Oncological principles for the resection of tumors affecting long bones were proposed more than 20 years ago by Enneking, an orthopedic surgical oncologist, and colleagues. The application of these principles to the spine was initially hindered by concerns about the complex paraspinal vascular and visceral anatomy, as well as by lack of reliable instrumentation for complex spinal reconstruction. Recently, several groups have optimized techniques for removing a single vertebra or as many as three contiguous vertebrae in an en bloc fashion. En bloc resection of tumors of the spine is a very demanding procedure that requires a highly trained team of spine surgeons, general surgeons, and anesthesiologists. These en bloc techniques are based on the principles of general surgical oncology, and preliminary reports demonstrate improved outcomes compared with intralesional techniques.

**TERMINOLOGY**

En bloc designates an attempt to remove the whole tumor in one piece, together with a layer of healthy tissue. The specimen can then be subjected to histological analysis to categorize the margins as either “intralesional,” “marginal,” or “wide,” according to the system of Boriani, et al. The term “intralesional” means that the surgeon has cut within the tumor mass; “marginal” means that the surgeon has dissected along the tumor pseudocapsule (the reactive interface between tumor and normal tissue); whereas the term “wide” means that the surgeon has removed the tumor together with a layer of healthy/normal tissue. Precisely speaking, intralesional resection offers only palliative (reduction of pain) or functional results (decompression of neural elements) compared with an en bloc operation that establishes either marginal or wide margins. In some cases it may be impossible to avoid at least some intralesional dissection for tumors affecting the spine. In these cases, however, recent reports have shown that outcomes for en bloc resection that left partially contaminated margins are better than those for entirely intralesional resections. Therefore, en bloc resection should be attempted, even if some portion of the margin has to be intralesional (that is, the surgeon has to cut across a pedicle that contains tumor to free the vertebra from the spine).

**INDICATIONS**

Indications for en bloc resection of spine tumors include aggressive primary benign tumors, primary malignant tumors, and isolated spinal metastases in the setting of controlled systemic disease, although the latter is controversial. Primary spine tumors that have been subjected to en bloc excision include chordoma, chondrosarcoma, osteosarcoma, giant cell tumor, solitary plasmacytoma,
malignant fibrous histiocytoma, Ewing sarcoma, osteoblastoma, and hemangioendothelioma. Recurrent tumors previously treated unsuccessfully with surgery (usually decompressive laminectomy) are also suitable for an attempt at en bloc excision. As many as three consecutive vertebrae have been removed as a single en bloc specimen. Contraindications include distant metastases, uncontrolled systemic disease, and encasement of adjacent visceral or vascular structures that cannot be excised.

**SURGICAL PLANNING**

For a vertebra to be removed in an en bloc fashion, the vertebral arch must be cut in at least two places. These cuts, of course, are necessary so that the remaining part of the vertebra can be pulled away from the contents of the dural tube without harming it. These cuts can be made either across both pedicles, completely freeing the posterior element complex, or across one pedicle and the contralateral lamina.

The Weinstein-Boriani-Biagini system was first described in 1997 as a method of spine tumor staging. This system offers a standardized and simple aid to understanding the optimal planning of an en bloc vertebrectomy. Briefly, the vertebra is divided into 12 radiating zones and these are used as a basis for selecting the optimal en bloc approach for resection of any unique spinal column tumor (Fig. 1). Ideally, both pedicles are cut if the tumor is restricted to the VB or the posterior elements only (Fig. 1 upper and center). Alternatively, a sagittal split ostetomy is performed if the tumor occupies one side of the VB and the ipsilateral pedicle/articular process (Fig. 1 lower). If tumor occupies both pedicles, then an approach is selected that minimizes the surface area of tumor that will be subjected to intralesional dissection.

**SURGICAL TECHNIQUE**

For either sagittal split osteotomy or complete vertebrectomy, we prefer a two-stage operation that involves a posterior stage followed by an anterior stage. In certain cases, a simultaneous anterior–posterior approach is preferred.

**Stage 1: Posterior Approach**

**Exposure.** The patient is placed prone on a Jackson table with chest, hip, and thigh supports. A midline vertical incision is made over the spinous processes and is extended one to three levels above and below the involved segment(s) of the thoracolumbar spine. The paraspinal muscles are elevated in a subperiosteal fashion. Exposure must be completed to the tips of the transverse processes of the affected vertebra and all adjacent vertebra that will serve as pedicle screw fixation points for the planned stabilization and arthrodesis. A wide exposure at the affected level is essential because it facilitates subsequent posterior or release of the vertebra. Using monopolar electrocautery, the dorsal elements of the affected vertebra are completely skeletonized. In the lumbar spine, the ventral surface of the transverse processes of the involved vertebra must be freed from surrounding tissue (Fig. 2 upper).

Similarly, in the thoracic spine the proximal portions of the ribs at the affected level must be freed from the underlying pleura, transected approximately 3 cm lateral to the vertebral articulation, and either removed as separate pieces or included with the specimen. The superior and inferior facet articulations of the affected vertebra are disrupted by completely stripping the capsular ligaments. Next, partial piecemeal removal of the posterior elements and ligamentum flavum of the adjacent unaffected rostral and caudal vertebrae is performed to create an extradural working space above and below the affected vertebra. This allows the dura to be dissected free from the involved vertebra, permitting a clear view of the pedicle, pars, and adjacent disc spaces.

**Osteotomy.** Either a threadwire saw or an osteotome can be used to perform the desired osteotomy and release.
of the posterior elements of the involved vertebra. We prefer using a threadwire saw because the cuts can be precisely controlled with minimal tissue disruption, bleeding, and cellular dispersion. Using a series of blunt-tipped dissectors, the tissue attached to the undersurface of the pars interarticularis is dissected free from the bone, with special attention given to the course of the corresponding exiting nerve root. The threadwire saw is then passed from rostral to caudal in a medial-to-lateral direction so that the tool becomes wrapped around the pedicle in a plane dorsal to the exiting nerve root. With reciprocating motion of the threadwire saw, the pedicle is safely cut. Repeating this procedure for the contralateral pedicle completes the release of the entire posterior element complex in one piece (Fig. 2 center). Alternatively, the osteotomy is made through the contralateral lamina instead of the pedicle, if the pedicle and associated osseous complex (transverse process, facet, and rib head) on that side contains gross tumor. In a way similar to the pedicular osteotomy, the threadwire saw can also be used to make the contralateral laminar osteotomy by passing the tool in a sublaminar fashion after carefully dissecting a passageway for it in the epidural space. Bone wax can be used to seal the cut surfaces if tumor cells are present at the osteotomy site.

**Posterior Ligamentous Release of the VB.** We consider the release of posterior ligamentous structures to be the most important part of the operation. If done well, it greatly simplifies the anterior stage of the procedure. The previously accomplished wide lateral exposure is now of paramount importance. Using blunt dissection, the dorsolateral two thirds of the VB are dissected free from the paraspinal anatomy. To make this dissection safe, it is of utmost importance first to identify the radicular artery and vein, which are located just inferior and lateral to the pedicle. Once the segmental vessels are ligated or coagulated bilaterally, the paraspinal structures can be safely elevated in a plane between the vertebra and the parietal pleura in the thoracic spine or between the vertebra and psoas muscle in the lumbar spine. In the lumbar spine and at the thoracolumbar junction, muscular attachments of the psoas muscle and diaphragm must be carefully released from the vertebra.

In the thoracic spine, unaffected exiting nerve roots can be sacrificed to make the exposure easier. Conversely, in the lumbar spine, care must be taken not to injure unaffected exiting lumbar roots. Nevertheless, if a lumbar nerve root is encased by tumor, it should be ligated and included with the specimen, because attempts to preserve the nerve root by intralesional tumor dissection will inevitably lead to disease recurrence and, as a result, to eventual loss of the nerve root.

Lateral dissection of the vertebra from paraspinal anatomy creates a safe working space in which to perform complete sectioning of the posterior one half to two thirds of the anulus fibrosus at both the rostral and caudal disc spaces. To aid with retraction of paraspinal anatomy, cottonoids or rolled gauze pads can be inserted between the vertebra and laterally dissected tissues. This latter maneuver greatly facilitates complete and safe cutting of the lateral parts of the anulus fibrosus. Next, after carefully freeing and retracting the dural tube from the posterior longitudinal ligament, the medial portion of the anulus fibrosus is sharply divided with a scalpel under direct visualization. Epidural venous bleeding is controlled with bipolar cautery and thrombin-soaked gelatin foam.

At this point, the only structures still attaching the vertebra to the patient are the anterior longitudinal ligament and the anterior portion of the anulus fibrosus. In our experience, it is best to release as much of the vertebra as possible via the posterior approach. Therefore, great care should be taken to optimize the lateral dissection of the vertebra from the paraspinous anatomy. Once sectioning of the anulus fibrosus is completed, near-total dissec-
tomies may be performed to ensure further that the vertebra has been adequately released.

In the case of sagittal split osteotomy, lateral dissection is not performed on the side opposite to the involved pedicle and VB. Instead, an osteotome is used to create a sagittal split through the uninvolved portion of the vertebra. As a final aid to ease performance of the subsequent anterior stage of the operation, a Silastic sheet is placed in the epidural space to separate the dura and exiting nerve roots physically from the involved vertebra (Fig. 2 lower). Pedicle screw fixation and posterolateral arthrodesis are performed one to three levels above and below the affected level. The wound is then closed in a layered fashion with closed suction drainage.

**Stage 2: Anterior Approach**

The anterior portion of the operation may be done on the same operative day or, if necessary, on a 2nd operative day.

**Exposure.** The patient is placed either lateral or supine on a standard operating room table. In most cases, we prefer lateral positioning and a lateral approach: either transthoracic, thoracoabdominal, or retroperitoneal. For tumors affecting the L-5 vertebra, we prefer a direct, anterior transabdominal approach. Incising the parietal pleura in the chest or retracting the psoas muscle dorsally in the abdomen reveals the effects of the posterior stage of the operation. If the posterior ligamentous release was done well, then the posteriorly incised portions of the anulus fibrosus and the Silastic sheet will be easily recognizable signposts.

**Anterior Ligamentous Release of the VB.** The ipsilateral segmental vessels are identified and they may need to be religated. Elevation of the segmental vessels off the vertebra leads to a well-developed and easily separable plane that exists between the great vessels and the anterior longitudinal ligament. The aorta and vena cava are then carefully elevated off the anterior portion of the vertebra by using blunt dissection. Any adhesions are explored and divided in an appropriate fashion. This maneuver completely reveals the small unsectioned portion of the anulus fibrosus and anterior longitudinal ligament. Once this is accomplished, a rolled gauze pad or large cottonoid is inserted between the vertebra and viscerovascular structures to provide stable, easily visualized, and low-profile retraction. The remaining ligamentous attachments (anulus fibrosus and anterior longitudinal ligament) are then sharply divided using a scalpel. The VB may then be rolled out in one piece (Fig. 3).

Again, this portion of the operation is relatively straightforward as long as great care is taken during the posterior stage to release the lateral ligamentous structures (in particular, those located contralateral to the side of the anterior approach). In the case of sagittal split osteotomy, the contralateral release is the osteotomy itself (Fig. 4). The anterior-most portion of the osteotomy may need to be completed during the anterior stage, in which case we have found that the cleavage plane of the anterior osteotomy will naturally connect with the already created posterior osteotomy. Depending on the extent of laterally exophytic tumor, additional dissection is performed to include a margin of healthy tissue (for example, psoas muscle or parietal pleura and rib head). In some cases, we use a combined anterior–posterior approach depending on the level of the spine affected and the anatomy affected by laterally exophytic tumor (Fig. 5).

**Reconstruction of the Anterior Column.** After removal of the en bloc specimen, the vertebral endplates of recipient vertebrae are prepared to accept a strut graft. Because posterior column stabilization has already been performed, it is difficult to distract the space to accept a fixed-height strut graft. Recently, we have found expandable cages to be particularly useful for this application. An appropriately sized cage is selected and expanded in situ (Fig. 6); it can then be filled with bone graft. Wounds are closed in a standard fashion.

**Postoperative Care**

Patients were observed in the intensive care unit and transferred to the ward when their condition was stable, typically on the 1st postoperative day. Mobilization is begun as soon as the patient can cooperate and is encouraged on the 1st postoperative day. Early mobilization helps avoid complications associated with prolonged bed rest, including poor wound healing, pneumonia, decubitus ulcers, and deep vein thrombosis. If patients undergo staged procedures or are unable to maintain optimal ca-
loric intake, they receive either enteral or parenteral nutrition. External orthoses are prescribed on an as-needed basis. Follow-up imaging to assess for hardware stability is performed during the 1st postoperative week, at 1 and 3 months postoperatively, and then every 3 months until fusion is documented. Adjunctive radiotherapy and/or chemotherapy are administered if necessary, depending on the final surgical margin and histopathological findings, as soon as the wounds are healed, usually approximately 2 weeks postsurgery.

**CONCLUSIONS**

In selected patients, en bloc vertebrectomy is indicated for aggressive benign and malignant primary tumors of the spine. We believe that this procedure is also indicated for solitary spinal metastases when systemic disease is limited and well controlled, although this is controversial. Preoperative staging is essential to define the optimal surgical approach. Marginal and wide margins offer superior

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**Fig. 4.** Photographs showing specimens of tumor obtained in a sagittal split osteotomy for a laterally exophytic L-5 chordoma. *Upper:* Intraoperative photograph obtained during the anterior (midline–transabdominal) stage of the operation, showing near-complete discectomies above and below the L-5 vertebra. An osteotome marks the location of the sagittal split osteotomy that was initiated during the posterior stage of the operation and completed during the anterior stage. The psoas muscle is retracted to the left side in this view and the aorta, vena cava, and iliac vessels to the right side. *Lower:* Photograph of gross specimen after axial sectioning by the pathologist. The specimen shows wide margins medially and “marginal” margins laterally. The exophytic part of the tumor was covered by a tough pseudocapsule that was dissected free of healthy lateral tissues, achieving a lateral marginal margin.

**Fig. 5.** Simultaneous anterior–posterior approach for en bloc vertebrectomy. This approach was chosen because the tumor involved the diaphragm and psoas muscle. *Upper:* Intraoperative photograph showing the exposure for a simultaneous thoracoabdominal/posterior spinal approach; the patient is positioned laterally. *Lower:* Gross specimen obtained during a two-level, en bloc vertebrectomy of T-12 and L-1. Portions of the diaphragm and psoas muscle that were infiltrated with tumor are attached to the right side of the specimen.

**Fig. 6.** Postoperative x-ray film showing an example of an anterior–posterior instrumented reconstruction after en bloc vertebrectomy. The expandable anterior cage has lordotic end pieces that match the lumbar lordosis.
oncological benefit compared with purely intralesional procedures. En bloc vertebrectomy is a technically demanding procedure that is best approached in a multidisciplinary fashion, relying on the expertise of specially trained complex spine surgeons, general/vascular surgeons, and anesthesiologists. The spine surgeon must have an expert understanding of the paraspinal vascular and visceral anatomy, however, to perform this procedure safely and comfortably.8

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