Total En Bloc Spondylectomy: A New Surgical Technique for Malignant Vertebral Tumors

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Conventionally, because of the difficulty in surgical approach and the anatomical proximity of the major vessels to the involved vertebra(e), curettage and resection of vertebral tumors have been commonly practiced, including removal of the malignant tissue in a piecemeal fashion. The disadvantages of these conventional approaches are clear, including a high possibility of tumor cell contamination of the surrounding structures and difficult identification of a demarcation zone separating neoplastic tissue from healthy tissue. These factors may contribute to incomplete resection of the tumor as well as recurrence of the spinal malignant neoplasm [1, 2].

To reduce local recurrence as much as possible and to increase survival rate, we have developed a new surgical technique of spondylectomy (vertebrectomy) termed total en bloc spondylectomy (TES) [1–5]. Using this technique, we were able to excise the tumor mass with a wide or narrow margin, but sometimes with an minimal intralesional margin in the pedicle.

Indications for Total En Bloc Spondylectomy

The TES operation was designed primarily for patients who met the following criteria: a primary malignant tumor, aggressive benign tumor, or solitary metastasis that did not spread into or invade adjacent visceral organs, showed little or no adhesion to the vena cava or aorta, and did not show multiple metastases. A contiguous involvement of three or fewer vertebrae represented a relative indication for the TES operation.

The indications for surgical treatment of spinal metastases are neurologic deficit, intractable pain, and spinal instability. The oncologic factors to be considered include the success of treatment of the primary tumor, whether the metastases are solitary and localized, if the metastases are limited and can be controlled, and if there is a life expectancy of at least 12 months.

To provide a more informative staging, a new surgical classification was devised that incorporated a description of the affected anatomical site and the extent of the tumor. The anatomical site of the neoplasm was classified as follows: (1) vertebral body, (2) the pedicle, (3) the lamina and spinous process, (4) spinal canal (epidural space), and (5) paravertebral area (Fig. 53.1). The numbers used to denote the anatomical sites reflect the common sequence of tumor progression. The number of anatomical sites is also related to the surgical classification as described here. Using the anatomical and surgical classification, the new surgical classification of vertebral tumors was designed (Fig. 53.2). The classification concept was modified from the surgical staging system of Enneking and coworkers [6]. For instance, type 3 lesion in our classification involves the vertebral body (anatomical site 1), the pedicle (anatomical site 1), and the lamina (anatomical site 3). We considered type 1, 2, and 3 lesions as intracompartmental and types 4, 5, and 6, as extracompartmental. Type 7 tumor is a multiple skip lesion. The TES operation is recommended for type 2, 3, 4, and 5 lesions, relatively indicated for type 1 and 6 lesions, and not recommended or contraindicated for type 7 lesions.

Surgical Technique

The TES technique consists of two steps: en bloc resection of the posterior element and en bloc resection of the anterior column. The following is a description of each step.

Step 1: En Bloc Laminectomy (En Bloc Resection of the Whole Posterior Element of the Vertebra)

1. Exposure

The patient is placed prone over the Relton–Hall four-poster frame to avoid compression to the vena cava. A straight vertical midline incision is made over the spinous processes and is extended three vertebrae above and below the involved

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segment(s). The paraspinal muscles are dissected from the spinous processes and the laminae, and then retracted laterally. If the patient underwent posterior route biopsy, the tracts are carefully resected in a manner similar to that used in a limb-salvaging procedure. After a careful dissection of the

Fig. 53.1 Definitions of anatomical sites of the vertebra. (From Tomita N, et al: Int Orthop 18:292, 1994)

area around the facet joints, a large articulated spinal retractor is applied. By spreading the retractor and detaching the muscles around the facet joints, a wider exposure is obtained. The operative field must be wide enough on both sides to allow dissection under the surface of the transverse processes. In the thoracic spine, the ribs on the affected level are transected 3 to 4 cm lateral to the costotransverse joint, and the pleura is bluntly separated from the vertebra (Fig. 53.3).

To expose the superior articular process of the uppermost vertebra, the spinous and the inferior articular processes of the neighboring vertebra are osteotomized and removed with dissection of the attached soft tissues, including the ligamentum flavum.

2. Introduction of the T-Saw Guide

To make an exit for the T-saw guide through the nerve root canal, the soft tissue attached to the inferior aspect of the pars interarticularis is dissected and removed, using utmost care so as not to damage the corresponding nerve root. A C-curved malleable T-saw guide is then introduced through the intervertebral foramen in a cephalocaudal direction. In this procedure, the tip of the T-saw guide should be introduced along the medial cortex of the lamina and the pedicle so as not to injure the spinal cord and the nerve root (Fig. 53.4). After passing the T-saw guide, its tip at the exit
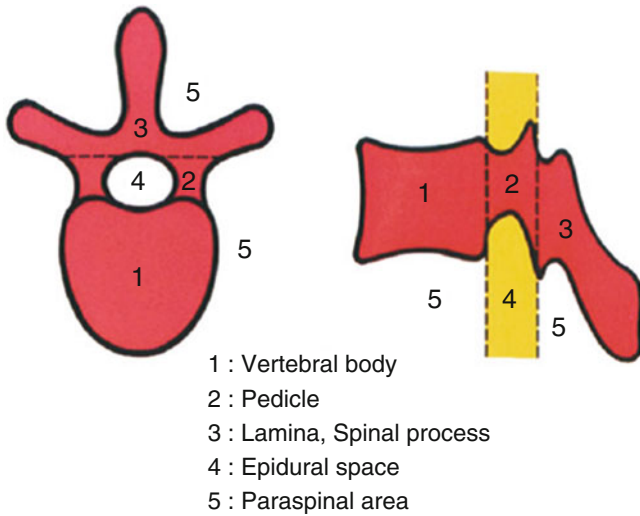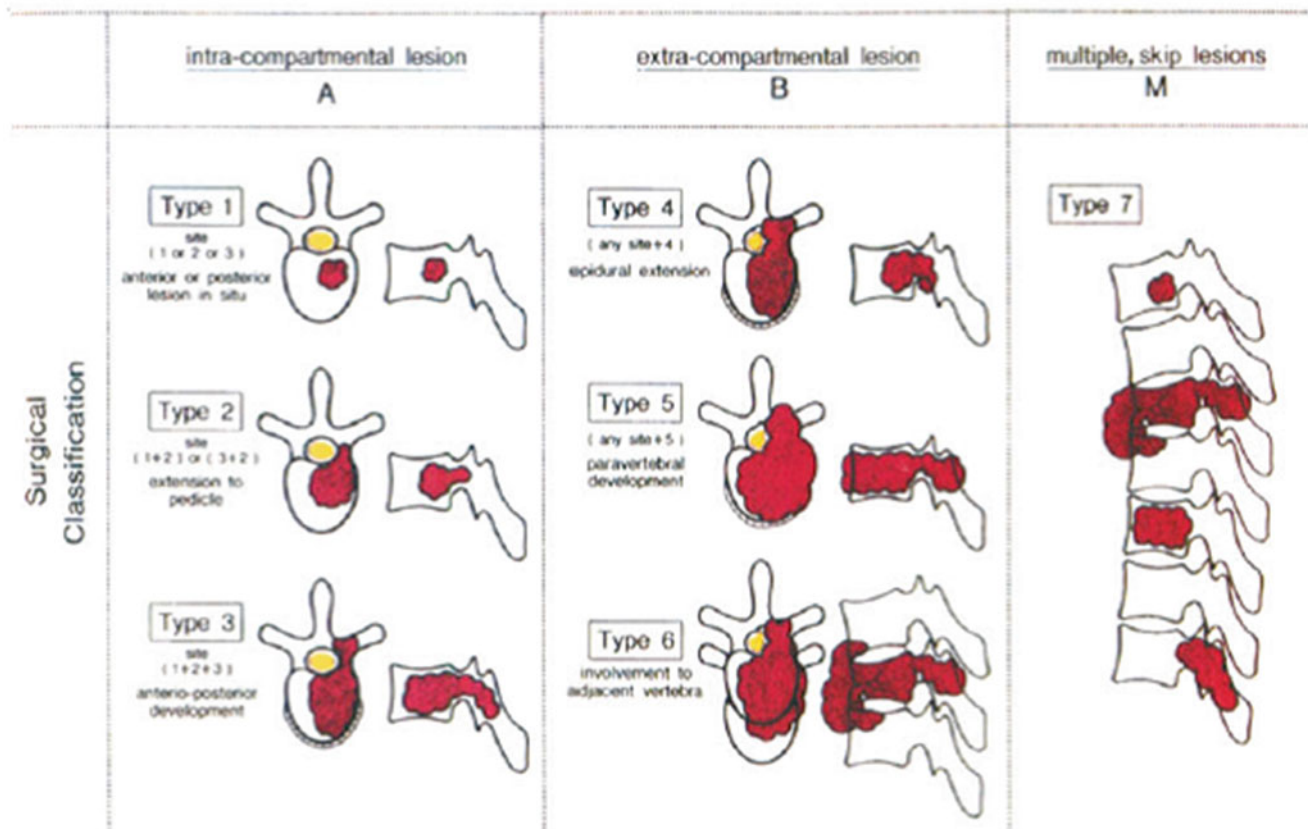

Fig. 53.2 Schematic diagram of surgical classification of vertebral tumors. (From Tomita N, et al: Int Orthop 18:292, 1994)

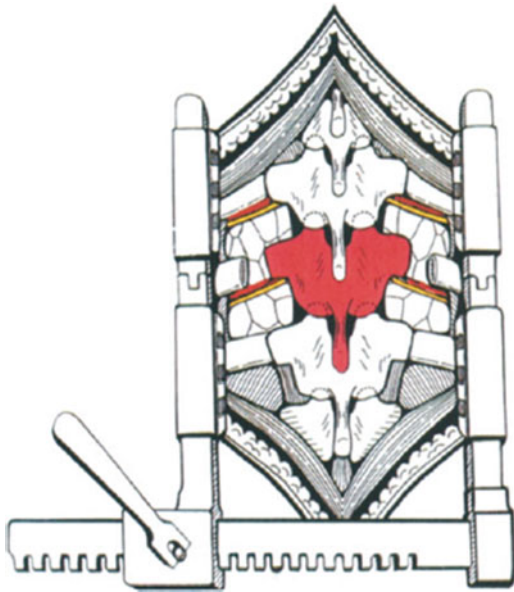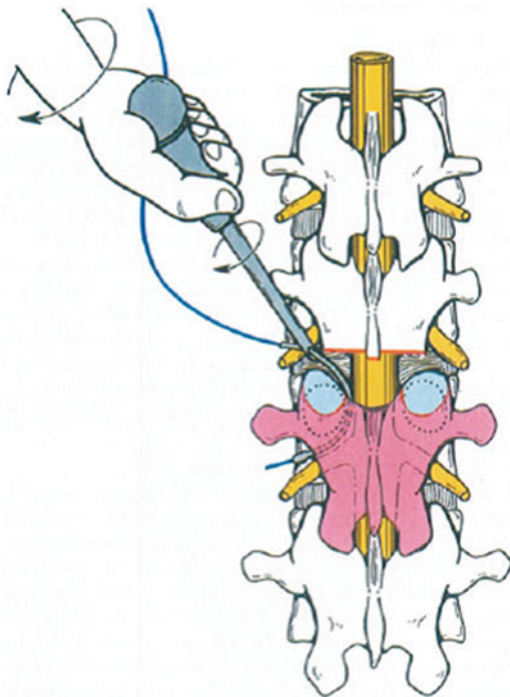**Fig. 53.3** Operative schema of the posterior exposure

Fig. 53.5 Photograph of the thread-wire saw (T-saw) compared with a Gigli saw and a match

Fig. 53.4 Operative schema of introducing the T-saw guide
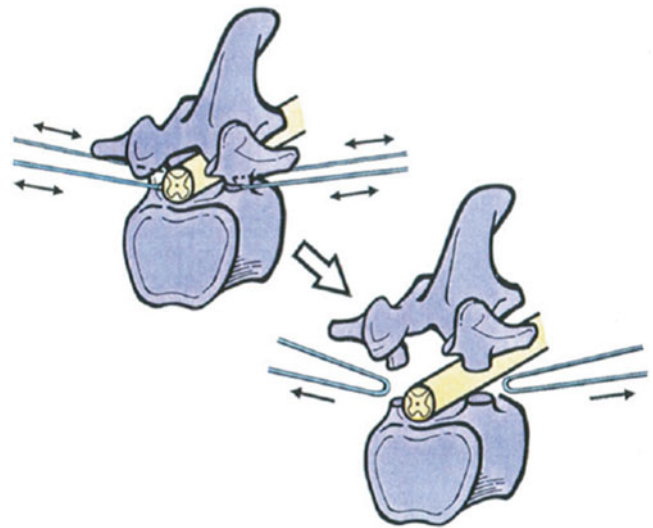
Fig. 53.6 Operative schema of the pediclotomy

of the nerve root canal can be found beneath the inferior border of the pars interarticularis. In the next step, a thread-wire saw (T-saw; flexible multifilament threadwire saw, 0.54 mm in diameter[7]; Fig. 53.5) is passed through the hole in the wire guide and is clamped with a T-saw holder at each end. The T-saw guide is removed, and tension on the T-saw is maintained. When two or three vertebrae are resected,
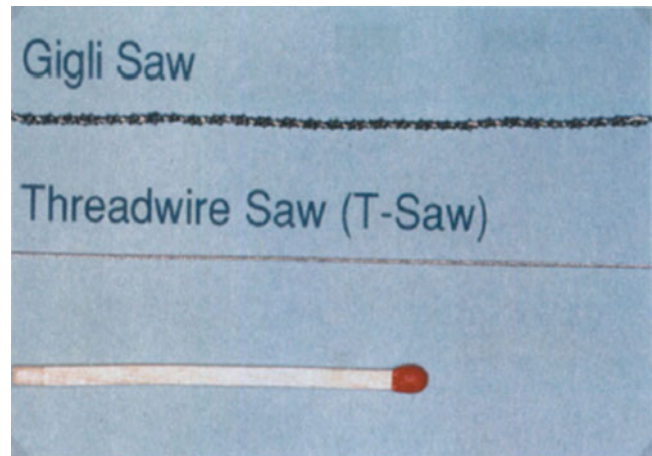
the T-saw is inserted into a thin polyethylene catheter (T-saw catheter) and both are passed under the lamina. This procedure is also applied to the contralateral side.

3. Cutting the Pedicles and Resection of the Posterior Element

While tension is maintained, the T-saw is placed beneath the superior articular and transverse processes with a specially designed T-saw manipulator. With this procedure, the T-saw placed around the lamina is wrapped around the pedicle. With a reciprocating motion of the T-saw, the pedicles are cut and then the whole posterior element of the spine (the spinous process, the superior and inferior articular processes, the transverse process, and the pedicle) is removed in one piece (Fig. 53.6). The cut surface of the pedicle is sealed with bone wax to reduce bleeding and to minimize contamination by
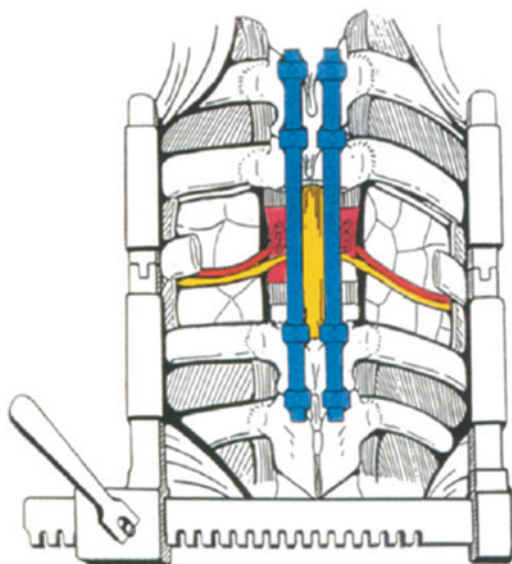
Fig. 53.7 Operative schema of setting the posterior instrumentation

Fig. 53.8 (**a**, **b**) Operative schema of anterior dissection around the vertebral body

tumor cells. To maintain stability after segmental resection of the anterior column, a temporary posterior instrumentation is performed (Fig. 53.7). When one vertebra is resected, segmental fixation at two above and two below is recomended. However, if two or three vertebrae are resected, more than two above and two below segmental fixation is mandatory.

Step 2: En Bloc Corpectomy (Resection of the Anterior Column of the Vertebra)

1. **Blunt Dissection Around the Vertebral Body**

   At the beginning of the second step, the segmental arteries must be identified bilaterally. The spinal branch of the segmental artery, which runs along the nerve root, is ligated and divided. This procedure exposes the segmental artery, which appears just lateral to the cut edge of the pedicle. In the thoracic spine, the nerve root is cut on the side from which the affected vertebra is removed. The blunt dissection is done on both sides through the plane between the pleura (or the iliopsoas muscle) and the vertebral body. Usually, the lateral aspect of the body is easily dissected with a curved vertebral spatula. Then, the segmental artery should be dissected from the vertebral body. By continuing dissection of both lateral sides of the vertebral body anteriorly, the aorta is carefully dissected posteriorly from the anterior aspect of the vertebral body with a spatula and the surgeon's fingers (Fig. 53.8a, 53.8b). When the surgeon's fingertips meet anterior to the vertebral body, a series of spatulas, starting from the smallest size, are inserted sequentially to extend the dissection. A pair of the largest spatulas is kept in the dissection site to prevent the surrounding tissues and organs from iatrogenic injury and to make the surgical field wide enough for manipulating the anterior column.
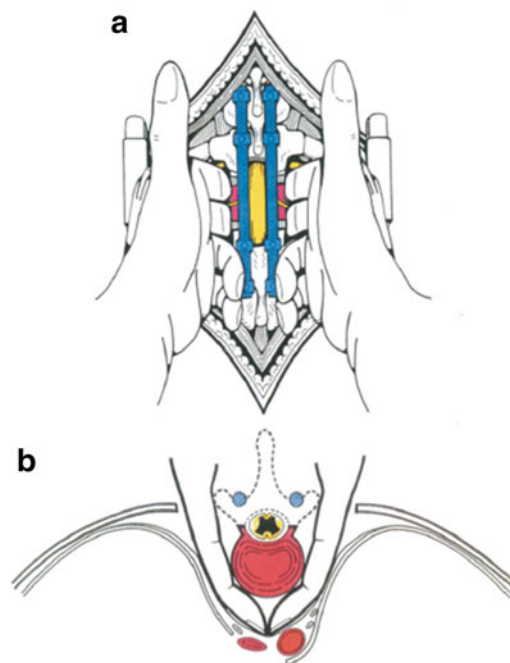
2. **Vascular Anatomy Around the Vertebral Body**

   It is important to understand vascuar anatomy around the vertebral body [8]. The first four segmental (posterior intercostal) arteries commonly run directly upward apart from the vertebral column and turn more transversely over the costovertebral joint (Fig. 53.9). The azygos vein cephalad to T4 ascends away from the vertebral column (Fig. 53.10). This anatomical specificity in the upper thoracic area indicates that there is a decreased chance of critical damage to these vessels during isolation of the affected vertebral body and paired discs posteriorly in total en bloc spondylectomy.

   At spinal levels caudal to T4, the thoracic and abdominal aorta descends downward in direct contact with the anterior vertebral column. Obviously, it is true that surgeons must be extremely careful not to violate the vessel but they can usually make sure of the aortic pulsation at their fingertips and thus the retraction of the aorta anteriorly from the affected vertebral body is relatively undemanding, technically speaking.

   In the cases of our cadavor reseach [8], the segmental artery to the vertebra had some variations: 48 of 348 segmental arteries in 17 subjects originated from intercostal arteries adjacent to the corresponding level, not from the thoracic aorta: 38 variants were identified at T4 or more cephalad and 10 at T5 or caudal. Adachi observed that 88 (9 %) of all 977 intercostal arteries did not originate from the thoracic aorta ($n = 48$): 28 of 88 variations were at T5 or caudal (Fig. 53.11) [9]. Adachi concluded that, in Japanese, approximately 4 % of thoracic segmental arteries do not originate directly from the thoracic aorta, and 8 % of the vertebrae lack a segmental
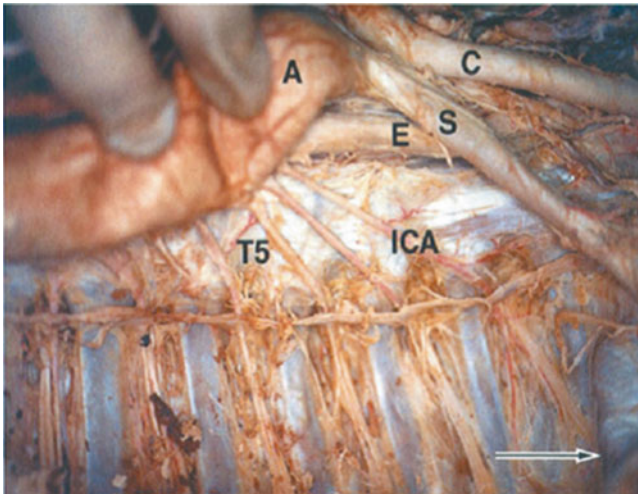
Fig. 53.9 Topographic view of the aortic arch and posterior intercostal arteries at the upper thoracic spine on the right side in the cadaveric study.8 The highest aortic arch level was at T3–T4, and the subsequent thoracic aorta descends in direct contact with the vertebrae at T5 or below. The second to fourth posterior intercostal arteries originate from the aorta at T5. *C*, common carotid artery; *S*, subclavian artery; *E*, esophagus; *A*, aortic arch; *T5*, T5 vertebral body; *ICA*, intercostal artery. *Arrow* indicates the cranial direction. (From Kawahara N, et al: Spine 21 (12):1402, 1996)
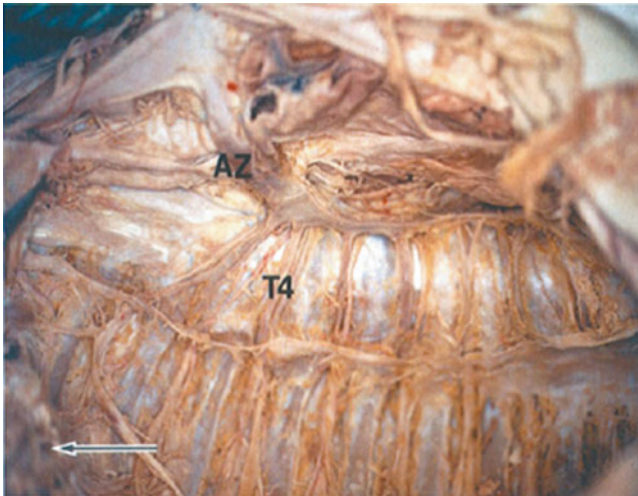

Fig. 53.10 Photograph shows the azygos vein ascending in the upper thoracic spine in the cadaveric study.8 The azygos vein directly contacts with the thoracic vertebrae at T4 or below. *AZ*, azygos vein; *T4*, T4 vertebra. *Arrow* indicates the cranial direction. (From Kawahara N, et al: Spine 21(12):1403, 1996)

Fig. 53.11 Variations in intercostal arteries in the cadaveric study.8 The left second, third, and fourth intercostal arteries branch from the fifth intercostal artery (*) anterior to the head of the fifth rib. The left sixth intercostal artery (**) branches as a variant seventh intercostal artery. *T6*, T6 vertebra. *Arrow* indicates the cranial direction. (From Kawahara N, et al: Spine 21(12):1404, 1996)

the posterior aortic midline display essentially horizontal segmental distribution, whereas those from L3 and L4 levels run vertically downward behind the aorta and then horizontally up to the intervertebral foramina. Variations in origins and distribution can occur and should be anticipated. In 63 cadavers, Adachi observed that 5 (1 %) variants in a total of 498 lumbar arteries had been recorded between L1 and L4 that did not arise from the abdominal aorta [9]. Based on anterior scoliosis surgery, Winter et al.10 reported that the number of lumbar arteries may vary: four in 70 % to 74 % of the clinical cases, three in 20 % to 22 %, and five in 5 % to 7 % of their cases. Variations include a conjoined form of lumbar artery distributing two segments simultaneously, and the collateral branched from the lumbar artery at neighboring levels.

The muscle fibers of the medial crus of the lumbar diaphragm originated most frequently and firmly from the L2–L3 disc levels bilaterally, and the second lumbar artery ran dorsally to the medial crus (Fig. 53.12). This important portion of the diaphragm must be separated posteriorly before the isolation and excision of vertebral tumors. In total en bloc spondylectomy attempted to this level, it is thus very important to separate the medial crus from its vertebral origin, followed by the exploration of the second lumbar artery from L2 involved with malignancy. At this spinal level, however, the aorta pulsates very strongly with decreased risk of injury if it is carefully retracted forward. The inferior vena cava ascends anterior to the medial crura of the diaphragm, primar-ily on the right. Additionally, great care must be taken because the azygos and hemiazygos veins are dorsal and cephalad to the medial crura of the diaphragm, especially in the case with an L1 vertebral tumor. Attention must

artery in the middle to lower thoracic spinal levels [9]. This anatomical variation must be kept in mind when no segmental arteries are identified around the affected vertebral bodies during total en bloc spondylectomy.

In the lumbar spine between LI and L4, the lumbar artery consistently arose from the abdominal aorta at each corresponding spinal level bilaterally in our cadaver series [8]. The first and second lumbar arteries arising on each side of
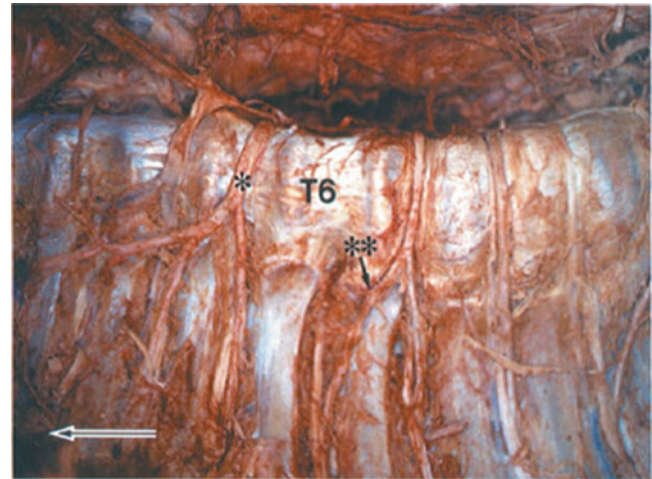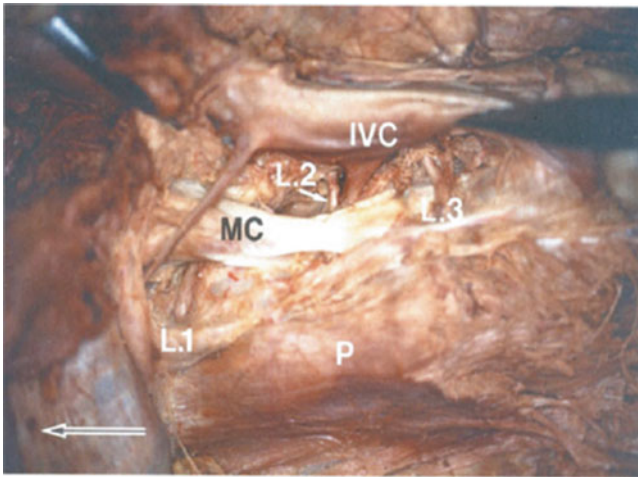
Fig. 53.12 Right medial crus of the lumbar diaphragm and surrounding vessels in the cadaveric study.8 The medial crus originates at L2–L3. *IVC*, inferior vena cava; *MC*, right medial crus; *P*, psoas muscle. *L.1, L.2*, and *L.3* indicate the first, second, and third lumbar arteries. *Arrow* indicates the cranial direction. (From Kawahara N, et al: Spine 21(12):1404, 1996)
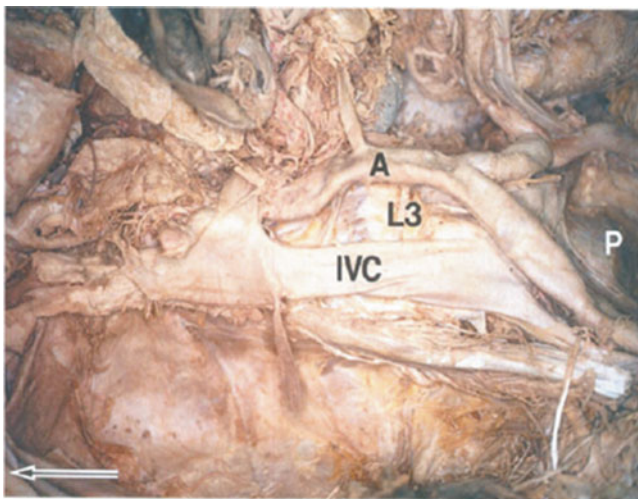

Fig. 53.14 Operative schemes for cutting the anterior column. A pair of the spatulas is kept around the affected vertebral body to prevent the surrounding tissues and organs from iatrogenic injury and to make the surgical field wide enough for manipulating the anterior column. The anterior column of the vertebra is cut by the T-saw, together with the anterior and posterior longitudinal ligaments. The teeth-cord protector, which has teeth on both edges to prevent the T-saw from slipping, is then applied

Fig. 53.13 Major vessels in the lumbar spine in the cadaveric study.8 The inferior vena cava ascends in tight contact with the vertebrae in conjunction with lordosis. A aorta; *IVC*, inferior vena cava; *P*, promontrium; *L3*, L3 vertebra. *Arrow* indicates the cranial direction. (From Kawahara N, et al: Spine 21 (12):1404, 1996)

also be paid not to injure the inferior vena cava posteriorly because it ascends in direct contact with the vertebral column at L3 and L4, the same as actual for aortic bifurcation as well as venous confluence at L4 and L5 (Fig. 53.13).

3. **Passage of the T-Saw**

T-Saws are inserted at the proximal and distal cutting levels of the vertebral bodies, where grooves are made along the desired cutting line using a V-notched osteotome after confirmation of the disc levels with needles.
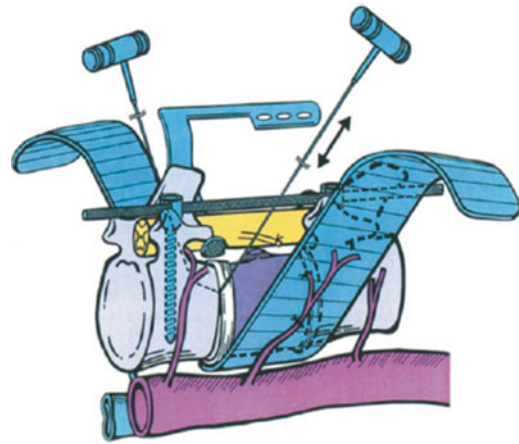
4. **Dissection of the Spinal Cord and Removal of the Vertebra**

Using a cord spatula, the spinal cord is mobilized from the surrounding venous plexus and the ligamentous tissue. The teeth-cord protector, which has teeth on both edges to prevent the T-saw from slipping, is then applied. The anterior column of the vertebra is cut by the T-saw, together with the anterior and posterior longitudinal ligaments (Fig. 53.14). After cutting the anterior column, the mobility of the vertebra is again checked to ensure a complete corpectomy.

The freed anterior column is rotated around the spinal cord and removed carefully to avoid injury to the spinal cord. With this procedure, a complete anterior and posterior decompression of the spinal cord (circumspinal decompression) and total en bloc resection of the vertebral tumor are achieved (Fig. 53.15).

5. **Anterior Reconstruction and Posterior Instrumentation**

Bleeding, mainly from the venous plexus within the spinal canal, should be exhaustively arrested. An anchor hole on the cut end of the remaining vertebra is made on each side to seat the graft. A vertebral spacer, such as autograft, fresh and/or frozen allograft, apatite-wollastonite glass ceramic prosthesis (Lederle, Tokyo, Japan), and a titanium mesh cylinder (MOSS-Miami, DePuy Motech, Warsaw, IN), is properly inserted to the anchor holes within the remaining healthy vertebrae. After checking the appropriate position of the vertebral spacer radiographically, the posterior instrumentation is adjusted to slightly compress the inserted vertebral spacer. If two or three vertebrae are resected, application of the connector device between the posterior rods and anterior spacer
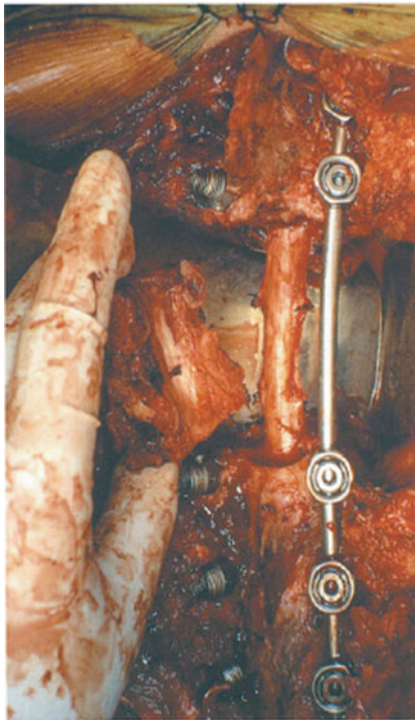
Fig. 53.15 Photograph of the en bloc corpectomy. The freed anterior column is rotated around the spinal cord and removed carefully to avoid injury to the spinal cord. With this procedure, a complete anterior and posterior decompression of the spinal cord (circumspinal decompression) and total en bloc resection of the vertebral tumor are achieved

Fig. 53.16 Operative schemes of spinal reconstruction. (**a**) When one vertebra is resected, two above and two below segmental fixation is enough. (**b**, **c**) However, if two or three vertebrae are resected, more than two above and two below segmental fixation is mandatory, and application of the connector device between the posterior rods and the anterior spacer is recommended

is recommended (Fig. 53.16a–53.16c). Finally, a Bard Marlex mesh (Bard, Billerica, MA, USA) covers the entire anterior and posterior reconstructed areas to establish the compartment for suppressing bleeding.

6. **Postoperative Management**

Suction draining is preferred for 2 to 3 days after surgery, and the patient is allowed to start walking 1 week after surgery. The patient wears a thoracolumbosacral orthosis for 2 to 3 months until the bony union or incorporation of the artificial vertebral prosthesis is attained.

Case Study

A 58-year-old man was hospitalized because of severe back pain and paraparesis. Eight years before admission, the patient was diagnosed with thyroid cancer, which was treated with thyroidectomy. Imaging workup showed a tumor growth throughout the entire T6 vertebra as well as the epidural space of T5 and T6 (Fig. 53.17). Examination of a biopsy material confirmed the lesion to be a metastatic thyroid cancer. Total en bloc spondylectomy was performed at the T5 and T6 vertebrae (Fig. 53.18). Anterior reconstruction was carried out using a titanium mesh cylinder, containing autogenous iliac cancellous chip bones. A MOSS Miami screw
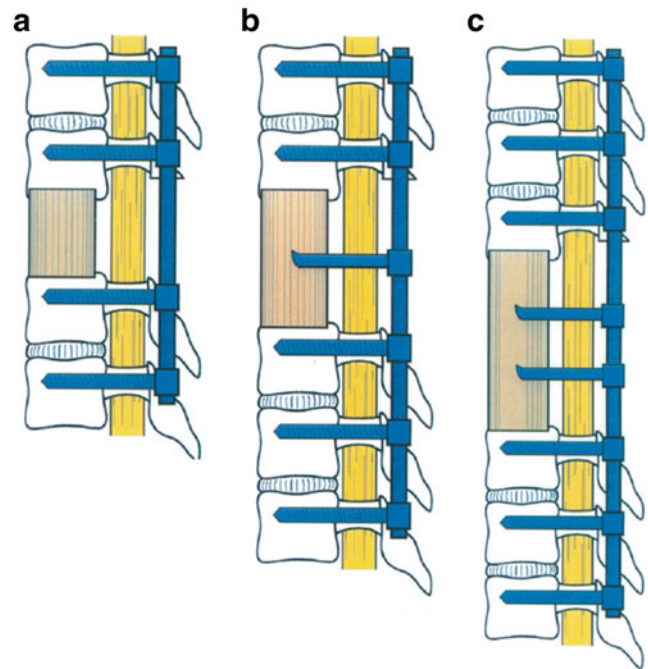

Fig. 53.17 The T_2-weighted magnetic resonance imaging of the patient with solitary thyroid cancer metastasis, showing compression of the cord at T5 and T6 levels

and rod arrangement was performed posteriorly between T2 and T9 levels. A pair of DLT bars of the Cotrel–Dubousset construct allowed the titanium mesh cylinder to be securely positioned. Radiographs did not show any loosening of the implants anteriorly and posteriorly at 2.5-year follow-up (Fig. 53.19a, 53.19b). The patient has been well for the past 3 postoperative years.

Discussion

The ring-shaped bony structure of the vertebra, containing the spinal cord, hinders a wide surgical margin. Other obstacles exist, such as the thin surrounding soft tissues, major vessels,
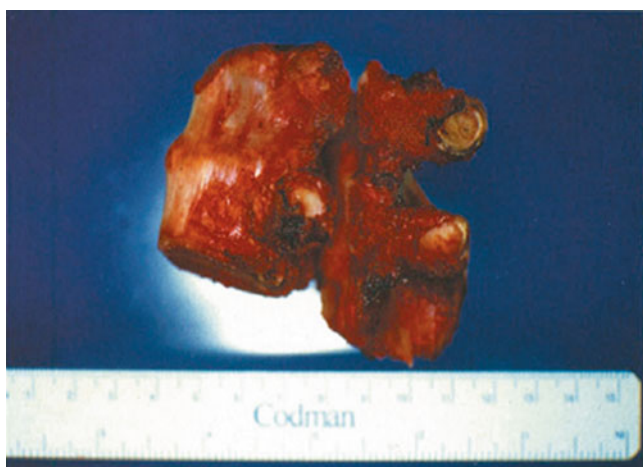

Fig. 53.18 Photograph of the resected specimen of the T5 and T6 vertebrae

and visceral organs neighboring the involved vertebra. Thus, most operations are amenable to curettage or piecemeal resection. However, the intralesional procedure apparently leads to incomplete resection and to definite contamination by tumor cells.

Roy-Camille et al. [11, 12], Stener [13–15], Stener and Johnson [16], Sundaresan et al. [17], and Boriani et al. [18, 19] have described total spondylectomy for improving local curability, with excellent clinical results. In contrast, our procedure involves peripheral manipulation, except for the pedicle, and the lesion is removed en bloc. The TES technique minimizes the risk of contamination compared with that described by these authors.

The major risks in TES operation include (1) mechanical damage to the adjacent neural structures during the excision of the pedicles; (2) possible contamination by tumor cells during pediculotomy; (3) injury of the major vessels during blunt dissection of the anterior aspect of the vertebral body; (4) disturbance of spinal cord circulation at the level of surgery; and (5) excessive bleeding from the internal vertebral vein and epidural venous plexus during the second step of surgery. To reduce the risk of nerve root and spinal cord damage, we designed the T-saw [7]. It is made of multifilament twisted stainless steel wires and has a smooth surface to cut hard bony materials with minimal damage to the surrounding soft tissues. If the T-saw is properly passed into the nerve root canal and pulled posteriorly, it should not damage the nerve root. It is obvious that resection of the vertebra in one piece without cutting a certain point of the ring-shaped bony structure is impossible because of the encasement of the spinal cord within the vertebra. The pedicle is the best site for this purpose since (1) it is the narrowest portion
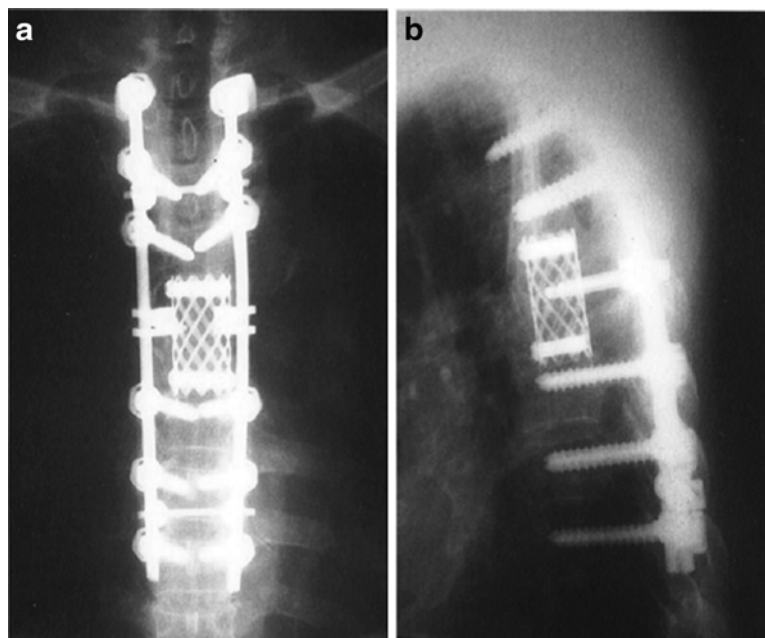
Fig. 53.19 Radiograph taken 2.5 years after surgery without instrumentation failure posteriorly. (**a**) Anteroposterior view. (**b**) Lateral view

connecting the posterior element with the anterior part so that the intralesional cut surface will minimize the chance of contamination to a great extent, and (2) the spinal cord and the nerve root can be freed easily atraumatically. Pediculotomy is thus justified from the anatomical standpoint. However, the pedicle does not always serve as a safe point for cutting, particularly when it is involved with the malignant process. Under such circumstances, the ipsilateral side of the lamina and contralateral part of the pedicle are cut together. These cutting levels may be considered separately in each case.

Blunt dissection of the anterior part of the vertebral body is another risky maneuver in the TES operation. The anatomical relationship between the vertebra, major vessels, and the visceral organs should be well acknowledged.[8] Based on anatomical studies on cadavers, TES is less likely to damage the thoracic aorta between T1 and T4. However, the artery must be carefully retracted anteriorly in areas caudal to T5 before manipulation of the affected vertebra(e). For a lesion at LI and L2, the diaphragm and the first two lumbar arteries should be treated with utmost care. Possible circulatory compromise after the ligation of the radicular artery is another concern. In the cat model, the authors [3] found that ligation of the Adamkiewicz artery reduced spinal cord blood flow by approximately 81 % of the control value, and this decrementation did not affect spinal cord evoked potentials. Abundant arterial network around the dura mater and the spinal cord may completely compensate for the ligation of one or two radicular arteries. Actually, there has been no neurologic degradation in all 60 patients in our series who underwent TES. Bleeding from the epidural venous plexus is often profuse. Hemostasis of tamponade in the epidural space using Oxycell cotton, Aviten, or fibrin glue is mandatory. In addition to hypotensive anesthesia (systolic blood pressure, 60–80 mmHg), exhaustive management to arrest bleeding must be followed.

Roy-Camille et al. [11, 12] suggested that the origin of the iliopsoas and iliac muscles from the lumbar spine make one-stage posterior total spondylectomy unfeasible. They also stressed the close proximity of major abdominal vessels to the anterior vertebral column in the lumbar spine, which enhances the risk in a patient with increased lumbar lordosis. For this reason, they recommended a two-stage operation to resect malignant vertebral neoplasms occurring between L2 and L4. Stener reported total spondylectomy through a single-stage posterior approach for tumors at L3 or cephalad but denied the indication of this procedure at L4 [15]. Stener advocated combined anteroposterior approach for a tumor at L4 based on the following reasons: the close contact of major vessels, especially the inferior vena cava with the L4 vertebral body, and interference by the iliac crest in accessing L4–L5 and L5 posteriorly. The authors [1–4] agree with these two anatomical annoyances pointed out by Stener [15] but, for a case with an iliac wing positioned rather distal, they do not always disagree

with single-stage posterior total en bloc spondylectomy for a solitary L4 vertebral tumor. For a tumor involving the L5 vertebra, it is undoubtedly necessary to use a two-stage anteroposterior approach because of the additional difficulty of managing the common iliac and iliolumbar arteries and veins as well as the lumbosacral neural plexus.

A wide surgical margin or at least a minimal margin is achievable around the affected vertebra(e) when the lesion is intracompartmental (type 1, 2, or 3), particularly when the healthy part of the lamina or pedicle is cut. For a vertebral tumor extending into the spinal canal (type 4) or one invading the paravertebral areas (type 5), a marginal margin may be possible when the lesion is well encapsulated with a fibrous reactive membrane. In type 6 lesions, it is possible to obtain a wide margin at the proximal and caudal osteotomized sites of the vertebrae, but paravertebral tumor sometimes adheres to or invades surrounding soft tissues, major vessels, and visceral organs neighboring the involved vertebra. In such a instance, anterior dissection followed by a posterior TES operation is indicated.

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