Minimally Invasive Methodologies in the Treatment of Spinal Metastatic Disease

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ABSTRACT
Metastasis to the spinal column may be a debilitating condition leading to neurological decline, pain, impaired mobility, and decreased quality of life. Historically, it has been a challenging disease to treat with traditional medical and surgical therapies only offering modest palliation of pain or neurological function. Improved systemic treatment of wide spread metastatic disease has resulted in longer survival of this patient population, demanding improved methods of local control. Stereotactic radiosurgery has revolutionized the treatment of spinal metastases. Similarly, improved technology and an increasingly advanced surgical technique have given rise to a number of minimally invasive surgical approaches for decompression of the neural elements and stabilization of the spinal column. These surgical approaches are particularly well-applied to this patient population with a high aggregate risk. We seek here to provide survey of these minimally invasive approaches and to provide a framework in which to utilize them. Minimally invasive surgical approaches may be one highly effective tool within the context of a multimodal treatment paradigm which likely provides distinct advantages to more aggressive surgical approaches, including less surgical morbidity, shorter rehabilitation, and greater facilitation of adjuvant therapies.

KEY WORDS: Epidural spinal cord compression, minimally invasive spine surgery, percutaneous instrumentation, stereotactic radiosurgery, spinal stability, vertebral metastasis, vertebroplasty

INTRODUCTION

The American Cancer Society estimates over 1.4 million new cases of invasive cancer and over 500,000 cancer deaths in the year 2008, making it second only to heart disease as the leading cause of death in the United States (40). At autopsy, approximately 30% patients who die of malignant neoplasm are found to have spinal metastases (60), making it the third-most common site of distant spread, following lung and liver. Vertebral metastatic disease may be a devastating condition leading to loss of neurological function, decreased mobility and quality of life, and increased mortality. In the early history of managing this disease, extensive open surgical approaches often left the patient with an extended rehabilitation at end of life with little or no oncological or neurological benefit. Thus, treatment of this disease has traditionally been limited to external beam radiotherapy for palliative care. Moreover, as systemic treatments for malignancy advance, the incidence of vertebral metastases increases due to overall increased survival of cancer patients.

While the goals of care have remained unchanged—namely, the palliation of pain and neurological function—the development of new technologies has revolutionized spinal oncology in recent years and promises to provide patients with improved clinical outcomes. The emergence and refinement of myriad techniques in radiation oncology, interventional radiology, and spine surgery have created a therapeutic landscape that can be difficult for the clinician to navigate. Indeed, management of the patient with spinal metastases is complex and must take into consideration the systemic disease burden, functional status, comorbid conditions, neurological function, mechanical stability, and more.
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particular, the application of invasive surgical methods demands extreme discretion in this patient population with high aggregate risk. In an effort to minimize this risk and maximize benefit, surgeons have developed less invasive approaches to decompress the neural elements and stabilize the spinal column. This has the advantage of comparatively lower direct surgical morbidity, shorter rehabilitation, early postoperative mobility, and facilitation of postoperative radiotherapy and chemotherapy. We aim here to provide the reader with a survey of this evolving landscape with the persuasion that 1) a rigorous and systematic framework in which to apply these treatment modalities is a requisite for the practitioner, and 2) a combined interdisciplinary and multimodality treatment plan may often provide patients with the greatest benefit.

The NOMS framework: emergence of a systematic treatment paradigm

The most comprehensive treatment strategy for the management of spinal metastatic disease has been developed at Memorial Sloan-Kettering Cancer Center, and it provides the physician or surgeon with a framework for considering the neurologic, oncologic, mechanical, and systemic (NOMS) implications of spinal metastatic tumors (49). This framework then invites the development of an evidence-based treatment algorithm for clinical decision making within each of the four categorical considerations.

Neurologic considerations. The incidence of malignant spinal cord compression among cancer patients is 3.4% according to an analysis of the Nationwide Inpatient Sample (53), while other population studies find metastatic spinal cord compression in approximately 5% of patients with cancer (4). Since a seminal report published in 2005 by Patchell and colleagues, direct surgical (circumferential) decompression and stabilization when indicated, has remained a sine qua non in the management of patients with acute neurological deficits on the basis of epidural metastatic spinal cord compression and with a reasonable overall prognosis (63). In this prospective randomized controlled trial, patients presenting with acute malignant spinal cord compression were assigned to undergo either the contemporary standard of care (high-dose steroids and external beam radiation) or early (≤24 hour) direct surgical decompression neoadjuvant to radiotherapy. Unlike prior trials where surgical approach was limited to simple laminectomies and posterior approaches, surgeons here sought immediate direct circumferential decompression employing newer and more advanced surgical techniques tailored to the pathology, with anterior and lateral approaches utilized where appropriate. Subjects in the cohort randomized to surgical decompression had superior ambulation, Frankel grade, steroid dependence, and even mortality.

Yet, patients with acute malignant spinal cord compression are a small minority of patients with spinal metastatic disease, and even a minority of patients with radiographic epidural disease. The most validated grading system of epidural spinal cord compression in magnetic resonance imaging (MRI) is the Spine Oncology Study Group (SOSG) grading system initially proposed by Bilsky and colleagues in 2001 (7), and it has subsequently been shown to be a reliable clinical instrument (8). In this scheme, grade 0 is disease limited to the vertebra; grade 1 indicates epidural disease without spinal cord compression; in grade 2 there is spinal cord compression, but still with cerebrospinal fluid (CSF) visible around the cord; and, lastly, grade 3 is the highest degree of spinal cord compression with no CSF visible around the cord. Grade 1 is further subdivided: grade 1a involves the epidural space alone, Grade 1b indicates deformation of the thecal sac, and grade 1c is seen when there is spinal cord abutment. In low grade lesions (grade 0-1), radiotherapy alone may be an appropriate choice for palliation and local control, but direct surgical decompression may be necessary in high-grade (grade 2-3) lesions prior to radiation treatment. The SOSG grading system finds its greatest application the context of stereotactic radiosurgery, where, despite the steep dose gradient, a nonetheless neurotoxic dose of radiation may be administered to the spinal cord. Conversely, underdosing the margin of tumor abutting the cord in order to avoid this neurotoxicity may result in poor local control of the metastatic disease.

Oncologic considerations. Within the context of the NOMS framework, a clinician must take into consideration the response of a particular tumor pathology to non-surgical methods when designing a multimodal treatment strategy. Conventional external beam radiation therapy historically has been the most established of these modalities, and primary tumor pathology may be classified on the basis of its radiosensitivity (55, 67). Lymphoma, plasmacytoma and myeloma, germ cell tumors, and small cell tumors are the most radiosensitive tumor types, indeed so much so that external beam radiation remains the primary treatment
method even in cases of spinal cord compression. Breast cancer and prostate cancer are generally held to have a more favorable prognosis with respect to fractionated radiation therapy and are of intermediate radiosensitivity. Other solid tumors including non-small cell lung cancer, renal cell carcinoma, gastrointestinal malignancies, and sarcomas are resistant to conventional external beam radiation therapy. Radiation therapy not only has a role in local tumor control but also in reducing bone pain and preventing and treating pathological fractures. In addition to radiation therapy, systemic treatments including chemotherapy, hormonal therapy, and newer biologic agents may all play a role in the treatment of widespread systemic disease including in patients with spinal metastases.

**Mechanical considerations.** Pain is the most common presentation of spinal metastatic disease. This may be on the basis of neuropathic pain from compression of the neural elements, biologic or inflammatory mediated pain, or pain due to mechanical instability. Distinguishing pain that is the result of mechanical instability from other causes is of great importance in developing a multidisciplinary treatment plan, since this particular type of pain is an indication for surgical management. Pain as the result of mechanical instability is exacerbated with movement, axial loading, and ambulation. It may be fully or partially relieved by recumbence and axial unloading or external orthosis. Pain as the result inflammation or distention of the vertebral periosteum is often worse and night or early morning prior to ambulating and is frequently ameliorated by glucocorticoids, activity, radiation therapy, bisphosphonates, and calcitonin. Mechanical instability may not only present as pain, but also as pathological fractures or deformity. A formal definition of instability within the context of spinal metastatic disease is provided by the Spine Oncology Study Group (SOSG): “loss of spinal integrity as a result of a neoplastic process that is associated with movement-related pain, symptomatic or progressive deformity, and/or neural compromise under physiologic loads” (24).” The spinal instability neoplastic score (SINS) is a clinical tool devised the by the SOSG in order to predict spinal instability on the basis of radiographic and clinical data. It includes an assessment of the location of the spinal segments involved, mechanical pain, the lytic or blastic nature of the lesion, radiographic spinal alignment and vertebral body height, and involvement of the posterior spinal elements. This SINS clinical decision tool has been subsequently determined to have good inter- and intraobserver reliability and has been validated with respect to expert consensus (12, 25, 26, 29). Prospective validation of SINS is yet to be performed. While SINS aids clinicians participating in the care of patients with spinal metastatic disease across a range of specialties by identifying a subset of patients with mechanical instability, it does not establish a treatment paradigm for that instability, be it medical or surgical. The SINS score has been incorporated into the NOMS framework by some authors to create a comprehensive so-called LMNOP approach (Location, Mechanical instability, Neurology, Oncology, and Patient Fitness/Prognosis) (38).

**Systemic considerations.** Patients with a poor functional status, inability to undergo physical rehabilitation, harboring significant comorbidities, or with uncontrolled systemic disease are unlikely to benefit from an extensive surgery. There are several reported scorings systems that are designed to predict the survival of patients with metastatic spinal disease (5, 78, 82, 84, 87). Notwithstanding their limitations, they may be useful to the surgeon in the preoperative evaluation. The prognostic scoring system described by Tokuhashi and colleagues is among the most widely reviewed (81). The scoring system includes six parameters: primary tumor type (most predictive of outcome), the Karnofsky performance status, extra-spinal bone metastases, vertebral metastases, visceral metastases, and the Frankel grade of spinal cord function. The original reports and multiple other authors have provided validation for the Tokuhashi score or provided an analysis which might guide the surgeon’s interpretation of the score (50, 51, 64, 66, 88, 92). Any prognostic scoring system should be used within the context of expert oncologic and surgical opinion, and additional caution must be used in its future application as the arsenal of anticancer agents evolves.

**Stereotactic radiosurgery**

External beam fractionated radiation is the historical standard of care for patients with both operative and non-operative spinal metastatic tumors. This lacks high precision or conformality, and the concern for radiotoxicity to the neighboring spinal cord limits the total available dose. However, the advent of stereotactic radiosurgery, which allows for a larger biologic equivalent dose of radiation to be delivered and has a steep dose gradient, has rendered even traditionally radioresistant tumors treatable and has improved clinical outcomes. It may be used as the primary treatment modality, as retreatment of locally progressive disease after conventional radiotherapy, and as adjuvant
therapy after spine surgery in the post-operative setting. The noninvasive nature of radiosurgery, in concert with trends in open spine surgery toward less invasive techniques, has on the whole defined the contemporary multidisciplinary treatment paradigm of spinal metastatic tumors.

The treatment of spinal metastatic disease remains complex even within this modern paradigm, and stereotactic radiosurgery must be utilized within the context of clear goals of care. Pain again is the most common presenting symptom of spinal metastatic disease, and pain control is an important consideration of palliative treatment. Conventional external beam radiation therapy has a pain control rate in the range of 60% (35, 90). However, reports of pain control in patients undergoing stereotactic radiosurgery are consistently higher than 80-90% and with good durability (21, 30, 32, 73, 74). These data hold true across a wide range of histopathologies of primary tumor. This not only provides a direct benefit, but also an indirect benefit by reducing narcotic pain medications and steroid dependence. Given the non-invasive nature of the treatment and the low procedure-related morbidity, this modality may also be utilized for palliation of painful lesions in the setting of more extensive spinal or extra-spinal disease where surgical therapies would not be appropriate. In addition to providing excellent pain control, stereotactic radiosurgery for spinal metastasis not surprisingly is associated with maintenance or improvement in overall quality of life measures (21, 30).

The role of stereotactic radiosurgery, however, is not limited to palliation. Although patients with spinal metastatic disease often have extensive systemic disease, local control remains an important treatment goal. In this regard, stereotactic radiosurgery has an oncological benefit, particularly in oligometastatic disease where tumors at other sites can be locally controlled with surgery or other means—or even where chemotherapeutic or biologic or hormonal agents offer good systemic control. The greatest oncological benefit of course may be in cases where there is a solitary spinal metastasis. The largest single series to date reported an impressive long-term local control rate in 90% of lesions primarily treated by radiosurgery (32). Tumor control was best in breast and non-small cell lung cancer (100% local control at median follow-up of 21 months). In more radioresistant pathologies local control was also good—renal cell carcinoma 87%, and melanoma 75%. Other large reviews report similar high rates of local control (3, 9, 13, 91). Predictors of failure of local control include high tumor volume and lower total volume prescription coverage (9, 13). Suboptimal coverage of the tumor volume is most likely in the setting of attempting to minimize spinal cord toxicity, and recurrences were more common at the epidural margin. Radiosurgery may also be applied with the intent of controlling disease locally in cases where patients have progressive or recurrent disease after conventional external beam radiotherapy. In these cases concern for radiation toxicity to the spinal cord is prohibitive of further conventional radiation therapy, or patients are not good candidates for surgery. Here, local control rates have been reported to be 80% at one year (15).

Immediate surgical decompression of the spinal cord is the current standard of care for patients with acute myelopathy or paresis from spinal metastases, but it must be supplemented with post-operative radiation therapy in order to achieve durable local control and prevent recurrent spinal cord compression. Conventional radiation therapy after surgical decompression has poor rates of long-term local control, 31% at one year (46). However, in a small series of 18 patients who underwent stereotactic radiosurgery to residual tumor postoperatively after surgical resection, all patients but one achieved good local control (69). Larger series have confirmed that adjuvant stereotactic radiosurgery after surgical decompression and stabilization achieved local control rates greater than 80% at one year (1, 59).

The observation that failure is often at the epidural margin, sometimes where this area is relatively under-dosed out of concern for spinal cord radiotoxicity, has led to the development of a multimodality treatment paradigm whereby stereotactic radiosurgery is preceded by “separation” surgery in order to decompress the spinal cord for neurological instability and also to create a space around the spinal cord as a buffer for stereotactic radiosurgery. In this way, the new gross tumor volume is able to be completely and adequately covered by the radiosurgery plan. This paradigm also implies that the surgeon only need resect a small portion of the tumor from around the thecal sac and mechanically stabilize the spine, resulting in smaller and, in many cases, less invasive surgeries. Patient selection for separation surgery is in part dependent on the Spine Oncology Study Group grading system of epidural spinal cord compression outlined above. Patients with grade 0 or 1 compression may directly undergo stereotactic radiosurgery, whereas those with grade 2 or 3 compression...
may benefit from surgery and adjuvant radiotherapy. This is a radiographic analysis, and patients with acute neurological deficit from spinal cord compression and a reasonable oncologic prognosis should undergo emergent surgical decompression according to the current standard of care. The results of this multimodal treatment paradigm have been reported in a large series of 186 patients undergoing such a separation surgery prior to stereotactic radiosurgery 2-4 weeks postoperatively (48). Of note, the radiosurgery plan was designed based upon the preoperative tumor volume to account for presumed microscopic residual tumor, and the entire vertebral body was typically targeted even if the tumor was smaller radiographically. In this series there was local progression of disease in 18.3% of patients within a median of 4.8 months. Long term local control rates at one year are reported as 83.6%, irrespective of primary tumor histology. This approach obviates the need for extensive oncological resections.

The initial prospective randomized controlled trial by Patchell and colleagues determined that surgical intervention with adjuvant radiation therapy was superior to radiotherapy alone in epidural spinal cord compression with acute neurological symptoms. The paradigm of separation surgery with adjuvant stereotactic radiosurgery expounds upon this approach and improves post-operative local control rates when compared to postoperative conventional external beam radiation therapy. But what, if any, are the implications of stereotactic radiosurgery as a primary modality in this patient population? No trial has directly compared surgical decompression and stereotactic radiosurgery in cases of epidural spinal cord compression. One might imagine that since stereotactic radiosurgery is effective in treating tumors traditionally thought to be radioresistant that may have a benefit not only with respect to pain and local control but also with respect to a patient’s neurological function. Indeed one study investigated the role of radiosurgery as the primary and sole modality of treatment in patients with high-grade epidural spinal cord compression, a subset of which with neurological deficits (75). In this prospective analysis, 62 consecutive patients with radiographic grade 2-3 compression and modified Medical Research Council grade 4/5 strength or better were treated with urgent radiosurgery within 48 hours of assessment. The radiation dose ranged from 14-20 Gy in a single fraction, and the plan was constrained by a maximal dose of 10 Gy to the 10% partial volume of the cord in the region of the target. In those patients with muscular weakness, 52% recovered to normal neurological function, and 63% had at least some improvement. In the cohort of patients who had full strength at presentation but radiographic high-grade compression, 94% remained intact. In the total study population, 16% of patients had some neurological decline. These data, suggest that radiosurgery alone may be an alternative to surgical decompression for a select group of patients with high-grade epidural spinal cord compression. This is particularly relevant for patients with high-grade compression who may not be good candidates for surgery or have a high burden of systemic disease, where the goal of treatment is to preserve existing neurological function.

Percutaneous ablative techniques

Percutaneous ablative procedures are now commonly used for the treatment of multiple neoplasms including metastatic disease in the liver, lung, and adrenal glands. One of the earliest applications of radiofrequency thermal ablation was reported in patients with osteoid osteoma undergoing the procedure for pain relief (71). The extension of this technology into the field of spinal oncology is a logical one, with the goal of local control and palliation of painful metastatic foci. In radiofrequency ablation, a partially insulated catheter is placed percutaneously under image guidance at the tumor epicenter. Current is then applied resulting in heating of the catheter tip, inducing tissue necrosis. The poor conductive properties of bone and the proximity of critical neural tissue present specific challenges in the case of spinal metastatic tumors. Advances in electrode technology and thermal monitoring have made this a safer procedure for small lesions where there is no spinal cord or nerve compression (22). Still, this technique cannot be applied to lesions abutting or within the spinal canal. Multiple case series have reported very effective pain relief and good local control in cases treated with radiofrequency ablation (18, 23, 34). The technique may be combined with vertebroplasty in cases where there is a pathological fracture or where there is concern for pain or minor mechanical instability (56). Cryoablation is an alternative to radiofrequency ablation, which is as effective as thermal ablation with respect to pain relief but may have the advantage of being able to directly visualize the zone of ablation on computed tomography (11, 83).

Cement augmentation

Percutaneous vertebroplasty is a minimally invasive procedure performed by a spine surgeon or interventional
radiologist in which acrylic bone cement is injected into the vertebral body, typically under local anesthesia or light sedation. Kyphoplasty is a variation in which a balloon is inflated within the cancellous bone of the vertebral body in order to restore some height and to create a cavity into which to inject the cement. This method was first described as treatment for a vertebral angioma in 1987 (31). In the United States, the prevailing indication for these procedures has been osteoporotic compression fractures. However, two randomized-controlled trials have not demonstrated improved pain control with vertebroplasty relative to placebo for this indication (10). A body of literature, however, suggests that in the special case of pathological compression fractures from metastatic disease, percutaneous vertebroplasty or kyphoplasty provides a palliative benefit with respect to pain control. Mechanically unstable osteolytic metastatic disease and pathological compression fractures may lead to decreased mobility, progressive spinal deformity, and impairment of functional status, ultimately decrementing a patient’s overall prognosis. Early studies in small cohorts of patients undergoing vertebroplasty for metastases reported significant pain relief in upwards of 90% of patients, which was independent of the amount of cement injected (19, 89). Subsequent larger series of both vertebroplasty and kyphoplasty continue to describe excellent pain relief (14, 20, 28, 52, 65), but there is no randomized prospective trial in this patient population specifically. Several authors present evidence that kyphoplasty, and vertebroplasty, may additionally partially restore vertebral body height and correct the segmental kyphosis angle. The most pertinent complication of the procedure is leakage of the acrylic cement outside of the vertebral body into the disc space, venous plexus, epidural space, or foramina. A small percentage of these patients may develop a neurological deficit as a result of compression of the neural elements from extracorporeal cement. Accordingly, caution should be used in applying this technique in patients with tumor that has caused retropulsion into the spinal canal.

Of course, percutaneous cement augmentation of the vertebral body does not treat neurological sequelae of metastatic disease, only the mechanical. The ideal candidate for percutaneous cement augmentation is the patient with significant mechanical back pain as the result of thoracolumbar osteolytic metastatic disease with low grade mechanical instability according to SINS (see above), without high grade epidural spinal cord compression. Percutaneous vertebroplasty or kyphoplasty palliates pain and can treat mild mechanical instability as the result of pathological compression fractures, but it is best used in the context of multimodal treatment. The addition of stereotactic radiosurgery to cement augmentation provides both local control and promises to provide more durable pain relief. Conversely, progressive collapse of the vertebral body is a major cause of failure after treatment with radiosurgery alone (76), and percutaneous cement augmentation may prevent this. Using this combined technique long-term pain improvement was reported in 92% of patients, correction of kyphosis and vertebral body height in over half of patients, and prevention of progressive deformity in over 95% of patients (33). This combined approach is minimally invasive, carries less morbidity than open surgery for spinal metastases, and can accomplish palliative and oncological goals in a large group of patients with metastatic pathologic compression fractures and mechanical pain.

**Percutaneous pedicle screws**

Instrumentation within the context of spine surgery is often used to provide a rigid construct to stabilize the spine and allow for arthrodesis where intended. Conventional open pedicle screw instrumentation is a safe and well-established operation in the setting of metastatic spinal disease (28); however, limitations remain relative to less invasive methodologies—a larger wound and surgical cavity for multi-segmental fixation, blood loss, and increased postoperative pain. These are important considerations in patients with spinal metastatic disease where every effort must be made to reduce surgical morbidity. Additionally, they will often need postoperative radiation which decreases wound healing. Overall prognosis is poor, and they may not tolerate the need for extensive rehabilitation; and, prolonged operative time and extensive blood loss may be a source of significant morbidity. Percutaneous placement of pedicle screws under fluoroscopic guidance provides many of the benefits of mechanical stabilization with small incisions, no significant surgical cavity, and minimal muscular dissection (27). Radiation therapy may be able to be initiated earlier after percutaneous procedures compared to extensive open surgeries. Additionally, arthrodesis may not be necessary or indicated in many cancer patients with a relatively short life expectancy. Tumor infiltration and inflammation, chemotheraphy, and radiotherapy create an environment adverse to bone fusion, and aggressive decorticatation and dissection necessary for fusion surgery violates natural barriers of direct tumor infiltration.
and may further destabilize the spine. All of this makes percutaneous pedicles screws an important tool in the spine surgeon's arsenal to treat mechanical instability as the result of metastatic disease. One small series reports pain reduction in over 90% of patients where mechanical pain was treated with percutaneous pedicle screw stabilization (62). This procedure would be indicated in patients with thoracolumbar mechanical pain, mild or moderate instability according to the Spinal Instability Neoplastic Score, and no significant degree of neural compression. The technique should be supplemented with radiation therapy or radiosurgery postoperatively. It may be particularly useful in patients with a contraindication to vertebroplasty, or, in fact, it may be coupled with cement augmentation.

Perhaps the greatest application of percutaneous pedicle screw fixation within the context of surgical spine oncology lays in the possibility of combining it with other surgical approaches. The ability to provide mechanical stability across many segments percutaneously allows the spine surgeon to design a patient-specific minimally invasive surgery that can accomplish both neurological decompression and mechanical stabilization. The neurological decompression or corpectomy can be accomplished through a targeted “mini-open” procedure at a single level and then be supplemented with percutaneously placed pedicle screws (36, 76, 77, 79). Patients treated with a minimally invasive decompression and percutaneous stabilization have similar neurological outcomes to patients undergoing a more extensive opens surgery, but patients treated with minimally invasive stabilization have improved recovery, less operative time, less blood loss, and less postoperative pain (58). Indeed, percutaneous stabilization with pedicle screws is an integral part of many minimally invasive surgeries for spine metastases.

**Mini-open corpectomy: posterior transpedicular approach**

While stereotactic radiosurgery does provide local control and some pain relief, it does not impact mechanical pain much, nor does it prevent progressive vertebral body collapse once there is a pathological fracture or significant loss of height. Percutaneous vertebroplasty and percutaneous pedicle screw placement, as outlined above, provide a minimally invasive method to provide stabilization and pain relief in the setting of mild or moderate mechanical instability—and are highly effective in this regard. These percutaneous surgical methods, however, are not sufficient means of stabilization where there is more severe mechanical instability or deformity as the result of osteolytic metastatic disease. Moreover, circumferential surgical decompression remains the standard of care in cases of metastatic epidural spinal cord compression with myelopathy or neurological deficit. Despite the need for apparently more extensive surgery for decompression and stabilization such cases, the goals of surgery remain palliative. Accordingly, the spine surgical profession has innovated less invasive operations with the goals of minimizing physical rehabilitation, maintaining performance status and quality of life, and expediting radiotherapy.

The historical approach for combined ventral and dorsal exposure of the spine, required for adequate circumferential decompression in the setting of metastatic disease, is the lateral extracavitary approach (47). While this approach did avoid the need for staged anterior and posterior approaches, it nonetheless involves a significant amount of tissue dissection and a large surgical cavity. The “mini-open” posterior bilateral transpedicular corpectomy was therefore developed as an alternative and less invasive approach in order to circumferentially decompress the spinal cord, taking advantage of an expandable interbody cage which allows for a small incision and also allows for preservation of the nerve roots (17). In this technique, a posterior midline approach is utilized for a laminectomy and transversectomy, with preservation of the rib heads; a bilateral transpedicular corpectomy and discectomies are completed each side in turn; and a rib-head disarticulation and trap-door osteotomy is performed in order to allow placement of the expandable cage (16). The construct may be supported with percutaneously placed pedicle screws at levels above and below the corpectomy site where arthrodesis is performed. Postoperative radiation therapy or radiosurgery must be performed for oncologic control of residual or microscopic tumor. Several case series have been reported of posterior-only corpectomy and reconstruction of the anterior column with good results and low complication rates (39, 57, 77); however, only one large series has been reported, and more prospective trials are needed. In select patients requiring a ventral decompression this approach promises a less invasive and less morbid surgical paradigm. In a variation of this technique, the corpectomy is performed percutaneously via paramedian, bilateral, tubular retractors in conjunction with percutaneously placed pedicle screws.
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The optimal surgical approach for compressive metastatic disease remains a complex decision-making process. Classically, an anterior approach to the lumbar spine would be indicated if ventral decompression of the canal is required or if a significant kyphotic deformity requires correction; however, anterior approaches are associated with a significant morbidity including risk to the diaphragm and viscera, blood loss, high postoperative pain, and long recovery time. The minimally invasive direct lateral approach offers yet another “mini-open” technique for ventral decompression of the spinal canal in the lower thoracic and lumbar spine that has emerged recently as a safe and less invasive alternative. The lateral retroperitoneal or retropleural approach uses a distractable tubular retractor system and avoids disruption of the posterolateral tissues including paraspinal musculature, posterior ligaments, nerve roots, and rib heads (2, 86). A rib is partially resected within the view of the vertebral body. The approach for access to the thoracic spine may be transpleural or retropleural; in our practice, a retropleural approach is favored as this obviates the need for chest tube placement. The approach for access to the lumbar spine is retroperitoneal and transpsoas. This muscle splitting approach puts the lumbar plexus at some risk for injury (6), but this can be minimized with intraoperative neuromonitoring, which is imperative for approaches to L2 through L4, and a careful understanding of the anatomy (85). Preservation of the posterior ligamentous complex and musculature is an advantage over the posterior transpedicular approach outlined in the prior section. The technique was initially developed as an approach for discectomy and interbody fusion (61) but later expanded upon to include deformity surgery, fusion revisions, thoracic discs, and tumors. There are several large series of direct

Figure 1: Mini-open corpectomy. A 59 year-old male was referred to our center with acute myelopathy, bilateral proximal lower extremity weakness, and inability to ambulate. He carried a recent diagnosis of non-small cell lung cancer, known to be metastatic to the spine, liver, and brain. He previously underwent external beam radiation therapy for his spinal lesion. A sagittal (A) and axial (B) T2-weighted MRI demonstrated a pathological compression fracture at T8 with >50% loss of height and SOSG grade 3 epidural spinal cord compression, with T2 signal change in the cord. Given his extensive disease burden and medical comorbidities, a minimally invasive approach for decompression and stabilization was designed. Intraoperative fluoroscopy demonstrates placement of bilateral percutaneous pedicle screws at T6-T10 (C), and an expandable interbody cage in place after a mini-open bilateral transpedicular corpectomy (D) for circumferential decompression of the spinal cord.
lateral lumbar fusions of which some patients underwent surgery for tumor (45, 70); however, there is a paucity in the literature of retrospective and prospective studies of patients undergoing the procedure specifically for metastatic disease.

Thorascopic surgery

Lesions of the thoracic spine requiring a complete or partial corpectomy may represent a special case in which spine surgeons can exploit video-assisted endoscopic techniques long-utilized by thoracic surgeons. This approach is applicable to the entire thoracic spine and allows for smaller operative corridors in both anterior and posterior approaches, without the need for large thoracotomies or scapular mobilization. There is often less morbidity with respect to the lungs and chest wall. Thorascopic spine surgery was first reported in 1993 (54), and in 1996 the first report of four patients undergoing thorascopic spine surgery for progressive neurological decline due to thoracic cord compression was published (72). In this small series of patients treated endoscopically, all patients had some degree of neurological recovery and remained independently ambulatory at long-term follow up. However, the largest series of thorascopic spinal surgery was reported retrospectively by Huang and colleagues in which 41 patients in the series underwent surgery for the indication of spinal metastases (37). Not surprisingly complications were higher.
in this sub-population of patients within the larger series. In spite of potential advantages, video assisted thorascopic surgery has yet to see wide adoption by spine surgeons. More modern reports, however, suggest a renewed interest in this technique as technology and methods advance—the video-assisted thorascopic approach has been used to successfully perform anterior thoracic corpectomies and interbody reconstruction using an expandable cage in a small series of patients with metastatic disease with good success and low morbidity (43).

**Transforaminal endoscopic surgery**

The fully endoscopic transformational approach is a methodology first applied to lumbar foraminotomy and discectomy (41), but it is an evolving approach for an increasing number of indications. This technique has the advantage of being ultra-minimally invasive using only a sub-centimeter skin incision, necessitating minimal soft tissue dissection, and performed in the awake patient for intraoperative clinical monitoring of the patient’s pain and neurological function. There are two cases reported in the literature utilizing this surgical approach for spine tumor surgery in the case of a ventral thoracic epidural sarcoma and a foraminal zone colon metastasis (42, 80). While the technique is not yet widely established in the management of spinal metastatic disease, it provides a unique operative corridor to the neural foramen and ventral epidural space that may obviate the need for an open costotransversectomy or transpedicular approach in select cases.

**CONCLUSION**

Treatment of spinal metastatic disease is most often aimed at palliating neurological function and pain. Rarely is surgical management carried out with intent to cure. This clarity of purpose as regards the patient’s goals of care is of unconditional importance to the spine surgeon.
Whenever possible, the pre-surgical workup should include tissue histopathological diagnosis by the safest means possible (often by percutaneous image-guided biopsy), oncological staging, and an assessment of the patient's medical comorbidities and functional status. A multimodal treatment plan tailored to a patient's disease is made in this information-rich context and in a truly multidisciplinary setting with spine surgeons, medical oncologists, radiation oncologists, and radiologists. While stereotactic radiosurgery has become the treatment of choice for limited spinal metastatic disease without significant neural compression, surgical decompensation of the spinal cord and mechanical stabilization remain critically important in relevant cases. The development of the minimally invasive surgical approaches outlined above complements the noninvasive nature of radiosurgery and provides distinct advantages to more aggressive surgical approaches, including less surgical morbidity, shorter rehabilitation, and greater facilitation of multimodal treatment. The complex nature of metastatic spine disease invites creative multidisciplinary treatment strategies and the development of innovative surgical approaches which promise to continue to evolve.

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