Spinal Oncologic Reconstruction

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ABSTRACT

The frequency of tumors is increasing and metastases to the spine also increase as life expectancy increases. Detailed planning and staging helps in the surgical resection and reconstruction and also to achieve better outcomes for these patients. Spinal deformities may occur with either benign or malignant spinal neoplasms. Involvement of the vertebral body occurs in 80% of malignant spinal tumors and 40% of benign lesions. The spine is the most common site for skeletal metastasis, with 39% of all patients with bone metastases having lesions in the axial skeleton. General principles for operating spine tumors include decompression of the tumoral cord compression, preserving uninvolved spine segments, making a stable construction, choosing an approach that is consistent with the anticipated reconstruction, and minimizing surgical morbidity. The priority in the treatment of spine metastases is to preserve mechanical and neurological function. Complete local eradication is the main goal in the treatment of primary tumors, as an oncologically appropriate surgical treatment can substantially improve the prognosis and even be considered a life-saving procedure.

KEY WORDS: Oncology, Reconstruction, Spine, Tumor

Background

The frequency of tumors is increasing and metastases to the spine also increase as life expectancy increases. Proper evaluation of the patient with a brief medical history, examination, and imaging studies help to identify the reasons of the symptoms. After a histological diagnosis, the next step is to plan the treatment options. Detailed planning and staging helps in the surgical resection and reconstruction and also to achieve better outcomes for these patients.

Tumors affecting the spine can arise from the structures of the spine (primary tumors), or spread to the spine from elsewhere (metastases, secondary tumors) in the body. Primary spinal tumors are rare lesions and may be classified as benign or malignant. Spinal deformities may occur with either benign or malignant spinal neoplasms. Involvement of the vertebral body occurs in 80% of malignant spinal tumors and 40% of benign lesions. Neurological deficits occur more frequently in malignant spinal tumors than in benign spinal tumors because of local invasion of the neural canal and pathological fractures.

Secondary tumors (metastases) may be multiple and originate from the lung, breast, prostate or bowel cancers. The metastasis to a vertebra may locally spread to adjacent vertebrae. Metastatic tumors may induce osteolytic or blastic lesions, diffuse osteopenia, or a variable combination of these. Since most of these spinal secondaries are in the bone, there may be weakness of the structure of the spine. Any section of the spine can be affected and there may be compression of the spinal cord or spinal nerve roots in the spinal canal.

The goal of the treatment of spinal tumors is successful oncological resection of the tumor, preserving neural function, eliminating pain, and restoring and maintaining spinal alignment and stability.

Clinical Findings

Approximately 70% of patients with cancer have evidence of metastatic disease at the time of death. The spine is the most common site for skeletal metastasis, with 39% of all patients with bone metastases having lesions in the axial skeleton (23). Paralleling vertebral
body size, metastases occur most frequently in the lumbar spine followed by the thoracic and then the cervical spine. However, thoracic lesions (70%) are most often symptomatic due to the smaller space available for the spinal cord in this region, followed by lumbar (20%) and cervical (10%) lesions. Eighty percent of spinal metastases involve vertebral bodies rather than posterior vertebral elements (9). Patients with spinal tumors often present with axial pain, and some with radicular pain (if the tumor extends to and compresses the nerves). Axial pain in patients with spinal tumors is mostly because of the destructive effect of the tumor, the cortical breakdown, and also from extension into the canal with compression of the cord. Weakening of the vertebrae may lead to fractures, micro or macro, causing pain. The extension of metastatic tumors to the axial spine is mainly through the vascular mechanism, either by seeding via the arterial system or a closer spread via the valveless extradural venous system (Batson's venous plexus).

**Tumoral Scoring Systems**

Several classification and scoring systems have been developed to assist in surgical decision-making. The WBB (Weinstein-Boriani-Biagini) staging system is based on viewing the affected vertebra in an axial view and dividing it into 12 equal radial segments (“clock-face”). The five outer to inner concentric layers are labeled A to E, with “A” as the extraosseous layer, and sequentially layering in to “E” as the dural involvement. In the cervical vertebrae, “F” indicates involvement of the vertebral foramen (Figure 1) (8).

Tomita’s scoring system describes the location of the tumor within the body (Type 1–3), extension outside the vertebra (Type 4–6), and involvement of other vertebrae (Type 7). In types 1 to 3, the extent of the tumor is either located within the body, extending to the pedicle, or to the lamina respectively. In Types 4 to 6, there is extension into the spinal canal alone, canal and lateral extraosseous extension, and to adjacent levels respectively. The categories help assist in planning the type of resection,

**Figure 1:** The Weinstein-Boriani-Biagini staging system (8).

**Figure 2:** Tomita’s classification of vertebral tumor involvement (15).
either vertebrectomy (partial or total) or palliative surgery because of extensive involvement and spread (Figure 2) (15).

The scoring system of Tomita and colleagues consists of three items: grade of the primary tumor, visceral metastases to vital organs (lungs, liver, kidneys, and brain), and bone metastases, including the spine. Scoring system for spinal metastases consists of three prognostic factors: 1) grade of malignancy (slow growth, 1 point; moderate growth, 2 points; rapid growth, 4 points), 2) visceral metastases (no metastasis, 0 points; treatable, 2 points; untreatable, 4 points), and 3) bone metastases (solitary or isolated, 1 point; multiple, 2 points). These three factors were added together to give a prognostic score between 2 and 10. The treatment goal for each patient was set according to this prognostic score (15).

This strategy indicated wide or marginal excision, such as total en bloc spondylectomy and spinal reconstruction for patients who had a total score of 2 or 3; intralesional excision (piecemeal excision, thorough debulking, if possible, total en bloc spondylectomy as a marginal excision) for a patient who had a total score of 4 or 5; palliative surgery, such as spinal cord decompression with spinal stabilization, for patients who had a total score of 6 or 7; and conservative therapy with supportive care for patients who had a total score of 8 to 10 (15).

**Diagnosis**

A biopsy is mandatory if the diagnosis of the spinal lesion is unknown. Before planning the biopsy, the imaging studies should be evaluated to ascertain the exact location of the tumor within the spinal column. The process of obtaining the tissue may be with a fine needle, core, incisional, or excisional. Needle and core biopsies are conducted percutaneously. Incisional biopsy is used when an open approach to the tumor is employed and a small piece of the tumor is obtained for analysis, leaving the rest in situ. In excisional biopsy, the whole tumor is removed with an intralesional, marginal, or wide margin.

Incisional or excisional biopsies must be properly planned. A small incision should be used to allow a future resection, in cases of recurrence or primary malignancy. Contamination of the surrounding tissues should be limited as much as possible, and the approach should be away from neurovascular structures.

**Surgical Management**

Local control in patients who have localized lesions and a life expectancy of at least 1 year is the main aim of surgery. Surgery is considered to be the most effective treatment for pain and paralysis caused by spinal instability. The indications for operative treatment are: progressive neurological deficit before, during, or after radiation therapy; intractable pain unresponsive to conservative treatment; need for histological diagnosis; radioresistant tumors; and spinal instability or vertebral collapse, with or without neurological deficit (23). General principles for operating on spine tumors include decompression of the tumoral cord compression, preserving uninvolved spine segments, making a stable construction, choosing an approach that is consistent with the anticipated reconstruction, and minimizing surgical morbidity. Fixation should not end on levels with pathology (2).

Surgical procedures for metastatic spine tumors can be classified as excisional procedures (complete resection of the involved vertebrae, followed by spinal instrumentation) and palliative procedures (posterior decompression and stabilization using spinal instrumentation for pain or paralysis) (12). When en bloc resection is not possible, aggressive intralesional total spondylectomy may be a good alternative. Intralesional total spondylectomy involves a combined posterior/anterior resection with the goal of complete gross tumor removal. An initial posterior approach removes the posterior spinal elements/pedicles,
exposes neural elements and the vertebral arteries, and stabilizes the region with instrumentation. A staged anterior approach subsequently removes the residual anterior tumor and allows anterior reconstruction. Tomita and colleagues (20) described a total en bloc spondylectomy technique consisting of two steps. First, en bloc laminectomy (en bloc resection of the whole posterior element of the vertebrae) and a temporary posterior instrumentation are performed. This is followed by en bloc corpectomy (resection of the anterior column of the vertebra) and anterior instrumentation with spacer grafting and posterior spinal instrumentation (20).

Surgical treatment of tumors in the musculo-skeletal system often requires extensive resection with safety margins reaching far into adjacent structures. This is often not possible for the surgical treatment of spinal tumors because of the close proximity of important neural and vascular tissue. Combined approaches, associated with en bloc vertebrectomy offer the greatest chance for long-term remission or cure. A posterior approach is performed first. Pedicle screws are placed in the pedicles two levels above and below the involved vertebra. A wide laminectomy of the involved vertebra is then performed. The pedicles of the involved vertebral body need to be resected at their base. This can be done with a Gigli saw or using rongeurs and a high-speed burr. Care should be taken to protect the nerve root during pedicle resection.

En bloc resection is defined as total removal of the tumor mass, including a cuff of healthy tissue (margin). Marginal dissection is performed through the reactive outer area of the tumor (pseudocapsule), potentially leaving microscopic tumor behind. Wide dissection covers a layer of peripheral healthy tissue, a dense fibrous cover (fascia), or an anatomic barrier not yet infiltrated. It fully cover the tumor, and pathologist reading shows a negative margin.

Radical resection of an affected vertebra requires the removal of the whole vertebra, and transection of the spinal cord or nerves. A radical resection would require the removal of the whole spinal canal and associated structures if the tumor extends into the spinal canal. The priority in the treatment of spine metastases is to preserve mechanical and neurological function. By contrast complete local eradication is the main goal in the treatment of primary tumors, as an oncologically appropriate surgical treatment can substantially improve the prognosis and even be considered a life-saving procedure (21).

Vertebrectomy is used to describe removal of the whole tumor in one piece and is also called ‘spondylectomy’. The procedure can be performed in two stages. The posterior approach (in the prone position) involves excision of the posterior elements. Using a midline incision, a wide exposure is obtained by resecting the biopsy tracts if the patient is undergoing biopsy by the posterior route. The surgical field must be wide enough to expose the transverse processes on both sides. The spinous and inferior articular processes of the adjacent vertebra are osteotomized and removed with dissection of the attached soft tissues, including the ligamentum flavum. The pedicles are cut and posterior elements are resected in one piece. The cut surface of the pedicle is sealed with bone wax to reduce bleeding and to minimize contamination (20). The posterior approach allows careful hemostasis of the epidural venous plexus and posterior instrumentation can be performed. The anterior approach (transpleural thoracotomy, retroperitoneal abdominal, or thoracoabdominal approach) allows the ligature of segmental vessels (at the lesional level, above and below), proximal and distal discectomies, and the en bloc removal of the vertebral body and anterior reconstruction (12).

The vascular anatomy of the vertebra is risky for total en bloc spondylectomy. Major and associated segmental vessels surrounding the vertebral column of the thoracic and lumbar spine were studied by Kawahara (14) in a cadaveric study. Posterior total en bloc spondylectomy presents a lower risk to damage the thoracic aorta from T1 to T4. Distal to T5, the aorta must be carefully retracted anteriorly before manipulation of the affected vertebra. For a malignant tumor involving L1 or L2, the medial and the intermediate crura of the diaphragm and the first two lumbar arteries must be treated carefully before spondylectomy. Malignant tumors involving the L3 and L4 vertebral bodies can be approached with a total en bloc spondylectomy technique only when the inferior vena cava has been safely retracted anteriorly (14).

**Spinal Reconstruction**

Following the decompression of the spinal cord and/or nerve roots, spinal instability requires instrumentation and fusion for reconstruction of the spine. The benefit of spinal stabilization is early mobilization, particularly in patients with limited survival time because of the nature of their malignancy. Early mobilization allows improvement of motor functions and quality-of life parameters.
Inappropriate reconstruction causing early failure and further deterioration of the patient's condition should be avoided. Revision surgery may be life threatening. It should not be forgotten that tumor surgery is not always the treatment of choice for patients with an unfavorable prognosis.

For a biomechanically intact reconstruction, principles of load transfer through the central axis of the human body should be taken into consideration. The big amount of axial load is transferred anteriorly. These loads change upon flexion and extension of the spine. The anterior column consists of the vertebral bodies and the intervertebral discs representing the “load-sharing” portion of the spine.

The posterior osseous structures in combination with the ligaments and joint capsules reflect the tension band of the construct. Tumor invasion disrupts this antero-posterior balance. When the stability of the anterior column is compromised by tumor destruction, surgical options vary from percutaneous cement injection to complete vertebral body replacement with interbody spacer. The expectation of such an anterior spacer is to compensate the load-bearing capacity of the removed vertebra, and transfer the load to the adjacent segment.

Autologous or allogeneic tricortical bone grafts are used to achieve anterior support following tumor resection. Custom-made polymethylmethacrylate inlays with or without metal reinforcement can also be used. A large selection of reinforcement devices made from different metal alloys, carbon fibers, synthetic plastics, or ceramic is currently on the market. Although most have been designed for trauma, they can also be used in tumor surgery.

Vertebroplasty, the injection of liquid bone cement into a vertebral segment, stabilizes and strengthens the anterior column. Vertebroplasty used to be reserved for the palliative treatment of vertebral cancers in patients with very limited life expectancies or who were poor surgical candidates. New techniques and materials have allowed application to patients presenting with symptomatic spinal lesions from a variety of oncological, metabolic, and traumatic processes (12). Significant pain relief was reported in 95% of patients treated by vertebroplasty for osteoporotic fractures or for neoplastic lesions (3). Neurological complications are directly related to leakage of polymethylmethacrylate through cortical defects, with epidural compression of the neural elements (10). The rarity of local tumor recurrence in most series suggests that percutaneous vertebroplasty may have an independent antitumoral effect. Local toxicity of polymethylmethacrylate, the heat of polymerization, and ischemia induced by cement injection are likely to be contributory (4).

Kyphoplasty is a modification of vertebroplasty designed to reduce deformity and spinal malalignment. A balloon-equipped bone tamp is passed into the vertebral body and inflated to restore lost vertebral height. Cement is then inserted into the preformed cavity, stabilizing the reconstruction (22).

Spinal instrumentation should be applied to a sufficient number of segments to ensure stability during the healing process. Hooks attaching to the lamina, facet joints, or transverse processes and pedicle screw systems are used for posterior instrumentation. As a general principle, posterior spinal instrumentation is attached to normal spinal elements above and below the decompressed area to restore stability. The number of levels and construct depend on the strength of the bone, the quality of fixation, and the presence of additional metastases within the fusion segment.

Pedicle screw fixation devices offer the most stable constructs for the posterior spine. Anterior defects may be reconstructed using autograft, allografts, titanium cages, expanding cages and carbon fiber cages, all combined with bone grafting for improved healing. Methylmethacrylate is not recommended in the treatment of primary tumors. Anterior plates enhance anterior column stability and minimize the chance of graft or cage displacement.

The spacers should allow enough room for osseous integration, partially at the endplates of the construct. Failures of anterior support after reconstruction in tumor surgery can have multiple factors. The tendency for dislocation of a graft will increase where the rotational forces in the reconstructed area has not been sufficiently reduced. Graft designs resulting in good primary anchoring at the graft-bone interface can provide further rotational stability, whereas grafts with smooth surfaces will increase the rotational instability. Subsidence of the spacer into the adjacent vertebrae is a result of excess stress to the bone, and can be caused by two main sources, poor bone quality and mechanical overload. A surgeon’s options for
poor bone quality are limited, although augmentation with small amounts of bone cement can increase the stability of the augmented segments. Fracture or collapse of the anterior device is observed with long bone graft constructs. Functional interaction between the pressure-resisting anterior column and a stable posterior tension band provides a high likelihood for spinal stability.

In cases of reconstruction of malignant tumors with metastases or patients with very limited bone stock (osteopenia), we tend to fill a mesh cage with bone cement, leaving a few millimeters at the ends of the cage cement free. In case of benign or primary malignant tumors without metastasis, the cage can be filled and surrounded by bone graft, where good osseous integration can be expected. Stabilization has to be planned to avoid severe intraoperative translation or dislocation (17).

Fixation techniques for cervical spine include anterior and posterior techniques. For upper cervical spine, anterior cervical plating (constrained or static plates, dynamic or hybrid plates, screws) and posterior cervical fixation techniques (wires and cables, hook plates, plate systems, rod-screw systems) can be applied. For the cervicothoracic junction, posterior stabilization techniques, anterior stabilization techniques (cages) (expandable cervical cage, mesh cage) and combined anterior and posterior techniques can be used (1).

The thoracic spine gains some stability from the ribcage (1). Minimally invasive transpedicular vertebrectomy is an effective palliative treatment option for thoracic metastatic disease in patients not eligible for more extensive anterior transthoracic surgery and stabilization. The procedure allows for anterior decompression with preservation of the spinous process and other posterior elements to minimize further destabilization. The minimally invasive transpedicular vertebrectomy and anterior stabilization technique is a feasible method to address thoracic metastatic tumors with neurological compromise. The approach also provides for better ventral decompression than standard laminectomies or transpedicular decompression (5).

For the thoracolumbar spine, anterior techniques (plates, rod systems, telescoping fixation systems, expandable or mesh cages) and posterior techniques (screws, rods, hooks) can be used. For the thoracolumbar and sacropelvic region, posterior fixation techniques with interbody spacers (PLIF/TLIF), anterior lumbar interbody fusion devices (ALIF), sacroiliac and iliac screws can be applied (1).

Radical resection is the best treatment for malignant sacral tumors. Sacroiliac stability is not so affected by resection if 50% or more of the sacroiliac joint is intact. Total sacrectomy, however, is difficult because of the site and size of the tumor and its anatomic relation and involvement with surrounding tissues and organs. After resection, a large cavity results that is susceptible to infection, and significant neurological and sexual deficits remain. Furthermore, there is vertical and rotational instability; thus, it would be desirable to establish bilateral union between the lumbar spine and the ilium, as well as reconstruction of the pelvic ring. Reconstruction of the lumbosacral junction may facilitate early mobilization and permit patients to walk sooner and resume normal activities earlier. Usually, one or more sacral bars or plates are placed between the iliac wings to fix opposing iliac bones to each other and thereby prevent axial rotation of the lumboiliac union. Bone is grafted between the iliac wings and the posterolateral side of the spinal column to promote fusion (7).

**DISCUSSION**

Anterior only constructs have failed to provide adequate stability after spondylectomy. Disch and colleagues (6) demonstrated that additional lateral devices increase primary stability. Posterior instrumentation in circumferential constructs with pedicle screw fixation two segments above and below the resected vertebra created more stable constructs when compared with single-segment screw placement. Fixation of multiple levels in the thoracic spine may be combined with single level fixation in the lumbar spine to accomplish maximum stability but also to preserve lumbar motion segments. However, additional stability is provided by application of a diagonal-connector. Mechanical testing of different transverse connector options demonstrated an increase of 10% in torsional stiffness when using two transverse connectors bridging the longitudinal rod screw system. However, a diagonal connector increased torsional stiffness by 60%. Another option in providing anterior support is the expandable vertebral body replacement device. These devices with an internal threaded mechanism are expanded cranio-caudally after implantation against the neighboring endplate (6).
In a study by Oda et al. (18), five types of spinal reconstruction techniques were compared biomechanically after total spondylectomy. Eight human cadaveric spines (T11–L5) were used. Total spondylectomy was performed at L2 and reconstructed using titanium mesh as an anterior strut. Anterior, posterior, or circumferential instrumentation techniques were then performed. Only circumferential fixation techniques provided more stability than the intact spine in all testing modes. Short circumferential instrumentation provides more stability than multilevel posterior instrumentation alone and requires fewer levels of spinal fusion. Multisegmental circumferential instrumentation may be required in cases of severe osteoporosis to prevent instrumentation failure including screw loosening and anterior strut migration.

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Anterior angular stable fixation showed higher primary and secondary stability following thoracolumbar corpectomy. The use of angular stable systems substantially increased stability in specimens with lower BMD (6).

Anterior column reconstruction with structural cortical allografts proved to be a reliable technique in patients with spine tumors (16). Kanayama et al. (13) suggested that anterior–posterior reconstruction should be used in all tumor cases that are treated with total spondylectomy because 70% to 90% of the axial load passes through the vertebral body, and anterior constructs alone demonstrated significantly lower stiffness than circumferential reconstructions.

The spinal instability is mechanical and is related to extensive bone destruction due either to tumor-mediated osteolysis or to iatrogenic causes, and the pain is due to vertebral fracture (11).

The radiological stability of titanium mesh cages (TMCs) when used for single-level corpectomy reconstruction of thoracic and thoracolumbar spine was evaluated by Robertson (19). Titanium mesh cages (TMCs) offer a potentially advantageous reconstruction technique after corpectomy in the thoracolumbar spine. The cages offer resistance to axial compression, lateral flexion, and axial rotation and when placed with distraction between superior and inferior adjacent vertebral bodies. They should also resist translation in both sagittal and coronal planes. TMCs offer the option of retaining the benefits of autogenous bone's osteoconductivity and osteoinductivity without the requirement of structural bulk autograft. Compression of the superior and inferior vertebrae “lock” the cage in place, providing resistance to axial compression, torsion, and translation with the additional stability achieved with anterior and/or posterior stabilizing implants. Distraction forces are unlikely to be resisted by the cage yet are resisted by the soft tissue tension and additional stabilization devices.

REFERENCES


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