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# Oncosurgical Results of Multilevel Thoracolumbar En-bloc Spondylectomy and Reconstruction with a Carbon Composite Vertebral Body Replacement System

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**Study Design.** Retrospective clinical study for patients receiving multilevel en-bloc spondylectomy resection for sarcomas and solitary metastases of the thoracolumbar spine.

**Objective.** Assess the clinical and radiologic outcome after multilevel en-bloc spondylectomy and reconstruction.

**Summary of Background Data.** Monolevel en-bloc spondylectomies have proven their oncosurgical effectiveness while reports on multilevel resections for extracompartmental tumor localizations are rare.

**Methods.** Patients treated by multilevel en-bloc spondylectomy and restoration with a carbon composite vertebral body replacement system were investigated. Patient charts, and clinical follow-up investigations were analyzed for histopathological tumor origin, preoperative symptoms, surgical peri- and postoperative data, applied adjuvant therapies, as well as the course of disease. Solitary metastases time until occurrence and prognostic scores were evaluated (Tomita/Tokuhashi Score). CT-scans were performed and analyzed at follow up. Oncological status was evaluated including local recurrence rates, cumulative disease specific, and metastases-free survival.

**Results.** Multilevel (2–5 segments) en-bloc spondylectomy of the thoracolumbar spine was performed in 20 patients (15 sarcomas and 5 solitary spinal metastases 9 male/11 female, mean age at surgery: 54 ± 15 years.). Wide and marginal surgical margins were achieved in 7 and 13 patients, respectively. Mean follow-up period was 25.0 (9–53) months. Thirteen patients received adjuvant therapy. No implant breakage or loosening was observed. Local recurrence occurred in one patient. Thirteen of the 18 surviving patients showed no evidence of the disease, two died of systemic disease.

**Conclusion.** Multilevel en-bloc spondylectomy offers a radical resection option for extracompartmental tumor involvement. It provides oncologically adequate resection margins with low local recurrence. However, the procedures are complex; the patient's stress is high and metastatic disease developed in one-third of patients. A judicious patient selection and a realistic feasibility evaluation must precede the decision for surgery. Reconstruction using a carbon composite cage system showed low complication rates and offers advantages for oncosurgical procedures.

**Key words:** en-bloc spondylectomy, multilevel, thoracolumbar spine, primary tumors, solitary metastases, carbon composite cage.

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Although not a radical option, intralesional spinal tumor resections were for decades considered the standard treatment as they were felt to be the only feasible surgery. Yet even in solitary tumor lesions and despite adequate adjuvant treatment strategies the associated oncological outcome after these procedures showed poor results.[1,2] Total en-bloc spondylectomy (TES) offered a new therapeutic approach. By enabling surgery to achieve marginal to wide resection margins, it applied the radical oncosurgical concepts of compartment-orientated resections to the spine.[3–5] Indications for radical resections were initially restricted to primary spinal tumors (*i.e.*, vertebral sarcomas)[1,6,7] and then later expanded to solitary metastases of biologically favorable tumors.[8–11] Today, high resolution radiologic imaging methods and precise histopathological diagnosis enable us to reliably specify tumor grading and to perform valid staging procedures. These techniques assist in decision guidance for adequate oncosurgical treatment regimens and for the

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planning of surgery.[6,12–14] The combination of standardized surgical procedures and advances in technique have led to decreased local recurrence rates, improved patient quality of life and increased overall survival rates.[15–17] These results and improved oncological outcomes have meant that TES are increasingly performed and published[15,18] underscoring the reliability of the technique. As surgical experience in monosegmental procedures grew and encouraging oncological results were observed, TES indications were expanded to patients with spinal tumor growth beyond the compartment borders of the vertebral body (*i.e.*, large vessel, chest wall, dural sac, visceral organ involvement). Although these conditions present with a higher surgical risk and perioperative morbiditiy multilevel and extracompartmental extension are no longer considered as an absolute limitation for radical surgery. Still, multilevel resections do require careful preoperative patient selection and preparation followed by specific investigations. To allow preoperative visualization of spinal cord perfusion (Adamkiewicz artery) and selective embolization of hypervascular lesions, a spinal angiography may be performed. In cases of thoracolumbar localizations the lung function, topographic relation to and possible tumor encasement of the aorta, caval and azygos vein as well as other neighboring organs must be evaluated. Analysis of the diagnostic results must be accurate and complete to plan surgery and to maximize the patient's security. However, there are few publications regarding multilevel en-bloc resections, most of them case control studies.[19–21] Oncosurgical reports assessing the results of multilevel TES in larger series of patients are not present in the literature. In particular, the prognostic benefit and the surgical feasibility with possibly higher surgical complication rates especially in comparison to one level en-bloc spondylectomies have yet to be clearly shown.

The reconstructions of en-bloc spondylectomy defects are a challenge because all load-bearing structures of the affected segments are removed. As multiple spinal segments become involved, spinal instability increases in proportions that are greater than the number of additional segments removed. Different types of vertebral body replacement (VBR) systems have been developed to secure the ventral column and posterior fixation by pedicle screw fixation has been to be an essential part in regaining primary stability.[22,23] Secondary bony integration can be expected in nonpalliative surgical reconstructions and is achieved with autologous bone graft mainly provided by filling of the VBR system. Expandable VBR systems are technically limited in graft volume whereas nonexpandable systems allow more space for bone filling. As a cage construction material for VBRs, carbon composite shows (especially in oncosurgical indications) interesting features in terms of elastic vibration to prevent stress-shielding and provide radiolucency for artifact-free restaging with local MRI-/CT-imaging.

We report the oncosurgical outcome of patients who underwent multilevel en-bloc spondylectomy because of primary tumors or solitary metastatic spinal lesions and subsequent reconstruction with a carbon composite VBR interconnected to posterior pedicle screw fixation system in two tumor centers.

## PATIENTS AND METHODS

### Patient Selection

We retrospectively investigated 20 patients (9 male/11 female) with a mean age of 54 (±16) years at surgery receiving multilevel en-bloc spondylectomy and subsequent reconstruction due to 15 primary tumors and five solitary metastases of the spine (Table 1). Patients were treated in two centers for musculoskeletal tumor surgery between 2001 and 2009. To achieve the oncological diagnosis native radiographs, local MRI-scans, CT-scans (local, thoracic/abdominal/pelvic), bone scintigraphy (radionuclid imaging, technetium bone scan) and in case of solitary metastases PET-CT-scans were performed. All patients underwent open transpedicular biopsy before ultimate surgery.

Before surgery all patients underwent the following preparation and selection criteria:

1. Indication for multilevel en-bloc spondylectomy was discussed and decided at the interdisciplinary musculoskeletal tumor board
2. Treatment with standardized adjuvant and/or neoadjuvant treatment protocols and the time point in the course of treatment were evenly initiated in a common agreement by the musculoskeletal tumor board
3. *Criteria for radical spinal surgery in the case of solitary metastases were defined as*
   a. Biologically favorable tumor entities (*e.g.*, breast cancer, hypernephroma)
   b. Radical resection of primary tumor
   c. Long time period of disease free survival before diagnosis of spinal metastases in relation to the grading of the primary tumor
   d. Identical histopathological pattern of the solitary metastases and the primary tumor
   e. Exclusion of additional metastatic lesions shown by CT-, PET-CT scan and bone scan
   f. Good expected survival according to established clinical prognostic scores (*e.g.*, Tokuhashi- or Tomita score)

Retrospective data were analyzed through detailed patients chart review. For primary spinal tumors histopathological diagnosis, tumor grading and stage, in case of solitary metastases the origin and the oncological status of the spreading tumor were reevaluated in relation to the initial biopsy. Previous intralesional spinal surgeries (*e.g.*, emergency laminectomy) were documented. The treatment with neoadjuvant, adjuvant, and radiation therapies was assessed. Compartmental tumor involvement was classified according to the classification of Tomita *et al*.[24] The Tokuhashi revised prognostic score[13,25] and the Tomita score[14] were evaluated for metastatic lesions.

### Oncological Data and Follow-up

Overall and postoperative oncological follow-up was analyzed. The oncological status at the latest follow-up (NED = no evidence of disease; AWD = alive with disease; DOD = dead

**TABLE 1. Oncological Data of the Investigated Patients**

| No | Sex | Age (yr) | Entities | Res. Segments | Primary Tumor Site | Tomita Prognostic Score | Tokuhashi Prognostic Score | Follow-up (mo) | Disease-free Survival Before Metastasis (mo) | Preperformed Surgery | Multimodal Therapy | Surgical Margins | Cum. Disease Specific Survival (mo) | Cum. Met. Free Survival (mo) | Oncol. Status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | M | 27 | Teratoma | L2–L3 | Testicular ca | 3 | 10 | 34 | 39 | | C + R pre | Marginal | 34 | 34 | NED |
| 2 | M | 71 | Renal cell cancer | T3–T4 | Right kidney | 2 | 10 | 27 | 27 | | C + R pre | Marginal | 27 | 12 | DOD |
| 3 | F | 54 | Breast cancer | T6–T7–8 | Right breast | 1 | 12 | 39 | 252 | | C + R pre | Wide | 39 | 39 | NED |
| 4 | F | 64 | Breast cancer | T8–T9–10 | Right breast | 2 | 11 | 53 | 48 | | C pre, R | Marginal | 53 | 53 | NED |
| 5 | M | 60 | Osteosarcoma | L1–L2–L3 | | | | 21 | | | C pre | Wide | 21 | 8 | AWD |
| 6 | M | 66 | Pleomorph. sarcoma | T7–T8–T9 | | | | 10 | | d + i | C + R pre | Marginal | 10 | 7 | DOD |
| 7 | F | 56 | Synovial sarcoma | L3–L4 | | | | 48 | | | C pre | Wide | 48 | 48 | NED |
| 8 | M | 71 | Chordoma | L2–L3–L4 | | | | 19 | | d + i | C + R pre | Marginal | 19 | 19 | NED |
| 9 | F | 25 | Osteoblastoma | T3–T4 | | | | 28 | | d + i | | Wide | 28 | 28 | NED |
| 10 | F | 46 | Chordoma | T7–T8–T9 | | | | 34 | | | | Wide | 34 | 34 | NED |
| 11 | F | 27 | Giant cell tumor | T12–L1–L2 | | | | 22 | | d + i | | Marginal | 22 | 7 | AWD |
| 12 | M | 64 | Chordoma | T10–T11–T12–L1 | | | | 40 | | | | Marginal | 40 | 23 | AWD |
| 13 | F | 71 | Chordoma | T5–T6–T7–T8–T9 | | | | 13 | | | | Marginal | 13 | 13 | NED |
| 14 | F | 53 | Renal cell cancer | T2–T3–T4 | Right kidney | 2 | 11 | 16 | 6 | d + i | C + R pre | Marginal | 16 | 16 | NED |
| 15 | F | 41 | Chondrosarcoma | T10–T11 | | | | 28 | | d + i | | Marginal | 28 | 3 | AWD |
| 16 | M | 57 | Neurofibrosarcoma | T12–L1 | | | | 17 | | | | Marginal | 12 | 12 | AWD |
| 17 | M | 48 | Osteosarcoma | T7–T8–T9–T10 | | | | 17 | | | C pre | Wide | 17 | 17 | NED |
| 18 | M | 50 | Solitary plasmocytoma | T9–T10–T11 | | | | 16 | | | C + R pre | Wide | 16 | 16 | NED |
| 19 | F | 54 | Chondrosarcoma | T6–T7–T8–T9 | | | | 14 | | | | Marginal | 14 | 14 | NED |
| 20 | F | 70 | Osteosarcoma | T5–T6 | | | | 9 | | d + i | R | Marginal | 9 | 9 | NED |

*d + i indicates decompression intralesional; C, chemotherapy; R, radiation; pre, preoperative; NED, no evidence of disease; AWD, alive with disease; DOD, dead of disease.*

of disease) was documented and further investigated for local recurrence-free survival, metastases-free survival, and disease-specific overall survival. Neurologic symptoms and their course after surgery were scored using the Frankel Scale. Each resection was classified as follows:

- Wide when the distance between the tumor tissue and excision margin was oncologically sufficient and/or when an intact anatomic barrier (*e.g.*, compartmental cortical wall of the vertebra) was present
- Marginal if the margin was less then wide but more than intralesional (thin tumor-free tissue layer or capsule)
- Intralesional if either visible tumor tissue was present, the tumor was cut through during the operation, or the excision margins were positive at the microscopic level[26]

Local bidimensional radiograph control was performed 3, 6, and 12 months after surgery, CT-scans at a minimum period of 6 months as well as at latest follow-up. They were analyzed for implant failure, loosening or dislocation, VBR integration and signs of local recurrence. Staging investigations included CT-scans (thoracic/abdominal/pelvic) and bone scintigraphy scans.

### Oncosurgical Technique

All patients underwent en-bloc resection under general anesthesia (hypotensive anesthesia) in prone position from a posterior approach by the technique described by Tomita *et al*[9,27] modified depending on tumor localization and involvement of neighboring structures as already published by our group.[15,28] In cases where the direct tumor affected neighboring structures that were not safely reachable posteriorly, an additional anterior approach was performed for tumor release and to secure subsequent posterior en-bloc resection. The extent of the posterior surgical approach was determined by the number of involved segments scheduled for resection including at least two to three cranial and caudal segments for posterior pedicle screw fixation. According to the technique after lateral preparation, that is, rib resection for thoracic locations, unilateral nerve root resection was required to enable removal the tumor. After pedicle screw placement, the dural sac was liberated by en-bloc resection of a unilateral lamina part. This step creates a corridor through which the resected segment can be passed while the dural sac is avoided to leave the spinal cord untouched during the rotation maneuver. In a key preparative step, both hands are used from the posterior approach to make a careful, blunt dissection of the anterior structures achieving a 360° circumferential liberation of the segments scheduled for resection. After ventral release and circumferential preparation of the dural sac the discs adjacent to the segments to be resected were marked with K-wires and controlled by intraoperative fluroscopy in the lateral plane. Thereafter, malleable S-shaped retractors to be positioned against the anterior spine were inserted from posterior to protect the anterior central vascular/mediastinal structures during disc excision. Using dura retractors to gently mobilize the dural sac, the posterior ligament was cut and the discs dissected with either sharp chisels or a scissors. The anterior longitudinal ligament was then cut. As the entire segment became more mobile for the rotation maneuver of the resected segment a unilateral working rod was secured to the pedicle screws. This insured spinal column stability for the period during final resection and subsequent reconstruction. Pedicle screws were at times used to make a slight distraction for easier disc dissection. As the dural sac was circumferentially liberated and the segments affected by the tumor were completely dissected from their adjacent discs and the surrounding ligamentous structures, the definitive rotation maneuver was performed gently passing the resected segments around dural sac/spinal cord through the previously created laminectomy gap (laminectomy corridor). After endplate preparation the length of the VBR was measured. A modular carbon composite cage (Trabis in OstaPek, CoLigne AG, Zurich, Switzerland) was assembled according to the required dimension. The system allowed defect-specific reconstruction using different length-, inclination- and endplate-sizes. The stackable modular VBR parts were finally secured using a titanium bolt through the length of the composite construct that was then copiously filled with autologous bone harvested from the iliac crest. Once the VBR was placed, artificial titanium pedicles were implanted to rigidly connect the VBR to the rods of the posterior fixation system. Furthermore VBR stability was achieved by finally inducing compression on the reconstructed segments *via* the cranial and caudal pedicle screws.

To describe the perioperative course further information and parameters were assessed. The number and type of previously performed surgery, the duration of surgery as well as the intraoperative bloodloss were analyzed. The necessity for a postoperative intensive care stay and the overall stay at the hospital were documented. Peri- and postoperative complications divided into minor and major.

## STATISTICAL ANALYSIS

Statistical analysis was performed using the SPSS software package (Microsoft Windows release 12.0; SPSS Inc., Chicago, IL). Data and results are presented as means, SD, and range. Local recurrence free survival, distant relapse free survivals, and disease-specific overall survival were assessed and analyzed according to the method of Kaplan-Meier using the SPSS program (MicroSoft Windows release 6.1; SPSS Inc.). Survival data were collected from the start of surgical treatment.

## RESULTS

Out of the 20 patients 15 suffered from primary spinal tumors, five from solitary metastases of biologic favorable entities. As for these five patients disease free survival before the appearance of metastases was 68 (6–252) months. The mean Tokuhashi Score of metastases patients was 10.8 (10–12) points and 2.0 (1–3) for the Tomita Score, respectively. Oncological data of all 20 patients investigated in the presented study is shown in Table 1. Seven patients (one patient twice) received emergency intralesional decompression of the spinal cord in external hospitals at a mean of 12 (5–27) months before TES. After diagnosis 13 patients underwent neoadjuvant

chemotherapy, seven preoperative radiation, and two after surgery. All chemotherapies were conducted in accordance to established therapy regimes.

Tumor expansion and localization was classified in accordance to Tomita as type six (multilevel extracompartmental) in all cases. Thirteen cases showed a thoracic, three thoracolumbar and four a lumbar localization. Aside of spinal tumor masses six patients showed further manifestation of adjacent structures that were equally en bloc resected to achieve sufficient margins. Three patients presented with an involvement of the diaphragm, two of the chest wall or aorta, one of the left lower lung lobe, or dural sac. For secure tumor liberation and better control during resection from posterior in 13 patients an additional anterior approach was chosen (left side thoracotomy n = 7, thoracophrenico-lumbotomy n = 2, retroperitoneal approach n = 4). Seven patients underwent TES solely by posterior surgery. Average duration of surgery was 10 (6–15) hours, the mean intraoperative blood loss 4600 (500–10,000) mL. For posterior pedicle screw instrumentation a minimum of two and a maximum of three levels below and above the defect were stabilized. Histopathological reports of the resected pieces showed wide resection margins in seven cases, marginal in 13 cases. After surgery patients were surveyed on an intensive care unit ward for 2.8 (±2.6) days. Investigated minor complications were local healing disturbances in three cases, one patient with CSF leakage, two temporary neurologic deficits completely relieving during hospital stay, and one hematoma that did not have be revised. Major complications showed a chylus fistula in two cases, one *postoperative ileus*, one pancreatitis, one *dural sac* compressing hematoma that needed to be revised surgically as well as one persistent neurologic deficit. At the first contact (before TES) four patients presented with neurologic deficits (two Frankel C, two Frankel D). After surgery one patient with a Frankel C deficit that suffered from *spinal cord* ischemia developed additional neurologic symptoms to Frankel B. At the latest follow-up 17 of 18 patients alive were ambulatory without any walking aid. Both patients who died in the course of disease were mobile without an aid after surgery.

At a follow-up (100%) time of 25 (9–53) months 13 patients showed no evidence of disease, five were alive with disease and two died of the disease. Oncosurgical results revealed one local tumor relapse of a sarcoma patient 8 months after surgery. Development of distant metastases (lung metastases n = 6, axillary lymph node metastases n = 1) occurred in seven patients (five out of the sarcoma group and two out of the solitary metastases group) after an average period of 9.7 (3–23) months on which two of these patients died after 10 and 27 months (Figures 1–3), respectively.

No correlation was found between the achieved resection margin and the oncological status at follow-up ($r = 0.32$) between preperformed surgeries and the oncological status ($r = 0.12$) as well as the treatment with adjuvant therapies and the onoclogical status at follow-up ($r = 0.21$).

Local radiologic follow-up including CT-scans were available for all patients. Seventeen had a minimum follow-up of 1 year. Controls showed no implant failure, loosening, or dislocation of the pedicle screw constructs. The interconnected carbon-composite-VBRs showed no dislocation. The endplate interfaces evidenced no stress shielding or noteworthy sintering (Figure 4).

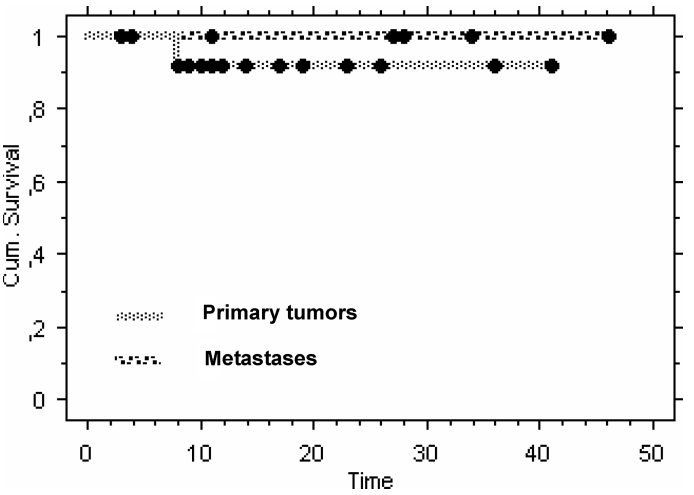


**Figure 1.** Local recurrence free survival showing one event in the primary tumor group 8 months after index surgery.

## DISCUSSION

Since the first descriptions of TES[3–5] various publications demonstrated its oncosurgical effectiveness in regard to decreased local recurrence rates, enhanced cumulative metastases free, and disease specific survival.[7,15,16,24,29,30] The published results, however, strongly depend on different influencing factors, for example, inclusion criteria, underlying primary tumors, surgical techniques and so on, emphasizing the heterogeneity in the patient groups that were considered to represent an indication for TES. From the prognostic point of view the entities of spinal primary tumors and solitary metastases are mainly characterized by their biologic behavior. In addition

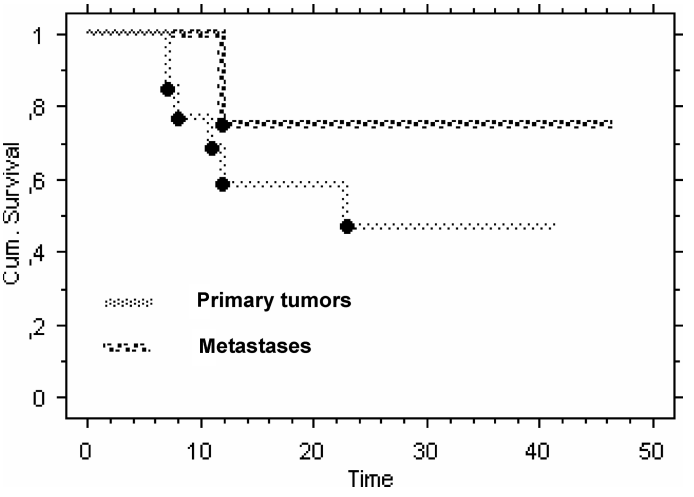


**Figure 2.** Metastases free survival displayed as cumulative Kaplan-Meier survival rates. Five patients out of the primary tumor and two patients out of the solitary metastases group developed further distant metastases.

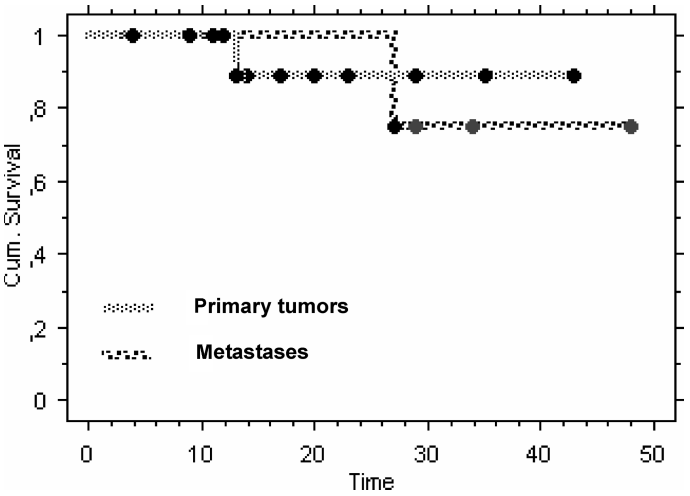


**Figure 3.** Disease specific survival displayed by cumulative Kaplan-Meier survival rates. Out of each group one patient died as a result of the disease.

to their response to systemic therapies, the initial localization, tumor aggressiveness, and growth tendencies in relation to anatomic borders present decisive factors that guide and determine further surgical treatment. Therefore, sufficient tumor resections must be oriented on biologic barriers represented by an anatomic compartment. On the basis of the oncosurgical work of Enneking *et al*[31,32] for peripheral tumor localizations (*e.g.*, extremities, pelvis) it was demonstrated that a systematic compartmental resection in preexisting anatomic borders enables surgeons to perform limb-salvage procedures with successful adequate local and systemic tumor control.[33] Weinstein and co-workers transferred this system to the spine based on a schematic classification showing the intra- or extracompartmental localization of a tumoral lesion relative to the vertebral body compartment.[6,29,34,35] Tumor growth beyond the boundaries of an anatomic compartment, that is, conversion from intra- to extracompartmental extension signals a decisive deterioration for the course of tumor disease. On the basis of their fair results Sakaura *et al*[17] followed that an extracompartmental vertebral metastatic tumor extension is a contraindication for TES because of the technical demands and potential risks. For tumors with paraspinal extensions they found a high incidence for local recurrences and reduced disease specific survival. In a previous study our group was able to demonstrate[15] that patients with solitary metastases and extracompartmental tumor localization treated by TES did not develop local recurrence while one third of the patients presented with distant metastases. In the presented study all tumors were classified according to Tomita *et al*[14,24] as type 6, that is, multisegmental extracompartmental extension. No local recurrence was found in the solitary metastases group. But in this study all solitary metastases patients received local radiation therapy combined with radical surgery and showed excellent local tumor control. Thus, these results seem to be comparable with studies investigating results after monolevel intracompartmental TES.[8,9] Although local oncosurgical results are encouraging, systemic disease control

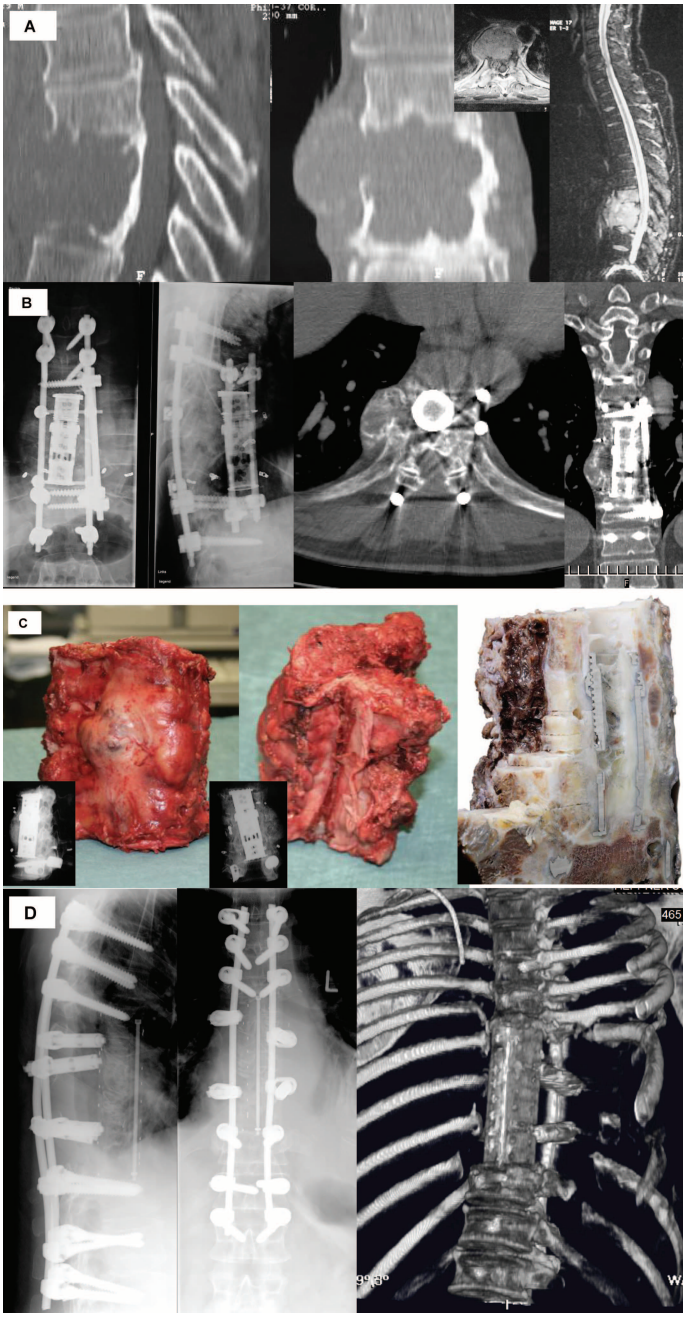


**Figure 4.** Example of a patient (42 yr/male) suffering from low-grade chondrosarcoma T7–T9. (**A**) First consultation at an external clinic due to persistent pain of the thoracic spine: CT/MRI images. (**B**) Radiographs and CT-scan revealing local recurrence 1 year after intralesional anterior-posterior resection in an external clinic. (**C**) On the basis of the local tumor board decision a four level en-bloc spondylectomy was performed after neoadjuvant chemotherapy: tumor specimen and corresponding radiographs; histopathological tumor transection. (**D**) radiograph and CT-scan control at follow-up showing a good reconstruction result.

seems to be unsolved. Despite their treatment with common chemotherapy regimes about 40% of metastases patients developed additional metastases in the course of the follow-up period. Among them one patient is already dead of disease.

The primary tumor group showed a local relapse in one patient (7%) with a neurofibrosarcoma and marginal resection

who underwent preoperative radiation therapy. In parallel to the group of patients with solitary metastases, distant metastatic disease development was seen in one-third of patients undergoing TES for primary multilevel tumors. The notion, that TES for multilevel extracompartmental tumor localization at the thoracolumbar spine represents a highly effective local therapy concept is furthermore emphasized by the absence of the following correlations: First, the histopathological status of resection margins (wide *vs*. marginal) did not demonstrate a correlation to the oncosurgical midterm outcome in this study. This however, may be because only wide and marginal resection margins were reached and no intralesional resections have been performed. Nevertheless, the importance of tumor-free and -contaminated margins for local and systemic tumor control has been shown.[26] Second, even a previously performed intralesional surgery did not correlate with the oncological status at follow-up. This may be due to the nature of the principle of TES as all structures of the vertebral segments affected by tumor growth are resected en bloc, including the circumferential border of the spinal canal, the laminae, and the former biopsy tract. In addition all these patients were treated by adjuvant radiochemotherapeutic protocols.

The described technique represents a radical resection option. On the basis of a multidisciplinary treatment concept its combination with radiation and (if available) chemotherapy is a sufficient solution for local tumor control. Nevertheless, in patients with entities typically nonresponsive to systemic adjuvant therapies (*e.g.*, chordomas, chondrosarcomas *etc.*) the successful combination of surgery and adjuvant therapy does not make prognostic sense. In these situations the surgical part of therapy, that is, the tumor resection with oncosurgical adequate margins, has major importance. In turn, these constellations could be more likely to result in local and systemic tumor relapse.[1]

In one-third of the investigated patients tumor involvement of adjacent paraspinal structures was seen, making interdisciplinary cooperation with thoracic or vascular surgeons essential for successful results. Performing an approach to attain tumor-free margins, multilevel TES required the chest wall, diaphragm, lung, dural sac, or aorta to be included into the en-bloc resection. Thus, the surgical margins—and consequently, the invasiveness of the procedure had to expanded. Surprisingly, this increase in surgical risk and morbidity did not result in the expected increase in complications.[36] This is even more remarkable with the high number of previously performed surgeries, preoperative chemotherapies and local radiation. In this context exact pre-, intra- and perioperative management is of tremendous importance and needs to be described as key steps and triggering factors to prevent severe complications typically found with radical surgery.[24,29,37] In this study resection of the diaphragm, chest wall, aorta, dural sack, or parts of the lung lobes were combined with TES. *All major and minor complications that appeared due to the extensive resections were reversible in the course of the hospital stay except in one case of a persisting neurologic deficit based on a spinal cord ischemia.* Angiography was performed in all cases before surgery. Though the Adamkiewicz artery was not affected intraoperatively, in the mentioned patient, neurologic deficits occurred due to *spinal cord* ischemia and was evidenced by postsurgical MRI. Our experiences demonstrate a subordinated role of the Adamkiewicz artery as already suggested by other publications.[38,39] Therefore, *spinal cord* ischemia in TES rather results from a summation of blood flow interruption of certain spinal levels.[40,41] In contrast, no neurologic deficits occurred in a five level resection comprising unilateral ligation of minimum five segmental vessels. We suggest a highly individualized spinal blood supply can only in part be predicted even with spinal angiography. Nevertheless, knowing that decrease in nerve root ligation-associated *spinal cord* perfusion may become a problem, preservation of nerve roots not involved in tumor extension should be attempted if oncosurgically possible, preferentially those roots with the dominant spinal arterial inflow.

The majority (72%) of the investigated patients received chemotherapy and/or local radiation as part of the interdisciplinary oncological concept. Even with this limitation[42–44] in healing capacity, no implant failure, subsidence, or loosening was radiologically evidenced in this study. In addition, no resorption of the transplanted autologous bone was seen. Therefore, the VBR volume uptake capacity for osteoinductive and -conductive materials, that is, autologous bone grafts, seems to be a key point for successful preservation of reconstructions after highly unstable multilevel en-bloc spondylectomy defects. Increased appearance of stress shielding at the bone implant interface has been shown[45] for constructs using maximized rigidity. To allow local remodelling stress has to be conducted through the anteriorly localized graft and this was demonstrated for reconstructions using posterior fixation and VBR implantation. In contrast, additional anterior fixation methods enhanced stress shielding and should therefore be avoided.[45] Biomechanically, postimplantational stability after en-bloc spondylectomy reconstruction, that is, before a secondary bony integration will be achieved, is mainly influenced by the number of adjacent segments used for posterior pedicle screw fixation. Additional anterolateral fixation devices—as shown to enhance stress shielding—has only a minor influence on construct stability if more than one adjacent segment is included in the posterior fixation.[22,23] All patients in this study received posterior pedicle screw fixation including a minimum of two cranial and caudal adjacent segments and anterior reconstruction with a VBR system perhaps explain the lack of stress shielding in radiograph and CT-scan control investigations. Remarkably, primary stability does not differ biomechanically either with the implantation of an expandable or a nonexpandable VBR system independent from the length of the posterior pedicle screw fixation. As a result, the advantage of expandable devices is avoidance of dislocation by a secure endplate anchorage. Conversely, the expansion mechanism itself limits the volume of bone graft. The carbon-composite-VBR system used in this series is rigidly fixed to the posterior fixation rods by artificial pedicles and offers thereby a maximized ratio between uptake graft volume and implant stability. Over the investigation time period

there was no implant failure observed either of the carbon composite VBR or the pedicle screw rod fixation system. The importance of long-term stable spinal reconstruction becomes even more evident as avoidance of spinal instability after surgery is a precondition for the excellent functional outcome of the presented study as well as for the low postoperative pain level we had observed in our patients.

However, the statistical power of the presented study is limited due to the relatively low number of patients suffering from malignant spinal tumors. In addition the patient cohort is heterogeneous regarding, for example, tumor entities, tumor size and location, type of adjuvant therapies. This limitation may be addressed with a multicenter study including a substantial larger number of patients.

## CONCLUSION

Extracompartmental and multisegmental tumor localizations of sarcomas and solitary metastases at the thoracolumbar spine can effectively be resected by TES. By achieving wide to marginal resection margins the combination of surgical procedure and adjuvant therapies demonstrated low local recurrence rates. Development of metastatic disease in contrast was seen in one-third of the patients at the midterm follow-up underscores the necessity for further advances in (neo-) adjuvant therapies aiming at prevention of systemic tumor spread. Without denying the intraoperative and surgical risks of that challenging procedure and the relative high patients stress, postoperative oncosurgical results confirm and support the importance and efficiency of this procedure. However, careful patient selection, interdisciplinary surgical planning and cooperation, aggressive management of complications together with extensive experience in spine tumor surgery and reconstruction are essential prerequisites for good oncological results, low complication rates, and acceptable functional results. Defect reconstruction with the described carbon-composite-VBR and the interconnected pedicle screw system demonstrated minimal complications, good healing capacity, and significant advantages for artifact-free imaging for local MRI- or CT- restaging studies.

### ➢ Key Points

- ❑ Multilevel thoracolumbar en-bloc spondylectomies for primary tumors and solitary metastases enables to achieve wide or marginal margins even in extracompartmental tumor involvement.
- ❑ On the basis of an exact patient selection and perioperative planning multilevel thoracolumbar en-bloc spondylectomy is a feasible and safe surgical procedure.
- ❑ In combination wit adjuvant therapies multilevel en-bloc spondylectomy showed low local recurrence rates whereas distant metastases developed in one-third of patients.
- ❑ Defect reconstruction using a carbon composite VBR system showed low complication rates and offers advantages for oncosurgical procedures.

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