The Role of Minimal Access Surgery in the Treatment of Spinal Metastatic Tumors

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Abstract
Study Design: Literature review.
Objective: To provide an overview of the recent advances in minimal access surgery (MAS) for spinal metastases.
Methods: Literature review.
Results: Experience gained from MAS in the trauma, degenerative and deformity settings has paved the road for MAS techniques for spinal cancer. Current MAS techniques for the treatment of spinal metastases include percutaneous instrumentation, mini-open approaches for decompression and tumor resection with or without tubular/expandable retractors and thoracoscopy/endoscopy. Cancer care requires a multidisciplinary effort and adherence to treatment algorithms facilitates decision making, ultimately improving patient outcomes. Specific algorithms exist to help guide decisions for MAS for extradural spinal metastases. One major paradigm shift has been the implementation of percutaneous stabilization for treatment of neoplastic spinal instability. Percutaneous stabilization can be enhanced with cement augmentation for increased durability and pain palliation. Unlike osteoporotic fractures, kyphoplasty and vertebroplasty are known to be effective therapies for symptomatic pathologic compression fractures as supported by high level evidence. The integration of systemic body radiation therapy for spinal metastases has eliminated the need for aggressive tumor resection allowing implementation of MAS epidural tumor decompression via tubular or expandable retractors and preliminary data exist regarding laser interstitial thermal therapy and radiofrequency ablation for tumor control. Neuronavigation and robotic systems offer increased precision, facilitating the role of MAS for spinal metastases.

Conclusions: MAS has a significant role in the treatment of spinal metastases. This review highlights the current utilization of minimally invasive surgical strategies for treatment of spinal metastases.

Keywords
spine, tumor, minimally invasive surgery, minimal access surgery, surgery

Introduction
Over the past 2 decades, we have witnessed an increase in utilization of minimal access surgery (MAS) for the treatment of spinal pathologies. The expertise gained from surgery for spinal trauma, deformity, and degenerative disease has stemmed the adoption of minimally invasive surgeries for spinal cancer. Patients with spinal tumors generally require a combination of surgical, radiation, and systemic therapies making rapid postoperative healing and return to treatment of paramount importance. Comparative data evaluating the benefit of MIS approaches versus open surgeries in spinal metastatic disease are still limited and a systematic review of surgical approaches for spinal metastases concluded that although some studies showed superiority of MAS approaches, data is low quality and strong recommendations cannot be made.1 Nevertheless, multiple studies have demonstrated decreased blood loss, transfusion rates, and hospitalization length with MAS stabilization techniques for spinal tumors.2-5 As an example, a retrospective study comparing outcomes of 25 MAS

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operations versus 25 open decompressions for spinal metastases, showed a mean of 340 versus 714 mL of blood loss, 3 versus 10 cases requiring transfusions and 2 versus 3.6 days of hospital stay, respectively. Moreover, postoperative radiation can occasionally be started within a minimally invasive surgery (MIS) compared with open surgeries where the risk of wound complications frequently delay radiation therapy. These benefits of MAS surgeries along with other potential benefits for patients with metastatic spinal disease result in expeditious recovery and return to multimodality cancer therapy and are thus becoming a more widely used. Current MAS techniques for the treatment of spinal metastases include percutaneous instrumentation, mini-open approaches for decompression, and tumor removal with or without tubular/expandable retractors and thoracoscopy/endoscopy. This review highlights the current available data on minimally invasive surgical strategies for treatment of metastatic extradural spinal metastases.

**Treatment Algorithms**

For treatment of spinal tumors, patients benefit from an evaluation by a multidisciplinary team, including neurosurgeons, radiation and medical oncologists, interventional radiologists, and pain specialists. The NOMS framework assesses 4 key factors to facilitate the decision making for patients with metastatic tumors: Neurologic, Oncologic, Mechanical, and Systemic. Neurologic consideration includes the presence of myelopathy or radiculopathy as well the degree of epidural spinal cord compression. The epidural spinal compression score facilitates this evaluation as scores of 2 (spinal cord displacement) and 3 (absence of cerebrospinal fluid around the spinal cord due to tumor extension) denote patients with high-grade epidural disease. Oncologic consideration evaluates the predicted tumor response to current available treatments, currently primarily reflecting tumor radiosensitivity. Mechanical assessment evaluates the stability of the spine, as facilitated by the Spinal Instability Neoplastic Score (SINS). Systemic refers to a comprehensive risk assessment of the patient’s ability to withstand the proposed treatment and the extent of the systemic tumor burden. This paradigm was the basis for development of a treatment algorithm for thoracolumbar MIS spine stabilization and decompression for spinal metastases. This algorithm facilitates the selection of optimal MAS strategy for patients requiring surgical treatment of thoracolumbar fractures (Figure 1). The 2 main surgical indications for patients with extradural spinal metastases include symptomatic spinal cord compression by radioresistant tumors and mechanical instability, both of which can be treated using MAS techniques.

**MIS Decompression**

1. Patients with high-grade spinal cord compression (ie, epidural spinal cord compression [ESCC] scores of 2 and 3) secondary to radioresistant tumors generally require surgical decompression and stabilization followed by radiation treatment (Figure 2).

2. Below the level of the conus, mechanical radiculopathy (ie, radicular pain secondary to axial loading) represents the primary indication for decompression, and patients are known to benefit from stabilization and decompression (Figure 3).

The integration of stereotactic body radiation therapy has revolutionized surgery for spine cancer since it eliminates the purpose of cytoreductive or gross total resections. Since the introduction of spinal stereotactic body radiation therapy (SBRT), an abundance of data has established the safety and efficacy of SBRT demonstrating high rates of tumor control with low complication profiles. Postoperative SBRT provides durable and consistent local control irrespective of tumor volume or tumor histology. Therefore, spinal SBRT diminishes the need for extensive tumor excision, with patients undergoing decompressive separation surgery to provide circumferential spinal cord or cauda equina decompression in order to optimize SBRT dosimetry. Among patients with lumbar radiculopathy manifested by severe radicular pain exacerbated by axial loads in the setting of lumbar burst fracture with tumor extension into the pedicle, facetectomy with fractured pedicle excision and instrumented stabilization provide reliable symptom relief.

As SBRT eliminated the need for extensive excisional operations, this strategy allowed exploration of even less invasive surgeries with goals of rapid continuation of concomitant cancer therapies. Chou et al, described the “mini-open” approach, using minimally invasive laminectomy and transcervical ventral epidural decompression with trans-fascial instrumented stabilization. Others have since described case series demonstrating the safety and efficacy with minimal access approaches using tubular and expandable retractors for either circumferential spinal cord decompression or facetectomy and nerve root decompression in the setting of mechanical radiculopathy. Our current MAS decompression strategy involves the use of a tubular or expandable retractor placed though one of the pedicle screw incisions, allowing us to perform a hemilaminotomy and/or facetectomy. For patients requiring a midline or bilateral decompression, an expandable midline retractor provides excellent exposure while minimizing the approach-related soft tissue injury. Spinal endoscopy is an emerging field for degenerative spine disease and considering the minimal access entailed, coupled with direct target visualization, it will likely play a role in surgery for spinal metastases in the future.

**Laser Interstitial Thermotherapy**

The search for less invasive methods for epidural tumor decompression has brought forth the adoption of image-guided laser interstitial thermal therapy (LITT) as an alternative to open surgery. LITT delivers thermal energy, under real-time magnetic resonance imaging (MRI) monitoring. The technical
safety and feasibility of LITT, initially developed for ablation of intracranial pathologies, has been described by Tatsui et al.\textsuperscript{23-26} In combination with SBRT, LITT reduced the epidural tumor volume while improving pain control and health-related quality of life (HRQoL).\textsuperscript{23,27} In brief, the laser probe is inserted under navigation to the affected epidural space, typically via a transpedicular, vertical, or translaminar approach.\textsuperscript{26} Thermal energy is then delivered under real-time MRI monitoring. A dedicated MRI sequence shows both intensity and spread of heat within the involved tissue providing real-time monitoring of the thermal damage.\textsuperscript{23} Despite this method’s promising potential, it has not been widely adopted likely due to significant technological and time requirements.

MAS Stabilization

Systemic and radiation therapy are the primary treatment modalities for spinal metastases, yet they do not treat neoplastic spinal instability. Hence, spinal stabilization serves as a separate surgical indication, regardless of oncologic or local control goals. To simplify the assessment of mechanical stability and to unify decision making and reporting across institutions, the spine oncology study group developed a scoring system—the SINS.\textsuperscript{28} SINS has become widely accepted and is used to determine stable, unstable, and intermediate scores ultimately expediting referrals for evaluation and treatment of spinal instability.

Patients with mechanical instability but without high-grade epidural extension of radioresistant tumors and without mechanical radiculopathy do not require surgical decompression and can be treated with stabilization alone. Cement and instrumented stabilization serve as the dominant modalities for spinal stabilization. Fracture morphology determines whether vertebral cement augmentation alone would suffice or whether additional instrumented stabilization is indicated.

1. Patients with mechanically unstable compression fractures without significant epidural extension, extensive posterior cortical destruction, or posterior element

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**Figure 1.** Minimal access treatment algorithm for metastatic thoracolumbar compression fractures. Adapted from Barzilai et al.\textsuperscript{14}
involvement can be treated with balloon kyphoplasty or vertebroplasty. The tumor requires postprocedure treatment with SBRT or cEBRT, with the tumor histology determining the choice of radiotherapy modality.

2. Patients with mechanically unstable fractures with extensive posterior cortical destruction and/or fracture extension into the posterior elements benefit from percutaneous stabilization combined with balloon kyphoplasty. The addition of percutaneous instrumentation provides stabilization of the posterior elements in addition to more robust stabilization of the vertebral body fracture. The tumor requires post-procedure treatment with SBRT or conventional external beam radiation therapy (cEBRT), with the tumor histology determining the choice of radiotherapy modality (Figure 4).

3. Patients with mechanically unstable fractures with significant epidural retropulsion caused by radiosensitive tumors (ie, lymphoma, multiple myeloma, or breast and prostate adenocarcinoma) benefit from percutaneous stabilization without kyphoplasty followed by cEBRT. Kyphoplasty should be avoided at the level of the fracture to avoid the risk of exacerbation of the epidural disease and spinal cord compression. The tumor requires postprocedure cEBRT with the expectation of resolution of the epidural tumor component.

Traditionally, stabilization was achieved via open surgery with low risk of hardware failure requiring surgical revision. However, with improvement in cancer care and prolonged survivals, long-term analyses show that these rates increase, yet remain acceptable. Implementation of MIS percutaneous stabilization in the cancer population, has allowed minimization of approach-related soft tissue injury and systemic stress, leading to preservation of muscle attachments, improved wound healing and shorter recovery times. Percutaneous stabilization can be performed using intraoperative fluoroscopic guidance or navigation systems.

**Cement Augmentation**

High-quality evidence strongly supports the use of balloon-assisted kyphoplasty and/or vertebroplasty in order to treat symptomatic tumor-related compression fractures. Berenson et al conducted a prospective randomized trial and found that patients who underwent balloon kyphoplasty experienced significantly better pain reduction and improvement in disability indexes that persist for up to 6 months compared with patients treated in the noninterventional control arm. Other, lower level evidence also support kyphoplasty for symptomatic osteolytic tumors with goal of pain palliation. Similarly, for vertebroplasty, pain reduction has been shown in patients treated for spinal metastases.

However, since cement injection only provide stability in the vertebral body, fractures that extend into the pedicles and joints require instrumented stabilization in order to provide support to the posterior elements in the spine. Therefore, such fractures require a combination of percutaneously placed pedicle instrumentation anchored above and below the fracture, and kyphoplasty at the level of the fracture. Of note, since kyphoplasty may result in retropulsion of fracture fragments and tumor into the spinal canal, thereby exacerbating the epidural tumor extension, kyphoplasty should be avoided in patients with high-grade epidural tumors.

Because of the osteolytic tumors, chemotherapy, radiation therapy, nutritional status, and other comorbidities, the expectation of achieving bony fusion is low. Hence, stabilizing...
constructs for both open and minimally invasive surgeries rely heavily on the instrumentation. Bone cement improves the osseous purchase of the pedicle screws and the advent of fenestrated screws has greatly facilitated screw cement augmentation. Fenestrated screws allow injection of polymethylmethacrylate (PMMA) bone cement through fenestrations in the screw shaft, simplifying screw cement augmentation and may be utilized in order to improve osseous purchase in osteoporotic patients with cancer. It is important to inject the cement under fluoroscopic, real-time, guidance to avoid cement leak into the spinal canal, foramen or distal embolus.

Radiofrequency Ablation

Radiofrequency ablation (RFA) can provide rapid relief (including for painful but benign lesions) and can be used synergistically with both cement augmentation and concurrent radiation therapy. RFA is a percutaneous procedure in which an electrode is percutaneously inserted into the involved vertebral body to deliver high-frequency alternating current into the lesion, resulting in heating, protein denaturation, and subsequent coagulative necrosis. Technically similar to pedicle cannulation for kyphoplasty or vertebroplasty, insertion of RFA catheters is achieved under fluoroscopic and computed tomography image guidance. Several studies demonstrated the palliative benefit for local pain control of bone metastases using RFA. The utility of RFA for purpose of local tumor control requires further study though it has been shown to provide some short-term benefit. RFA has traditionally been limited in posterior vertebral body lesions due to the close anatomical proximity to spinal cord and nerve roots with new bipolar devices attempting to overcome this shortcoming.
Long-term outcomes are unclear, but this technology may be a useful addition to the minimally invasive methods available for palliative treatment. While combined RFA and vertebral augmentation have theoretical benefits, comparative trials have not been performed to establish superiority of combined therapy.

Navigation and Robotics

Spinal navigation is gaining popularity in the degenerative, deformity, and trauma populations and has been shown to reduce screw placement time, improve hardware placement accuracy and decrease risk of reoperation. For minimally invasive surgeries, intraoperative navigation has been particularly impactful for hardware placement. Given the increased risk for surgical morbidity and complications, modern surgical treatment of spinal metastases aims to minimize surgical exposure, operative time, and complications. Thus, the role for neuronavigation in spine cancer is currently under exploration. A variety of 2- or 3-dimensional intraoperative navigation systems are currently used in spine tumor surgery. These systems register to an intraoperative scan from either fluoroscopic based systems or, more recently, intraoperative computed tomography devices. To date, the key role of navigation in surgery for spinal metastases is to aid in instrumented stabilization while minimizing staff and patient exposure to radiation. Unlike for primary bone tumors where navigation can be used for planning osteotomies, the role for navigated decompression in metastatic disease is limited since there is a very limited role for cytoreduction or gross total resection, except for institutions in which SBRT is not readily available. Still, navigated drills, probes and curettes in conjunction with intraoperative ultrasound may be useful in facilitating ventral decompression.

Another promising area of innovation is the integration of robotic technologies in spine surgery. Though limited data and experience exist with these devices in general, as they become more available in spine surgery, it is likely that they will be used in minimally invasive surgery for spinal metastases as well. Robotic systems such as SpineAssist (MAZOR Robotics Ltd, Cesarea, Israel) and ROSA (Zimmer Biomet, Warsaw, IN) have been used for accurate placement of pedicle screws. In essence, these robots assist the surgeon in finding and maintaining an accurate screw placement trajectory. In the future, with technological advances such as force and torque sensors, pedicle screw placement may one day be automated.

Patient-Reported Outcomes (and Other Outcomes Using MAS)

Patient-reported outcomes (PROs) and other HRQoL measures are increasingly recognized as an important method to evaluate treatment outcomes. As mentioned, minimally invasive spine surgery has demonstrated benefit in reduction of blood loss, operating times and length of stay, even when dealing with spinal metastases. While PRO improvement after MAS has been illustrated, comparative data of PRO after open and MAS
techniques are lacking.59-61 Prospective62,63 as well as large-scale multicenter retrospective data show that surgery, along with radiation and systemic therapy, provides improvement in PRO and other HRQoL measures with acceptable risks and complications. Similarly, prospective data demonstrate MAS for the treatment of spinal metastases results in significant decrease in pain severity and symptom interference with daily activities.14 There are currently no comparative PRO data evaluating open versus MAS for extradural metastases and future studies will determine whether there is a clinically meaningful difference between the approaches.

Conclusions
MAS techniques gained prominence in the treatment of extradural spinal metastases and have a clear role in the treatment of neoplastic spinal instability and metastatic ESCC. The purported advantages include reduced blood loss, shorter length of stay, decreased systemic stress of surgery, lower risk of complications, and most important, rapid return to systemic and radiation therapy. Percutaneous instrumented and cement stabilization has been widely used for the treatment of neoplastic instability. Furthermore, MAS muscle-sparing approaches may be used for decompression of the spinal cord and nerve roots. While PRO data illustrate the benefit of MAS in the treatment of metastatic spine disease, high-quality data comparing MAS and open surgical techniques in the treatment of spinal metastases are lacking. Initial efforts focused on identifying appropriate candidates and current efforts aim to improve surgical techniques and continue to minimize surgical extent with greater precision. Neuronavigation and robotics improve accuracy and are likely to continue to improve MIS surgical outcomes.

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