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Total en bloc spondylectomy for primary tumors of the lumbar spine

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Abstract

This was a retrospective clinical study.

This study aimed to evaluate our institution's experience with total en bloc spondylectomy (TES) in patients treated for primary lumbar spine tumors and investigate postoperative clinical outcomes.

TES is a widely accepted by spinal and musculoskeletal surgical oncologists and results in favorable health-related quality of life outcomes. However, this procedure still imposes major risks and complications.

The cases of TES performed for primary lumbar spine tumors between 1993 and 2015 were retrospectively analyzed. Primary outcome measures were the rates of perioperative complications and reoperation for instrumentation failure.

We enrolled 30 patients (13 men and 17 women; median age and follow-up, 38 years and 87 months, respectively). Three, 7, and 5 cases involved previous radiotherapy, intralesional resection, and chemotherapy, respectively. The most common tumor was giant cell tumor (14 cases) followed by osteosarcoma (4 cases) and plasmacytoma (3 cases). The median estimated blood loss was 1450 mL, and the median operative time was 11 hours. At least 1 perioperative complication occurred in 26 patients (86.7%), with the most common being postoperative muscle weakness (24 patients, 80.0%) followed by surgical site infection and postoperative cerebrospinal fluid leakage (7 patients, respectively; 23.3% each). Revision surgery for instrumentation failure was required in 6 patients (20.0%) at a median of 33 months after the index TES. Four patients experienced local tumor recurrence (13.3%), and their 10-year disease-free rate was 75.0%.

TES is a feasible and effective procedure for primary lumbar spine tumors, but the risks of perioperative complications and late instrumentation failure should be acknowledged. Surgical oncologic outcomes were good, especially in patients who underwent TES as their first surgical treatment. Therefore, being familiar with the indications for TES and the surgical technique is important.

Abbreviations: cerebrospinal fluid, CI = confidence interval, EBL = estimated blood loss, IQR = interquartile ranges, OR = odds ratio, SSI = surgical site infection, TES = total en bloc spondylectomy.

Keywords: lumbar vertebrae, neoplasms, outcome assessment (health care), retrospective studies, total en bloc spondylectomy

1. Introduction

Total en bloc spondylectomy (TES) is a relatively aggressive surgical treatment for spinal neoplasms [1–3] and involves en bloc removal of an entire vertebral body and posterior elements to achieve tumor resection with negative margins. This procedure results in low recurrence rates and favorable health-related quality of life outcomes [1,2,4–6] and is now widely accepted by spinal and musculoskeletal surgical oncologists. With advances in surgical techniques,[7,8] TES indications have been expanded to include patients with extra-compartmental or consecutive multilevel spinal tumors.[9] However, the procedure still imposes major risks including spinal cord injury, pleural effusion, and postoperative cerebrospinal fluid leakage.[10,11] Additionally, late instrumentation failure reportedly occurs in approximately 40% of patients undergoing TES.[12,13] Due to the unique anatomy of the lumbar region, lumbar spine TES remains a challenge, and the close relationship between the vertebrae and abdominal structures results in the risk of a major vessel, lumbar plexus, or bowel injury. Unlike thoracic spine TES performed with transection of nerve roots, lumbar spine TES usually necessitates extensive nerve root dissection with frequent retraction to preserve lower extremity motor function. Thus, TES in the lumbar spine typically requires an anterior-posterior combined procedure, while thoracic spine TES can often be performed using a solely posterior approach. For these reasons, the majority of published accounts describing lumbar spine TES performed for primary tumors are case reports or small case series.[13] Therefore, this study aimed to assess our institution's experience with TES performed in cases of primary aggressive benign and malignant lumbar spine tumors and investigate the

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The study design was approved by our institution's ethics committee.

The devices are FDA approved or approved by a corresponding national agency for this indication.All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent was obtained from all individual participants included in the study. The authors declare no conflicts of interest.

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rates of postoperative complications and revision surgery for instrumentation failure and oncological outcomes.

2. Materials and methods

2.1. Study design and inclusion criteria

We performed a retrospective chart review of all cases of surgically treated primary malignant or locally aggressive benign spinal tumor at our institution between 1993 and 2015. The patients who underwent TES for treatment of a tumor primarily located in the lumbar spine (L1–L5) were included. In cases of solitary plasmacytoma for which the primary treatment is local radiotherapy,[14] TES was performed where severe spinal instability or neurologic impairment was identified. The patients who underwent anterior en bloc corpectomy alone or en bloc resection of only the posterior elements were excluded. Our institution's ethics committee approved the study, and informed consent was obtained from all patients.

2.2. Recorded data

Patients' data including age, sex, history of intralesional resection, previous chemotherapy and radiotherapy, and tumor histology were obtained from clinical notes. Surgical data such as the approach, resected vertebrae, operative time, estimated blood loss (EBL), and occurrence of surgical complications were gathered from operative and follow-up clinical notes. Our primary outcome measures were the rates of perioperative complications and reoperation for instrumentation failure. The follow-up protocol included an examination with x-ray imaging, a computed tomography scan, and magnetic resonance imaging every 3 months for the first year, every 6 months for the second year, and yearly thereafter. Secondary outcome measures included local recurrence and disease-free survival.

2.3. Statistical analysis

General descriptive statistics were performed for the study population. Data are presented as proportions or median values with interquartile ranges (IQR). A simple logistic regression analysis was performed to investigate the relationship between specific patient and operative parameters and instrumentation failure occurrence. Results are presented as odds ratios (OR) with 95% confidence intervals (CI). All statistical analyses were performed using SPSS version 20 (IBM Corp., Armonk, NY). A probability value (P) of $<.05$ was considered statistically significant.

3. Results

3.1. Patient data

A total of 30 patients were included in this study, and Table 1 shows their characteristics. The median age at the time of surgery was 38 years (IQR: 32–48), and 13 patients were men (43.3%). Three (10.0%) and 5 (16.7%) patients had received previous radiotherapy or chemotherapy, respectively, and 7 (23.3%) had a history of intralesional resection. The most common tumor was giant cell tumor (14 cases, 46.7%) followed by osteosarcoma (4 cases, 13.3%); plasmacytoma (3 cases, 10.0%); aggressive hemangioma, chondrosarcoma, and chordoma (2 cases, respectively; 6.7% each); and hemangiopericytoma, synovial sarcoma, and osteoblastoma (1 case, respectively; 3.3% each). Twenty-four patients (80.0%) underwent single-level TES, 2 (6.7%) underwent 2-level TES, and 4 (13.3%) underwent 3-level TES. The median follow-up time in all patients was 87 months (IQR: 37–119).

3.2. Surgical procedure

The lumbar spine tumor TES technique was previously described.[15] Twenty-two cases (73.3%) required a combined anterior-posterior approach. Twelve and 10 cases were single-stage and 2-stage surgeries, respectively. The remaining 8 patients underwent TES with a single-stage solely posterior approach. Anterior retroperitoneal and anterior transperitoneal approaches were utilized in 16 (53.3%) and 6 patients (20.0%), respectively, with the aid of a general surgeon. Anterior reconstruction was performed using a titanium mesh cage enclosing a locally obtained autograft or autologous iliac bone in all patients. Pediculotomies were accomplished using a T-saw. Posterior reconstruction was performed using a combination of pedicle screws, sacral screws, iliac screws, rods, and transverse connectors (Fig. 1). The median EBL was 1450 mL (IQR: 670–3100), and the median operative time was 11.0 hours (IQR: 9.9–19.6).

3.3. Complications

Twenty-six patients (86.7%) developed at least 1 perioperative complication (Table 2), with the most common being postoperative lower extremity muscle weakness (24 patients, 80.0%) followed by surgical site infection (SSI) and postoperative cerebrospinal fluid (CSF) leakage (7 patients, respectively; 23.3% each). Postoperative muscle weakness occurred in all cases of TES at L3 or below and in half of those at L1 or L2. Of the 24 patients with postoperative muscle weakness, 19 completely recovered within 6 months postoperatively, and all patients could walk without any support at the last follow-up appointment. All 7 patients with an SSI required reoperation for debridement, and 1 required an exchange of spinal instrumentation. All SSIs had resolved by the final follow-up examination. No patient experienced a fatal pulmonary embolism or major vessel injury.

3.4. Instrumentation failure and oncological outcomes

Revision surgery for instrumentation failure was required in 6 patients (20.0%) at a median time of 33 months (IQR: 29–39) after the index TES. Logistic regression analysis showed no significant factors associated with instrumentation failure (Table 3). During the follow-up period, local tumor recurrence occurred in 4 patients (13.3%), and all had undergone previous intralesional resection. Three (1 and 2 cases of chondrosarcoma and osteosarcoma, respectively) of the 4 patients with a local recurrence died from the disease, while 1 locally recurrent giant cell tumor was controlled with denosumab. Four patients (13.3%) died from their disease, and the 10-year disease-free rate was 75.0% (Fig. 2).

4. Discussion

We investigated our institution's 22-year experience with TES in patients treated for primary tumors located in the lumbar spine and assessed postoperative clinical outcomes to augment the currently limited number of published accounts describing this challenging procedure.

Table 1

Clinical and surgical characteristics in 30 patients with primary lumbar spine tumors treated with total en bloc spondylectomy.

Age, y	Sex	Histology	Resected vertebrae	Previous surgery	Preop chemo	Preop radiation	Surgical approach	Staged surgery	Operative time, min	EBL, mL	SSI	CSF leakage	Postop muscle weakness	Instrumentation failure	FU, mos	Local Recurrence	Oncological status
48	M	Hemangioma	L3	–	–	–	Posterior	–	340	710	–	–	+	–	224	–	NED
49	M	Chondrosarcoma	L5	+	+	–	Combined	+	1240	19225	+	–	+	–	116	+	DOD
36	M	GCT	L2	–	–	–	Posterior	–	675	5500	–	–	+	–	216	–	NED
52	M	Osteosarcoma	L2	+	–	+	Combined	–	835	7580	+	–	–	–	6	+	DOD
40	M	GCT	L5	–	–	–	Combined	–	1205	12370	+	–	+	–	177	–	NED
38	F	GCT	L3	–	–	–	Posterior	–	600	1800	–	–	+	–	233	–	NED
6	M	Osteoblastoma	L2	–	+	+	Posterior	–	545	1160	–	–	–	–	208	–	NED
58	F	Plasmacytoma	L3	–	–	–	Combined	–	595	3330	–	––	+	–	32	–	DOC
28	M	Osteosarcoma	L2–4	+	–	–	Combined	+	1325	7150	–	–	+	–	36	+	DOD
24	F	GCT	L4	–	–	–	Combined	–	890	1630	–	–	+	–	159	–	NED
61	F	Plasmacytoma	L2	–	–	––	Combined	–	605	1000	–	+	+	–	77	–	NED
34	M	Synovial sarcoma	L2–4	–	+	+	Combined	+	1015	1170	–	–	+	–	6	–	DOD
66	F	Plasmacytoma	L3	+	–	–	Combined	–	554	945	–	–	+	–	126	–	NED
37	F	GCT	L3-5	–	–	–	Combined	+	1320	3220	–	–	+	+	47	–	NED
32	F	GCT	L4–5	–	–	–	Combined	+	1279	2390	–	–	+	–	120	–	NED
36	M	Hemangioma	L4	–	–	–	Combined	+	1210	2090	–	+	+	–	66	–	NED
32	F	GCT	L1	–	–	–	Posterior	–	488	1300	–	–	–	–	115	–	NED
39	M	GCT	L4	–	–	–	Combined	–	660	1960	+	–	+	–	101	–	NED
46	F	Hemangiopericytoma	L1	+	–	–	Posterior	–	655	1600	–	+	+	+	100	–	NED
38	F	GCT	L2	–	–	–	Combined	–	596	690	–	+	–	–	99	–	NED
36	F	GCT	L3–5	+	–	–	Combined	+	1516	5510	–	–	+	+	97	+	AWD
49	F	GCT	L4–5	–	–	–	Combined	+	1,408	2610	–	+	+	+	88	–	NED
25	F	GCT	L4	–	–	–	Combined	+	1086	660	–	+	+	+	85	–	NED
16	M	Chordoma	L3	–	–	–	Combined	–	594	190	+	–	+	+	63	–	NED
40	F	Chordoma	L2	–	–	–	Combined	–	674	210	–	–	+	–	42	–	NED
58	F	Chondrosarcoma	L1	–	–	–	Posterior	–	384	180	–	–	–	–	41	–	NED
20	M	GCT	L2	–	–	–	Combined	–	475	160	–	–	+	–	33	–	NED
15	F	GCT	L1	–	–	–	Posterior	–	346	150	–	–	+	–	19	–	NED
39	M	Osteosarcoma	L2	–	+	–	Combined	–	894	630	–	+	+	–	14	–	NED
33	F	Osteosarcoma	L2	–	–	–	Combined	+	591	600	–	–	+	–	12	–	NED

AWD = alive with disease, CSF = cerebrospinal fluid, DOC = died from other cause, DOD = died of disease, EBL = estimated blood loss; chemo, chemotherapy, F = female, FU = follow-up, GCT = giant cell tumor, M = male, NED = no evidence of disease, SSI = surgical site infection.

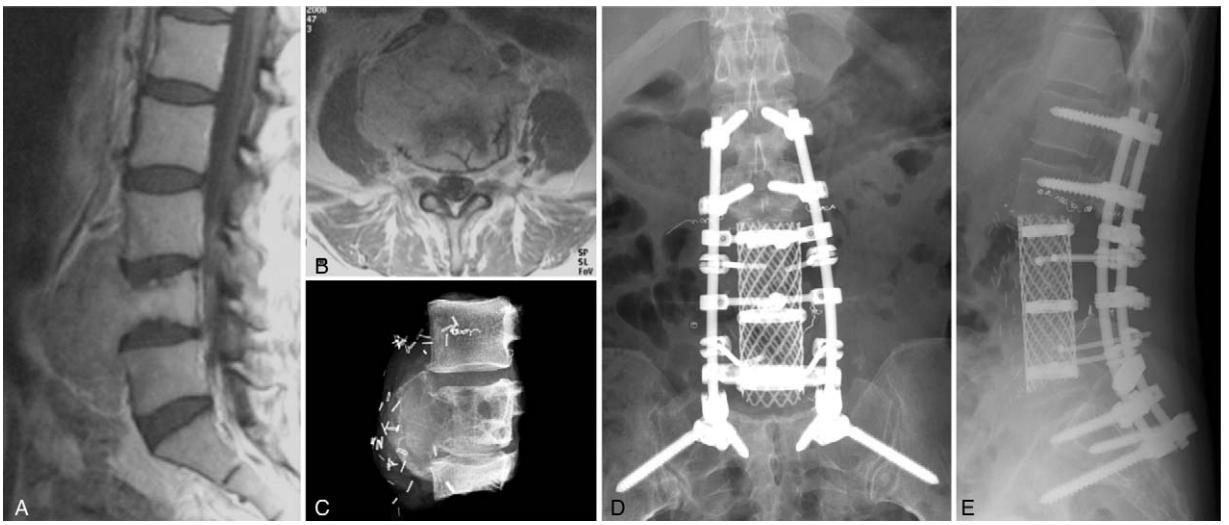

Figure 1. A giant cell tumor of the lumbar spine in a 38-year-old female. T1-gadolinium-enhanced magnetic resonance imaging shows the L4 vertebral tumor extending to neighboring vertebrae (A) and largely expanding outside the vertebral body. B, Postoperative imaging after total en bloc spondylectomy with a posterior-anterior combined approach shows the paravertebral tumor and the vertebral bodies of L3 and L4, and half of L5 were removed en bloc with a marginal margin. C, Images show the spinal reconstruction with a titanium mesh cage enclosing an autologous bone graft after posterior instrumentation (D and E).

Sciubba et al[13] reported outcomes in 23 patients who underwent TES for an aggressive or malignant primary tumor of the lumbar spine. All but 1 underwent a 2-stage posterior-anterior approach; the median total EBL was 3200 mL, and the median total operative time was 18.5 hours. Fifteen patients developed at least 1 perioperative complication (65.2%). There were 6 cases of wound infection and ileus (26.1% each), 4 of deep vein thrombosis with pulmonary embolism (17.4%), and 3 of CSF leakage (13.0%). There were 9 cases of instrumentation failure requiring revision surgery (39.1%) at a median time of 23 months after the index spondylectomy.[13] Compared to the complication rate reported by Sciubba et al,[13] the postoperative complication rate in our series was considerably higher at 86.7% versus 65.2%. The most common complication was postoperative muscle weakness (24 patients, 80.0%). Further, postoperative muscle weakness occurred in all cases of TES at L3 or below. We hypothesize that the incidence of muscle weakness after TES at L1 and L2 was lower than after TES at L3 or below because no muscle is dominated by the L1 or L2 nerve root alone and compensation by the other nerve roots masked the weakness.[16] In previous reports, postoperative muscle weakness after lumbar TES was insufficiently investigated or not mentioned. The cause of the weakness must be extensive nerve root dissection with frequent retraction and detachment of the iliopsoas muscles. As discussed above, lumbar spine TES is performed through a surgical window formed by widely dissected and retracted nerve roots, the development of which strains the nerve roots. Although this is an inevitable feature of lumbar spine TES, the majority of patients who developed lower extremity weakness recovered within 6 months postoperatively, and all patients were able to walk at their final follow-up appointment. However, postoperative muscle weakness is an important problem, and future improvement is necessary.

The second most common complications were SSI and CSF leakage, each seen in 23.3% of patients, rates similar to those of previous reports.[13] Patients often undergo chemo- or radiotherapy before TES, and both have been shown to impair wound healing.[11,17,18] Additionally, a large skin incision, extensive damage to soft tissues, and a sizable dead space inhibit wound healing.[18] Hayashi et al[19] found that a combined approach to TES was an independent risk factor for SSI, and long operative time has also been associated with SSI after TES. Therefore, lumbar spine TES is thought to impose a high risk of SSI because it is a lengthy operation and often requires an anterior/posterior combined approach. However, the median total operative time in our study was approximately 11 hours, shorter than that of

Table 2

Perioperative complications in 30 patients after total en bloc spondylectomy for a primary lumbar spine tumor.

Complication	Patient number (%)
At least one complication	26 (86.7)
Lower extremity muscle weakness	24 (80.0)
SSI	7 (23.3)
CSF leakage	7 (23.3)
Ileus	2 (6.7)
Extradural hematoma	1 (3.3)
Pneumothorax	1 (3.3)

CSF = cerebrospinal fluid, SSI = surgical site infection.

Table 3

Factors associated with instrumentation failure after primary lumbar spine tumor total en bloc spondylectomy.

Parameter	OR (95%CI)	*P*
Increasing age	0.98 (0.92–1.05)	.570
Male sex	0.20 (0.02–1.98)	.169
Previous chemotherapy	1	–
Previous radiotherapy	1	–
Previous intralesional resection	1.01 (0.09–11.0)	1.000
Multilevel spondylectomy	7.00 (0.94–52.0)	.057
SSI	1.01 (0.09–11.0)	1.000
CSF leakage	5.00 (0.73–34.3)	.102
Local recurrence	2.2 (0.17–29.3)	.551

CI = confidence interval, CSF = cerebrospinal fluid, OR = odds ratio, SSI = surgical site infection.

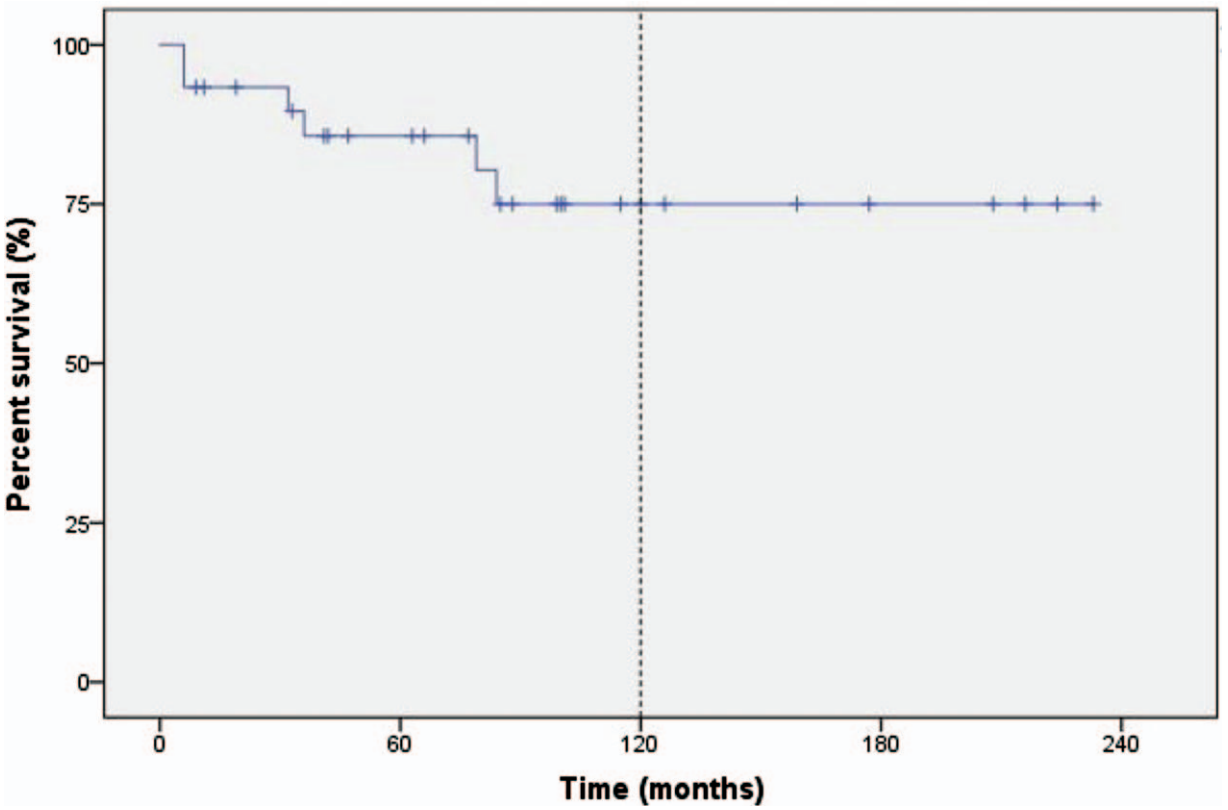

Figure 2. Kaplan–Meier survival curves show disease-free survival rates in all patients.

previous reports, but we did not observe a corresponding reduction in infection rate. Although some have suggested a posterior-only approach as a means to reduce operative time,[20,21] a combined approach is often necessary, especially at L2 or below, to ensure surgical safety. Although no major vessel, nerve root, or bowel injuries occurred in our series, there have been reports of major vessel injury during lumbar spine TES.[13,22] The high risk of major vessel injury in reoperation and post-irradiation cases is considered to be a result of tissue adhesion and scarring. Particularly in these cases, adding an anterior approach is important to avoid injury to major vessels.[22–24]

The rate of instrumentation failure requiring revision surgery was 20.0% in this study. Although logistic regression analysis showed no significant factors associated with instrumentation failure, the failure rate after multilevel resection was much higher than single vertebra resection (50.0% vs 12.5%), a result similar to that of previous reports.[13] The lack of statistical significance was probably due to our small sample size. Robust spinal reconstruction, for example, using 3 or more rods or extending the instrumented vertebra level, should be considered to achieve bony fusion in patients who require multilevel resections.[10,12] Although radiation therapy was not identified as a risk factor for instrumentation failure in our study, 2 previous studies reported irradiation as a significant risk factor.[12,13] Despite radiotherapy being associated with instrumentation failure, the use of this treatment modality cannot always be avoided as it serves as adjuvant therapy for tumor treatment. However, radiation therapy should only be used after careful treatment planning, and indiscriminate irradiation must be avoided.

Sciubba et al[13] reported only one local recurrence in their study of 23 cases (4.3%) of lumbar TES for primary tumors. In our study, 4 local recurrences occurred (13.3%), but all occurred after an intralesional surgery where it was difficult to achieve tumor-free surgical margins. In contrast, no local recurrences occurred in patients who underwent TES as the first treatment, so local control of primary lumbar tumors can be said to be excellent after TES.

This study has some limitations. First, this is a single arm study in a single institute, and the relatively small sample size could have caused it to be underpowered and unable to detect statistical significance in some analyses. Larger studies with comparative groups are needed to further validate and generalize our findings. Second, because of the retrospective design of this study, some complications might have been overlooked due to the collected data obtained from electronic medical records were not designed to address this study. Third, changes in the oncological and surgical treatment of several tumors during this study, such as the use of denosumab for giant cell tumors,[24] may have affected the results. Despite the recognized limitations, to our knowledge, this study included the largest number of patients after lumbar TES to date. We found that TES in the lumbar spine could result in favorable oncological outcomes while maintaining lower extremity function, albeit with a high risk for complications and instrumentation failure.

In conclusion, TES is a feasible and effective procedure for the treatment of primary tumors of the lumbar spine, but the risks of perioperative complications and late instrumentation failure should be acknowledged. Although postoperative transient lower extremity muscle weakness is an almost inevitable feature of

lumbar spine TES, oncologic outcomes were good, especially in patients who underwent TES as their first surgical treatment. Therefore, being familiar with the indications for TES and the surgical technique is important.

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References

[1] Kato S, Murakami H, Demura S, et al. Patient-reported outcome and quality of life after total en bloc spondylectomy for a primary spinal tumour. Bone Joint J 2014;96-B:1693–8.
[2] Kato S, Murakami H, Demura S, et al. More than 10-year follow-up after total en bloc spondylectomy for spinal tumors. Ann Surg Oncol 2014;21:1330–6.
[3] Tomita K, Kawahara N, Baba H, et al. Total en bloc spondylectomy. A new surgical technique for primary malignant vertebral tumors. Spine (Phila Pa 1976) 1997;22:324–33.
[4] Boriani S, De Iure F, Bandiera S, et al. Chondrosarcoma of the mobile spine: report on 22 cases. Spine (Phila Pa 1976) 2000;25:804–12.
[5] Hart RA, Boriani S, Biagini R, et al. A system for surgical staging and management of spine tumors. A clinical outcome study of giant cell tumors of the spine. Spine (Phila Pa 1976) 1997;22:1773–82.
[6] Tomita K, Kawahara N, Murakami H, et al. Total en bloc spondylectomy for spinal tumors: improvement of the technique and its associated basic background. J Orthop Sci 2006;11:3–12.
[7] Ishii T, Murakami H, Demura S, et al. Invasiveness reduction of recent total en bloc spondylectomy: assessment of the learning curve. Asian Spine J 2016;10:522–7.
[8] Kawahara N, Tomita K, Murakami H, et al. Total en bloc spondylectomy for spinal tumors: surgical techniques and related basic background. Orthop Clin North Am 2009;40:47–63. vi.
[9] Yoshioka K, Murakami H, Demura S, et al. Clinical outcome of spinal reconstruction after total en bloc spondylectomy at 3 or more levels. Spine (Phila Pa 1976) 2013;38:E1511–6.
[10] Liljenqvist U, Lerner T, Halm H, et al. En bloc spondylectomy in malignant tumors of the spine. Eur Spine J 2008;17:600–9.
[11] Yokogawa N, Murakami H, Demura S, et al. Perioperative complications of total en bloc spondylectomy: adverse effects of preoperative irradiation. PLoS One 2014;9:e98797.
[12] Matsumoto M, Watanabe K, Tsuji T, et al. Late instrumentation failure after total en bloc spondylectomy. J Neurosurg Spine 2011; 15:320–7.
[13] Sciubba DM, De la Garza Ramos R, Goodwin CR, et al. Total en bloc spondylectomy for locally aggressive and primary malignant tumors of the lumbar spine. Eur Spine J 2016;25:4080–7.
[14] Dimopoulos MA, Moulopoulos LA, Maniatis A, et al. Solitary plasmacytoma of bone and asymptomatic multiple myeloma. Blood 2000;96:2037–44.
[15] Kawahara N, Tomita K, Murakami H, et al. Total en bloc spondylectomy of the lower lumbar spine: a surgical techniques of combined posterior-anterior approach. Spine (Phila Pa 1976) 2011; 36:74–82.
[16] Agur AMR, Dalley AF. Grant's atlas of anatomy. Edition 14. ed. Philadelphia: Wolters Kluwer; 2016.
[17] Payne WG, Naidu DK, Wheeler CK, et al. Wound healing in patients with cancer. Eplasty 2008;8:e9.
[18] Kim JE, Pang J, Christensen JM, et al. Soft-tissue reconstruction after total en bloc sacrectomy. J Neurosurg Spine 2015;22:571–81.
[19] Hayashi H, Murakami H, Demura S, et al. Surgical site infection after total en bloc spondylectomy: risk factors and the preventive new technology. Spine J 2015;15:132–7.
[20] Hsieh PC, Li KW, Sciubba DM, et al. Posterior-only approach for total en bloc spondylectomy for malignant primary spinal neoplasms: anatomic considerations and operative nuances. Neurosurgery 2009;65: 173–81.
[21] Huang L, Chen K, Ye JC, et al. Modified total en bloc spondylectomy for thoracolumbar spinal tumors via a single posterior approach. Eur Spine J 2013;22:556–64.
[22] Mesfin A, El Dafrawy MH, Jain A, et al. Total en bloc spondylectomy for primary and metastatic spine tumors. Orthopedics 2015;38:e995–1000.
[23] Cloyd JM, Acosta FLJr, Polley MY, et al. En bloc resection for primary and metastatic tumors of the spine: a systematic review of the literature. Neurosurgery 2010;67:435–44.
[24] Yamazaki T, McLoughlin GS, Patel S, et al. Feasibility and safety of en bloc resection for primary spine tumors: a systematic review by the Spine Oncology Study Group. Spine (Phila Pa 1976) 2009;34(22 Suppl): S31–8.