Surgical treatment of spinal tumors involves multidisciplinary preoperative planning, a high index of suspicion in the event of a problem, and prompt treatment.

Spinal Tumor Surgery: Management and the Avoidance of Complications
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Background: Complication avoidance is paramount to the success of any surgical procedure. In the case of spine tumor surgery, the risk of complications is increased because of the primary disease process and the radiotherapy and chemotherapeutics used to treat the disease. If complications do occur, then life-saving adjuvant treatment must be delayed or withheld until the issue is resolved, potentially impacting overall disease control.

Methods: We reviewed the literature and our own best practices to provide recommendations on complication avoidance as well as the management of complications that may occur. Appropriate workup of suspected complications and treatment algorithms are also discussed.

Results: Appropriate patient selection and a multidisciplinary workup are imperative in the setting of spinal tumors. Intraoperative complications may be avoided by employing proper surgical technique and an understanding of the pathological changes in anatomy. Major postoperative issues include wound complications and spinal reconstruction failure. Preoperative surgical planning must include postoperative reconstruction. Patients undergoing spinal tumor resection should be closely monitored for local tumor recurrence, recurrence along the biopsy tract, and for distant metastatic disease. Any suspected recurrence should be closely watched, biopsied if necessary, and promptly treated.

Conclusions: Because patients with spinal tumors are normally treated with a multidisciplinary approach, emphasis should be placed on the recognition of surgical complications beyond the surgical setting.

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**Introduction**

Successful surgical treatment of spinal column tumors entails avoiding and promptly treating surgical complications. Although the goals of surgery are different in cases of metastatic and primary tumors, many of the same principles of complication management may be applied.

Surgical treatment is palliative in patients with metastatic disease. Skeletal metastases are a frequent issue because 10% of patients with cancer will develop symptomatic spinal metastases; of these, 50% will require treatment due to pain or neurological deficit. Mirroring the overall rate of prevalence, the most common solid primary tumors to metastasize to the spine are those in the breast, lung, prostate, and colon. Decompression of neurological elements and stabilization of the spinal column are primarily performed to preserve neurological function. Early and complete spinal cord decompression and spinal column stabilization have been shown to preserve or restore ambulation and continence, and maximize quality of life. However, surgery necessitates the temporary suspension of life-prolonging adjuvant cytotoxic therapies to allow healing at the surgical site. Surgical complications, especially those involving wound healing, may further delay the resumption of these therapies and ultimately shorten a patient's life. Thus, optimizing outcomes in metastatic spine disease focuses on the preservation of function, early mobilization, and the prevention of complications that may delay adjuvant treatment.

By contrast, primary tumors make up less than 5% of spinal column tumors, but these lesions offer spinal oncologists the opportunity to induce a surgical cure. Because many lesions metastasize late, it is possible to remove the tumor in its undisrupted entirety and completely eliminate the disease. However, such radical “en bloc” procedures are technically challenging and often highly morbid. To remove the tumor in en bloc fashion, surgeons may plan to sacrifice normal tissue and function with the goal of achieving a cure. Strategies to lessen the negative impact of the planned functional loss must be incorporated into the surgical and subsequent treatment plans. Because the goal in this case is cure, the surgeon must also focus on the long-term durability of the procedure. To avoid late failures, an emphasis on restoring biomechanical function with true bony fusion is necessary in patients with long life expectancies.

This article will explore the preoperative, intraoperative, and postoperative management options of spinal tumors, emphasizing the prevention of complications. Appropriate workup of suspected complications and treatment algorithms will also be discussed. In general, issues involving primary and metastatic tumor surgery are similar; however, where appropriate, unique features of en bloc resections of primary lesions will be specifically addressed.

**Presurgical Planning**

Appropriate patient selection and thoughtful multidisciplinary workup are imperative for patients with spinal tumors. The overall rates of disease burden, medical comorbidities, and neurological status must be investigated to determine the expected surgical benefits and anticipated morbidity before committing a patient to an extensive procedure. An appropriate metastatic workup to assess disease burden is also necessary. Radical surgery for cure is possible in patients with disease localized to the primary site, and palliative surgery for functional gains is possible if the patient has a reasonable chance of maintaining or regaining quality of life. A medical evaluation should be performed to ensure that the patient can tolerate the expected physiological challenges of surgery and healing, and that he or she has an expected life span long enough to enjoy the benefits of the procedure. Reasonable expectations should be provided regarding useful neurological function or pain reduction postoperatively and at the convalescence stage. If these basic criteria are not met, then the patient may not achieve the surgical goals of potential cure or successful palliation.

If the patient is a surgical candidate, then accurately assessing the feasibility of the procedure and anticipating challenges is the best way to avoid complications. Patient selection and surgical planning for both primary and metastatic tumor surgery are discussed in more detail by Dr Kaloostian and colleagues on page 133 of this issue.

**Biopsy and Diagnosis**

Special mention should be made of biopsying suspected primary tumors. If the surgeon desires to affect a cure, then the tumor must be removed in a single, nonviolated mass. Any tumor spillage can result in local recurrence or eventual metastatic spread. Thus, we recommend that the diagnosis be obtained through fine-needle aspirate biopsy with consideration for biopsy tract resection at the time of definitive surgery. To accomplish this, the interventional team should discuss the potential surgical trajectory to ensure tract resection is possible at a later time. Failure to heed this procedure may eliminate the possibility of cure.

In many cases, primary tumor pathology is not expected and the patient will undergo open biopsy or partial resection. If the surgeon suspects primary tumor pathology during such a procedure, then he or she should promptly contain the tumor and reduce further spillage, stop the procedure, and complete the workup before proceeding any further. At this point, the surgical site is contaminated. Recommendations on dealing with intraoperative capsular violations are...
discussed below, including postoperative monitoring and adjuvant therapy options.

**Hemorrhage Prevention**

Although intraoperative hemorrhage due to oncological factors is rare, it must be considered, particularly in cases of metastatic spine disease. The cause of hemorrhage in these patients is twofold, coagulation dysfunction due to the primary disease and the direct violation of a hemorrhagic lesion. The preoperative correction of coagulation abnormalities, presurgical and surgical strategies to minimize blood loss, and a plan for intraoperative resuscitation should be outlined prior to the procedure. Of note, intraoperative blood salvage is always avoided due to the risk of metastasizing tumor from the operative site.

Frequently the coagulation pathway is disrupted in patients with cancer. Patients with hematological malignancies, those with liver lesions, and patients treated with agents that suppress bone marrow are at especially high risk for hemorrhagic complications. A preoperative assessment of the coagulation cascade and factor correction is mandatory. Blood, fluid, and body warming devices may reduce the likelihood of coagulopathy. Conversely, some patients with cancer are hypercoagulable and are at risk for disseminated intravascular coagulation, deep venous thrombosis, and pulmonary emboli. These later complications may be magnified by reduced mobility in the setting of neurological compromise or pain. Thus, sequential compression devices and early mobilization are mandatory. When feasible, postoperative anticoagulation, such as subcutaneous heparin, may be considered. Therefore, health care professionals should have a low threshold for workup and aggressive treatment of suspected deep venous thrombosis and pulmonary emboli due to these risks.

Many highly vascular tumors bleed until they are completely resected and may be difficult to cauterize. In these cases, preoperative embolization may provide an opportunity to decrease overall blood loss and provide greater intraoperative visualization of the surgical field. Renal cell carcinoma, follicular thyroid carcinoma, neuroendocrine tumors, and those suspected of hypervascularity on preoperative imaging studies may be considered for preoperative embolization. Embolization has the added benefit of localizing important feeding vessels such as the artery of Adamkiewicz, which may be avoided to lessen the risk of spinal cord infarction. If embolization is not technically feasible and the risk of hemorrhage precludes an intralesional tumor resection, en bloc resection may be considered. This allows the surgeon to avoid violating the hemorrhagic tumor and potentially lessening blood loss; however, the technique is more challenging than intralesional resection.

**Intraoperative Complications**

Intraoperative complications in spinal tumor surgery may be avoided by employing proper surgical technique and an understanding of the pathological changes in anatomy. Tenets such as gentle tissue handling, adequate exposure, ongoing hemostasis, and approaching from normal to abnormal are important. Systematically protecting vital structures and achieving good visualization of the surgical field will make surgery easier in the event of an unanticipated complication. Specific intraoperative complications and management strategies are discussed in the Table.

### Table. — Selected Intraoperative Complications and Management Strategies of Spinal Tumor Surgery

<table>
<thead>
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<th>Type</th>
<th>Prevention Strategies</th>
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| Neurological             | Preoperative: Steroids, Positioning  
Intraoperative: Electrophysiological monitoring, Elevation of blood pressure  
Postoperative: Steroids, Control of blood pressure |
| Wound Complications      | Preoperative: Appropriate antibiotics  
Intraoperative: Consider plastic surgery closure/flaps, drains to reduce dead space, and attention to CSF leak repair  
Postoperative: Consider colostomy if planned sacral root sacrifice and incontinence |
| CSF Leak                 | Intraoperative: Primary repair, Attention to negative pressure drains/spaces (eg, pleural cavity) |
| Vascular Injury          | Preoperative: Embolization  
Intraoperative: Vascular surgery or Interventional teams |
| Visceral Organ Injury    | Intraoperative: Protect with adequate retraction  
General surgery repair |
| Instrumentation Failure  | Intraoperative: Technically adequate reconstruction (eg, load-sharing)  
Postoperative: Close follow-up to catch late failures |

CSF = cerebrospinal fluid.
Neurological Injury
Worsening neurological injury through spinal cord or nerve root damage is one complication of spinal tumor surgery. The use of preoperative neuroprotectants, taking care with operative positioning, performing intraoperative electrophysiologic monitoring, and taking a standard approach to suspected injuries should be employed in all cases.

In cases of new neurological deficit, high-dose steroids are often preoperatively employed to reduce traumatic edema and potential tumor compression. Dosing remains controversial, but often a high loading dose and subsequent maintenance doses as described by Patchell et al are used. Following surgery, dosing is tapered off or supplied at an oncologically appropriate dose.

Patient positioning is important to protect the central and peripheral nervous systems. Most patients with operative metastatic spine disease also have metastatic epidural spinal cord compression, spinal column instability, or both, so care must be taken to avoid worsening spinal cord compression upon positioning. A documented preoperative neurological examination and prepositioning electrophysiological monitoring provide useful baseline data. Patients should be carefully positioned using the log-rolling or Jackson table sandwich technique. Postpositioning electrophysiological monitoring, radiographic studies of alignment, and wake-up tests may be required before proceeding. If a change occurs during the examination, then the positioning changes should be reversed, the patient awakened and reassessed, and a spinal cord injury protocol considered (as outlined below). In addition, patients may have been exposed to neurotoxic chemotherapeutic agents, thus increasing their risk of compressive peripheral neuropathies with positioning, which can be reduced with judicious attention to operative table padding and straps.

Intraoperative electrophysiological monitoring may be helpful for continuously assessing the patient for signs of spinal cord or root dysfunction. Monitoring of somatosensory evoked potentials and motor evoked potentials in cases of spinal cord compression can be employed. In cases of root compression, free-running electromyography may be used. Preoperative baseline data are useful for determining changes. In some cases, spinal cord dysfunction may be so severe that monitoring is not possible.

The surgical anesthesia and monitoring teams should quickly respond in the event of an electrophysiological monitoring change. The monitoring technicians should ensure that equipment is properly functioning and not providing erroneous readings. It is useful to monitor proximal to the surgical lesion, because a sudden loss in all signals would indicate an equipment failure rather than a local issue at the surgical site. The anesthesia team should ascertain whether a change has occurred in the anesthetic agents used and whether the blood pressure is sufficient for cord perfusion. When a signal change occurs, perfusion pressure may be increased and a steroid infusion begun. The surgical team should assess the spinal cord for reversible compression, particularly if instrumentation placement or deformity correction preceded the change. Immediately relieving the compression, including reversing the deformity correction, should be performed.

The blood pressure level may be artificially elevated postoperatively to continue spinal cord perfusion and steroids may be given to the patient, especially in the setting of a new deficit. In both primary and metastatic tumor surgery, nerve roots are often sacrificed to remove the tumor. Because the radicular arteries supplying the cord may also be sacrificed, spinal cord perfusion may be altered, thus putting the patient at risk for ischemic injury. Therefore, even without a neurological deficit, efforts should be taken to avoid hypotension during the perioperative period.

Cerebral Spinal Fluid Leak
Leakage of cerebral spinal fluid (CSF) may impair wound healing and cause intradural tumor seeding. In some cases, the thecal sac or nerve roots are tied off or a portion of the dura is removed if it has been invaded by the tumor or rhizotomy is performed to provide surgical access. Commonly these are planned events, so the surgeon can plan the repair. However, inadvertent durotomies may also occur and should be promptly addressed. In most cases, repair is accomplished using the standard techniques, such as primary repair, muscle pledget, and dural sealants. Patch grafting may be necessary if a portion of dual is missing. Consideration may be given to temporary lumbar drainage to decrease the level of hydrostatic pressure on the repair.

CSF leaks into spaces of negative pressure, such as the thoracic cavity, deserve special mention because metastases most commonly occur in the thoracic spine. Of the two major thoracic approaches, the transthoracic approach has a higher likelihood of an ongoing CSF leak than costotransversectomy, although pleural violations are possible with the latter procedure. If a leak does occur, then close attention to the primary repair is mandatory, and an attempt should be made to separate the leak from the negative pressure chest cavity and tube. In multidisciplinary cases, excellent communication is needed between departmental figures because experts in nonspinal fields may be less attuned to drain management in the event of a CSF leak. Ongoing leakage may lead to CSF hypotension and intracranial subdural hemato-
mas. Any patient with changes in mental status and a known spinal fluid leak should have his or her drains removed from suction and computed tomography of the head should be performed.

Spinal fluid leaks can also impair wound healing and promote infection. Although a stable pseudomeningocele (Fig 1) is not ideal, it is also acceptable; however, a multilayer, watertight closure is more durable. Any transcutaneous fistula must be promptly addressed. In these cases, reoperation, attempts at primary closure, and plastic surgery flap placement may be necessary. In addition, CSF diversion techniques, including subfascial drain placement, lumbar drainage, and various lumboventriculoperitoneal shunts may be employed to promote wound healing.

Adjacent Organ and Vascular Injury
Surgery may be complicated by injury to an adjacent structure; this is because pathological and anatomical changes may draw normal structures into the operating field. Recognizing this complication preoperatively may allow the patient to undergo protective interventions such as endovascular vessel sacrifice or ureteral stent placement. Specific injuries may prompt emergent intervention by specialty-specific teams. The most life-threatening injury is major vascular transgression. If this occurs, the surgeon must simultaneously alert the anesthesia team to potential, rapid, high-volume blood loss and attempt to control bleeding. Vascular surgery and interventionalist teams may be required. Similarly, esophageal and bowel injuries often require the prompt attention of otorhinolaryngology or general surgery teams to attempt repair. It should be noted that gastrointestinal tract transgressions greatly increase the risk of infection, and attention must be given to antibiotic management and infection parameters during the postoperative period.

Expected Morbidity and Planned Sacrifice
In some cases surgical treatment necessitates the sacrifice of adjacent structures, either due to their involvement with the tumor or in order to access the operative cavity. Oftentimes neural structures are sacrificed, the most of which are distal spinal roots in the setting of sacrectomies with a known loss of volitional bowel and bladder control. In these cases, attention to dural repair is necessary to avoid potential wound complications, particularly during possible adjuvant therapies. Chest wall and lung resections, major vascular reanastomoses, and diverting colostomies are common adjuvant procedures depending on the complexity of planned surgical resection. Many permanent long-term sequelae can be predicted based on the surgical plan.

Capsular Violation in En Bloc Resection
As noted above, tumor capsule violation may be a planned event in some cases; however, in most cases this is an unplanned occurrence during surgery. Due to the complexity of the cases, the tumor is exposed to trauma and is subjected to manipulation; therefore, both sharp and blunt violations may occur. At the time the violation occurs, the surgeon must quickly react to reduce and contain tumor spillage. Once the tumor and surrounding tissue has been appropriately addressed, any sterile item that may have contacted the tumor must be permanently removed from the sterile field, and all health care professionals present should regown and reglove prior to proceeding to lessen the likelihood of further contamination.

The most easily treated violations are those in bone. Because most primary lesions originate in the vertebral body, the most commonly encountered site of bony invasion is tumor that has grown through the pedicles and into the posterior elements. If the bone has been skeletonized prior to encountering tumor, then the visible tumor is coated in bone wax to prevent further egress. If there is surrounding tissue that becomes contaminated, then it is removed and the skeletonized bone cauterized and waxed. The simplest area for planned tumor violation is the pedicles, in which case they are skeletonized, the surrounding area covered in surgical patties to minimize

Fig 1. — A patient underwent a resection for metastatic renal cell carcinoma complicated by a dural tear, followed by local external beam radiotherapy. Three years later, adjacent segment degeneration necessitated revision fusion. At the time of surgery, the previously stable pseudomeningocele (A-B) was breached and the surrounding tissue was friable and devascularized. Despite plastic surgery closure (C), the patient had repeated fascial dehiscences that required multiple wound revisions, lumbar- and ventriculoperitoneal shunt placements, and the permanent use of a corset brace. The patient was hospitalized for 4 months due to wound complications.
contamination, and the posterior elements removed and immediately taken from the surgical field. The remaining pedicle stubs are promptly waxed, the area examined for evidence of contamination, and the surgical patties discarded from the field.

By contrast, soft-tissue capsular violations are more difficult. The tumor is often soft and surrounded by a fibrous capsule. If the capsule is disrupted, then the tumor can extrude through the rent due to the pressure of manipulation; therefore, it is important to occlude the rent and reinforce the capsule to prevent further extrusion with ongoing manipulation. Internally debulking a portion of the tumor through the tear may also be necessary to reduce the likelihood of extrusion under pressure. If the surgeon is able, he or she should oversew the capsular tear to regain a degree of structural integrity. If it is possible to occlude the rent in a watertight fashion, then further tumor extrusion may be avoided. Following reapproximation of the rent, a fibrin sealant may be applied to further protect against spillage. In cases in which a large piece of the tumor breaks away and the capsule cannot be approximated, cautery and fibrin sealant are used. Care should be taken to manipulate this area as little as possible to prevent further contamination. In all cases, the surrounding area should be inspected, cauterized, and, if possible, resected once the tumor has been sealed to minimize local recurrence.

**Postoperative Complications**

Major postoperative issues include wound complications and spinal reconstruction failure. Both incisional closure and spinal reconstructions are challenging, but adjuvant radiation and chemotherapy compound the healing process. Preoperative surgical planning must include postoperative reconstruction. Patients must be followed for appropriate signs of healing, and early intervention should be employed if wound or construct failures are noted.

**Wound Healing**

Wound dehiscence and infection are challenging issues that have considerable morbidity and can delay adjuvant therapies (Fig 2). Patients with cancer have a higher risk of surgical site infection than other patients undergoing spinal surgery. Immunosuppressing adjuvant therapies, local radiation, and systemic factors such as anemia and decreased nutritional status predispose patients with metastatic tumors to issues of wound healing and infection. In the setting of primary tumors, a patient’s risk increases with surgical site issues, such as previous radiation, long surgical duration, CSF leakage, and previous local radiation. In some cases, radiation is employed to promote local tumor control prior to surgery; however, in other cases, surgery is an unplanned necessity in a previously irradiated field. Radiation may result in devitalized tissue in the operative bed, increasing the likelihood of healing and infection issues. Radiation treatment that includes issue sparing should be considered even if surgery is not planned at the time of treatment. Image-guided radiotherapy may allow tumor bed treatment without irradiating the skin and fascial closure, thus promoting wound healing. In addition, the surgeon should have a low threshold for plastic surgery intervention and well-vascularized soft-tissue flap closure.

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Fig 2A-C.—A patient 65 years of age with a sacral aggressive hemangioma who had received 3 operations and radiation therapy twice underwent a fourth debulking for pain relief and to preserve continence. The patient's incision became infected and required a 6-month inpatient course of multiple plastic surgery revisions to stabilize. This included (A) debridement, (B) a DermaClose (Wound Care Technologies, Chanhassen, Minnesota) tensioning device to slowly close the wound, and (C) use of a vacuum-assisted closure device before definitive closure with a vascularized latissimus dorsi flap.
The morphology of the surgical site places the patient at risk for wound complications. Oncological spine approaches, particularly en bloc resections, require wide operative corridors to allow the surgeon to control the tumor and surrounding structures. Incisions may be difficult to approximate due to their size, location, or unusual features, such as those J-shaped in size to provide access. In addition, large voids in which the tumor or surrounding resected tissue was removed may create a large dead space that must be addressed. In many cases, plastic surgery may be useful at the time of original reconstruction to ensure closure of the dead space and coverage of the surgical site. In most cases in which a posterior approach is employed, paraspinal muscle flaps are the simplest and most effective way to provide soft-tissue coverage. Repeat wound infection or dehiscence also warrants plastic surgery intervention. In many cases, specific surgical site issues are present that make healing difficult. For example, protruding bone or hardware with inadequate soft-tissue coverage promotes wound breakdown. Likewise, ongoing spinal fluid leakage from open dural openings, ongoing chyle leak, or bowel injury may result in fluid collections, tissue tension, and local infection that preclude adequate healing. The surgeon should explore wounds and rule out or repair auxiliary issues before attempting plastic surgery closure. Three areas of the spine are challenging, including the upper cervical spine, the thoracic spine and chest wall, and the lower lumbar and sacral spine.

Transoral or extended transoral/transmandibular split approaches may be necessary in the upper cervical spine. In these cases, reconstruction is likely required and may include titanium cages, cadaver bone, or, on occasion, vascularized autograft. A single layer of pharyngeal tissue may cover this graft, and the patient may be subjected to local adjuvant radiation depending on the surgical situation. Local rotational flaps used can include the trapezius, sternocleidomastoid, and the pectoralis major. Due to the extensive vascular supply in the head and neck, vascularized free flaps are also commonly employed. Otolaryngological and anesthesia support are required to compete these procedures, and delayed extubation, postoperative feeding tubes, and close attention to diet and swallowing functions are mandatory. Any sign of wound dehiscence must be treated with reclosure and intravenous antibiotics. It may not be possible to remove the instrument due to the nature to reconstruction following high cervical en bloc resections.

In the thoracic spine, wound closure may involve reconstruction of the chest wall to re-create respiratory biomechanics. In these cases, mesh and methylmethacrylate may be used to provide the scaffolding upon which the chest, shoulder, and back muscles will sit. It should be noted that lung expansion is not limited to the original chest volume. In some cases of circumferential decompression of the thoracic spinal cord, reinflation of the lungs resulted in decreased intraoperative spinal monitoring signals, and it was noted that the lungs themselves were compressing the spinal cord.15 Thus, re-creating the spinal canal may also be important. Local vascularized flaps may be rotated to provide soft-tissue coverage, with local paraspinal musculature, trapezius, and intercostal flaps most commonly employed.

The sacral spine is challenging to reconstruct. A paucity of soft tissue covers the reconstruction cavity in this region, and nearby tissues have little flexibility. Most centers employ an anterior–posterior approach to large sacral resections, allowing the vascularized abdominis rectus flap to be harvested, which can then be passed through the surgical defect to close the skin under tension and fill the large dead space following tumor resection.16–18 A posterior-only approach has been advocated to reduce operative time and the additional morbidity of the anterior approach without an increase in wound issues.19,20 In this case, superior gluteal vascularized muscle flaps and paraspinal muscle advancement may be employed.

Beyond the technical aspects of closure, planned incontinence increases the likelihood of wound infection in sacral tumor resections.21 In many cases, involved pelvic structures, including bowel or sacral roots, are resected along with the surgical specimen, leaving the patient with little to no voluntary bowel and bladder control in the setting of reduced mobility during the postoperative period. Combined with the proximity of the sacral wound, infection is common.22 Surgical techniques have been employed in an attempt to reduce infection, including preoperative povidone–iodine enemas, tight closures with a layer of surgical glue, and watertight dressings. Diverting colostomies may assist patients in coping with incontinence while also simultaneously protecting the wound.16,23–28

Any sign of infection or wound dehiscence should be promptly treated. Imaging studies to assess the extent of the issue, baseline serologic inflammatory markers, cultures, and antibiotics under the supervision of infectious disease services should be employed. Oftentimes infections, especially those in the pharyngeal and sacral areas, may be caused by organisms not commonly seen in a neurosurgical or orthopedic setting. Patients may not present in a standard fashion, but instead with an insidious infection without a large systemic response, and they will not improve on standard skin-flora-specific antibiotics. In cases of suspected infection, there should be a low threshold for intraoperative culture and washout. Antibiotics can then be tailored to the causative agents.
**Spinal Reconstruction Failure**

In most cases of spinal tumor resection, the biomechanical capacity of the spinal column must be reconstructed. However, the situation is unusual because multisegment gaps are common when all spinal elements have been removed. These gaps must be filled to restore the load-bearing capacity of the spine. This procedure is usually performed with titanium cages or bone grafts. In addition, the spine must be stabilized so that the weight is supported despite dynamic stresses, thus a posterior tension band involving screws and rods is usually employed. In certain areas such as the occipitocervical and spinopelvic regions, the transfer of forces is more complex. In the upper cervical region, the main load is transferred through the occipital condyles and lateral masses of C1 and C2, not the vertebral bodies, so multiple constructs have been employed. In the spinopelvic region, forces are transferred from the spine to the pelvic ring and onto the lower limbs. To restore function, this must be reapproximated despite very high biomechanical loads.

Spinal reconstructions can fail in 3 major ways. Early failures occur before expected bony healing can occur. Examples of these failures include screw pullout and cage subsidence. Although early failures may involve technically poor surgery, the bone quality of patients with cancer exacerbates this issue due to bony tumor involvement, poor bone metabolism, and osteodestructive medications such as steroids. Many of the same techniques used to manage osteoporotic bone are useful in tumor reconstruction. Increasing the load sharing by lengthening constructs, undertapping, or not tapping screw holes may increase the purchase, and buttressing instrumentation with methylmethacrylate are useful adjuncts.

Late failures involve a failure of bony healing. These cases manifest in pseudarthroses and rod breakage. Because the main goal of primary tumor surgery is to obtain a cure and many patients with metastatic tumors lead long lives, attention to successful arthrodesis is important. Bone healing is impaired by cancer-induced metabolic changes and adjuvant therapies, particularly local radiation. In some cases, reconstruction may include vascularized bone grafts, such as from the fibula or rib, to optimize healing. Bone morphogenic protein should not be used due to uncertainties regarding its effects on tumor growth.

Late failures occur in the setting of successful fixation (Fig 3). In this case, junctional issues may occur above or below the construct in the same fashion as late adjacent segment disease manifests in spinal fusions for other conditions. Attention to basic spine surgical principals to optimize durability should be employed at the time of surgery. It may be possible to use cement augmentation to salvage junctional fractures above or below the construct without resorting to instrumentation revision, potentially allowing the patient to continue adjuvant treatments while avoiding a major surgical intervention.

Despite the best surgical plans, instrumentation and construct failure may occur and may be catastrophic. As challenging as the reconstruction is at the index procedure, scarring, radiation changes, and broken bone or instrumentation may leave the surgeon with fewer options. However, any construct failure that risks further injury must be addressed. Further surgery may be warranted in cases of increased dis-
ease burden or in cases in which ongoing instability creates mobility-limiting pain.

Recurrent Tumor

All patients undergoing spinal tumor resection should be closely monitored for local tumor recurrence, recurrence along the biopsy tract, and for distant metastatic disease. Any suspected recurrence should be closely watched, biopsied if necessary, and promptly treated.

In most cases, primary tumors locally recur. Local recurrence is more closely linked to overall survival than with distant metastatic disease. If local recurrence is noted, then the patient should be restaged to determine if metastatic disease is present. If metastatic disease is located, treatment should be palliative, with adjuvant therapy and potential resection determined on a case-by-case basis. If the local recurrence is the only region of disease, then en bloc resection may be warranted. A paucity of evidence exists to determine the survival advantage to en bloc resection in these cases, but if the patient has not developed metastases, local control may still be possible. These cases are considered to have contaminated margins and postoperative local adjuvant therapy is warranted to maximize response.

Although local tumor recurrence is frequent in metastatic disease, distant metastases and overall disease burden may dictate future treatment options. It is reasonable to restage patients to determine their overall fitness and to pursue further surgical options if new or recurrent spinal metastases are noted.

Conclusions

Surgical resection of spinal tumors is one of the most rewarding areas of surgical oncology. However, these technically complex cases also have a unique set of potential complications. Metuculous multidisciplinary preoperative planning, a high index of suspicion in the event of a problem, and prompt, aggressive treatment are mandatory.

References