	25	66.7	None	22 months/ NED
17	31/F	4–10 B-D	4	E	13	P	175	1200	TES	None	De	26	81.3	None	21 months/ NED
18	14/F	12–6 A-D	4	E	23	P	360	2000	SE	None	De	28	83.3	None	15 months/ NED
19	25/F	4–9 B-D	4	E	16	P	340	1000	TES	None	De	25	69.2	None	13 months/ NED

Table 1 (continued)

Case no	Age/Sex	WBB staging	Tomita classification	E/B	JOAS Pre	Approach	OT, min	BL, ml	Excision Model	Complications	AT	JOAS Post	JOA RR (%)	LR	Outcomes
20	26/F	5–9 A-C	3	E	12	P	330	1600	TES	None	De	23	64.7	None	12 months/NED
$\overline{X}$	*33.45*				*14.6*		*353.75*	*1680*				*24*			*49.2*

F, Female; M, Male; E, Embolization; B, Balloon; JOAS, JOA Score; Pre, Preoperative; A, Anterior; P, Posterior; OT, Operation time; BL, Blood loss; IC, Intralesional curettage; TES, Total en bloc spondylectomy; SE, Sagittal en bloc resection; II, Incision infection; DIH, Delayed incision healing; NLL, Numbness of the left lower limb; RFD, Right foot drop; AT, Adjuvant therapy; Bp, Bisphosphonate; De, Denosumab; Post, Postoperative; RR, Recovery rate; LR, Local recurrence; AWD, Alive with disease; NED, No evidence of disease

have demonstrated the possibility of removing vertebral body intactly via the posterior-only approach in cases where the anterior–posterior diameter of the L5 vertebral body is shorter than 34.96 mm [24]. Yang et al. reported that isolation of the nerve roots superior and inferior to the involved level was extremely important for vertebral resection [16]. The mean length of the lumbar nerve root in their series was 3.36 ± 0.12 cm [16]. Previous studies have demonstrated that the prone position can significantly increase both distal and proximal lumbar lordosis, and that placement of the chest rolls or a Jackson table also has been shown to increase lumbar lordosis [25, 26]. In addition, the lordosis would further increase when the posterior muscles are separated from the spinous process, lamina and facet joint. We applied pedicle screws and titanium rods to restore the degree of lumbosacral spine lordosis. No statistically significant difference was observed between the pre- and postoperative spinopelvic alignment parameters including lumbar lordosis of L1-S1 and L4-S1, PI and PT. Our improved procedure can eliminate the influence from the blockage of the iliac wings and is conducive to the placement of the artificial vertebral body between L4 and S1. Maintenance of physiologic lordosis during lumbar spine surgery can not only optimize the surgical outcome but effectively prevent anterior slippage of the artificial vertebral body or titanium mesh. Meanwhile, L4 and L5 nerve roots on the side of the tumor rotated out were dissected for adequate length caudally to gain larger space for removing the vertebral neoplasm. In addition, the seven patients in this group were mainly female with a relatively lower iliac crest and a squashed vertebral body due to pathological fracture, which both facilitated complete removal of the tumor.

Luksanapruksa et al. reported that the postoperative complication rate in patients undergoing IC was higher than that in those undergoing TES (36.4 *vs.* 11.1%) [9]. Many factors may contribute to the postoperative complications, including comorbidities, severity of disease, the follow-up period, adjuvant therapy, and lesion location. In the largest and most recent retrospective observational study, Boriani et al. reported that 35.1% patients who underwent TES experienced at least one complication [8]. According to previous reports, the most common complication was postoperative muscle weakness, followed by surgical site infection and cerebrospinal fluid (CSF) leakage seen in 23.3% patients [22]. In addition, there have also been reports of major vessel injury during lumbar spine TES [23]. The high risk of major vessel injury in reoperation and post-irradiation cases is considered contributable to tissue adhesion and scarring. To avoid major vessels injury, surgery through the anterior approach is preferable in such cases. Brau et al. reported that vessel injury at the L4-5 level occurred only in about 1.9% cases undergoing surgery through the anterior approach

[23]. The rate of instrumentation failure requiring revision surgery was 20.0% [22]. In our study, we restored the lumbar lordosis during surgery and properly fit the upper and lower contact surfaces of the artificial vertebra or titanium mesh with the endplates. In some cases, we also used titanium cables or nonabsorbable sutures to restrain displacement of the artificial vertebra or titanium mesh. Finally, a tailored supporter was required to restrict the lumbar motion for at least 6 months for all patients [12]. IC has been demonstrated as the most important factor associated with local recurrence. One previous study reported that the recurrence rate for TES and intralesional resection was 7.7 and 47%, respectively [8]. Their results are similar to our previous findings [19].

As complete resection of spinal GCT lesions remains a surgical challenge, numbers of adjuvant therapies have been used to reduce the rate of recurrence. Denosumab is a novel monoclonal antibody that can downregulate osteoclast activity by specifically binding the receptor activator of nuclear factor kappa-B ligand (RANK-L). It has recently been used to treat adults and skeletally mature adolescents with GCTB, whose tumor is unresectable or for whom surgical resection is likely to result in severe morbidity [18]. Luksanapruksa et al. reviewed 81 studies and strongly recommended the use of denosumab for 6 months even after wide resection [27]. According to our experience, preoperative application of denosumab is necessary for patients with GCT and large paravertebral masses for 4 times in one month before surgery on days 1, 8, 15, 28, in that it can increase the rigidity of the GCT vertebral body and make the resection boundary clearer. Boriani et al. recommended that denosumab should be used for 6–12 months before en bloc resection [28]. However, long-term preoperative use of denosumab may increase the risk of adhesions between the tumor mass and major vessel. Postoperative use of denosumab was suggested in patients with violated margins [28]. Subcutaneous injection of 120 mg denosumab once a month is recommended within at least two years after the operation for all patients in our institution. And good local GCT control is achieved in these patients and no side effect is found on the mandible. Whether continuous use of denosumab after two years from the operation is based on the recurrence risk of GCT. Compared with bisphosphonates, denosumab has gradually become a better choice of adjuvant therapy for SGCT due to its more convenient administration, lower incidences of adverse effects and minimal renal toxicity.

There are controversies over the efficacy of radiotherapy for SGCT. Some studies reported that radiotherapy was effective for SGCT, while others argued that radiotherapy could not reduce SGCT recurrence. In our previous study, we performed a multivariate analysis of 102 SGCT patients, finding that adjuvant radiotherapy with surgery did not improve recurrence rates at either 2 or 5 years after treatment [2]. Besides, the risks of spinal cord myelitis and malignant transformation caused by radiotherapy have also been reported [29]. Over the past few years, advances in radiotherapy technology may have improved the effectiveness of radiotherapy for SGCT. Ma et al. reported that therapeutic radiotherapy was an alternative treatment option for SGCT patients who are not suitable for surgery and the prognosis was satisfactory in most cases, but repeated recurrence could be a risk factor for poor prognosis [30]. Of the 20 patients included in our study, only two patients received radiotherapy after local recurrence of the tumor with unsatisfactory therapeutic effects.

Conclusion

Lower lumbar GCT is not uncommon. Single-stage posterior TES without iliac osteotomy was previously considered impossible. With the improvement of surgical techniques, Single-stage posterior TES is feasible and has shown promising advantages as compared with the conventional surgical methods in terms of intraoperative blood loss and the complication and recurrence rates. Postoperative use of denosumab is recommended for better local recurrence control.

Limitations

This study has several limitations. The retrospective essence of this study makes the risk of information bias inevitable. The relatively small sample size and short follow-up period in some cases may affect the statistical significance in some analyses. Despite the existing limitations, this study has elaborated profound understanding of TES and an inspiring surgical strategy.

Keypoints

1. TES is obviously superior to IC in controlling intraoperative blood loss and local relapse.
2. By restoring the lumbar lordosis and dissecting the nerve roots up to sufficient length, the fifth lumbar vertebra could be removed intactly without osteotomy of the iliac graft.
3. Maintenance of physiologic lordosis could effectively prevent failure of internal fixation.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00586-023-07753-x.

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Declarations

Conflicts of interest The authors disclose no conflicts.

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