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Minimally Invasive Treatment of Spinal Metastasis

Eric R. Mong and Daniel K. Fahim

Abstract

Advancements in the treatment of systemic cancer have improved life expectancy in cancer patients and consequently the incidence of spinal metastasis. Traditionally, open spinal approaches combined with cEBRT (conventional external beam radiation therapy) allowed for local tumor control as well as stabilization and decompression of the spine and neural elements, but these larger operations can be fraught with one complications and delayed healing as well as additional morbidity. Recently, minimally invasive spine techniques are becoming increasingly popular in the treatment of spinal metastasis for many reasons, including smaller incisions with less perioperative complications and potential for expedited time to radiation therapy. These techniques include kyphoplasty with radiofrequency ablation, percutaneous stabilization, laminectomy, and epidural tumor resection through tubular retractors, as well as minimally invasive corpectomy. These techniques combined with highly conformal stereotactic radiosurgery have led to the advent of separation surgery, which allows for decompression of neural elements while creating space between neural elements and the tumor so adequate radiation may be delivered, improving local tumor control. The versatility of these minimally invasive techniques has significantly improved the modern management of metastatic disease of the spine by protecting and restoring the patient's quality of life while allowing them to quickly resume radiation and systemic treatment.

Keywords: minimally invasive spine, spinal tumors, spinal metastasis, separation surgery, spinal stabilization

1. Introduction

The spine is the most common site of bony metastases [1]. Significant improvements in treatment modalities in the form of chemotherapy, immunotherapy, and radiation therapy have led to increased life expectancy for cancer patients [2]. Consequently, the incidence of metastatic cancer has been increasing. Twenty to seventy percent of patients with metastatic cancer are expected to develop spinal metastases during the course of their disease [3, 4]. The increased incidence of spinal metastases has increased the need for surgical treatment of its complications including symptomatic cord compression and mechanical instability. The goal of neurosurgical treatment includes addressing mechanical instability, correcting deformity, halting or reversing neurologic deficit, and improving pain and quality of life [5]. Traditionally, open surgical approaches have been used for surgical management of spinal metastatic disease. Through the advances made in minimally invasive spine surgery (MISS) for trauma and deformity, MISS for tumors

is becoming more common due to decreased perioperative morbidity in cancer patients with similar efficacy to traditional open approaches.

2. Evaluation of patients with spinal metastases

Patients with metastatic spinal cancer often have significant comorbidities and complex clinical scenarios that require multidisciplinary evaluation and treatment. The NOMS (neurologic, oncologic, mechanical, systemic) framework, developed at the Memorial Sloan-Kettering Cancer Center, assesses neurologic, oncologic, mechanical, and systemic factors during the decision-making process for the treatment of spinal tumors across multiple specialties. The oncologic factors include the predicted responses and durability of available treatment modalities including chemotherapy, immunotherapy, and radiotherapy [5, 6]. The systemic consideration predicts both the patient's ability to tolerate multimodal treatments and overall survival based on the grade and stage of disease as well as the overall health of the patient [5]. The neurologic and mechanical criteria are of particular interest to the neurosurgeon involved in the patient's care.

The neurologic component of the NOMS framework assesses the presence of myelopathy or radiculopathy and is related to epidural compression of the spinal cord and nerve roots. It is estimated that symptomatic cord compression occurs in up to 20% of patients with metastatic cancer and may be the initial symptom in 5–10% [7, 8]. Cord compression above the conus may present with myelopathy, weakness, numbness, urinary urgency. Below the level of the conus, compression of the cauda equina may present with lower motor neuron symptoms of unilateral or bilateral motor weakness, radiculopathy, numbness, or urinary retention. Such symptoms require urgent neurosurgical intervention to either stabilize or improve neurologic function.

The mechanical criteria concerns the stability of the vertebral column affected by metastatic tumor and can be further analyzed by the SINS (spinal instability neoplastic score) criteria [9]. The SINS criteria assess the location of the spine affected including junctional areas, the presence of mechanical pain, type of bony lesions, spinal alignment, amount of vertebral body collapse, and posterolateral involvement [9]. Scores of 0–6 are deemed stable, whereas 7–12 are indeterminate but suggest the possibility of instability, 13–18 are unstable. SINS scores of 7–18 warrant neurosurgical consultation. Overall, the sensitivity and specificity of the SINS criteria for potentially unstable and unstable spinal lesions are 95.7% and 79.5%, respectively [9].

3. Traditional/open operative intervention

Historically, symptomatic metastatic spine disease has been treated with open surgical approaches. Traditional open approaches provide adequate visualization of tumor as well as spinal anatomy. The wide exposures allow for sufficient decompression of the spinal cord and nerve roots, stabilization for mechanical instability, and the opportunity for gross total resection, if indicated. However, the larger incisions with open approaches often lead to prolonged wound healing, which may delay postoperative chemotherapy and radiation. Larger surgical incisions also involve greater blood loss, which is concerning given the high rate of bone marrow toxicity and anemia in metastatic cancer patients, essentially all of whom exhibit preoperative anemia. Larger incisions also have higher incidence of wound breakdown and infections. Greater tissue damage contributes

to greater postoperative pain, opioid requirements, and poor quality of life in patients with limited life expectancy.

4. The evolving role of MISS

The advent of MISS techniques, initially for the treatment of degenerative conditions followed by applications in trauma, has led to the adoption of these techniques for oncological disease of the spine as well. MISS offers the opportunity to treat mechanical instability and epidural spinal compression in patients who otherwise may not tolerate a more extensive surgical approach due to heavy systemic disease burden [4, 10]. When considering the need for radiation and systemic chemotherapy, one postoperative barrier to adjuvant treatment is proper healing of the surgical incision. Smaller incisions involved with minimally invasive approaches may offer expedited time to chemotherapy and radiation therapy [4].

Many benefits of MISS can be attributed to minimizing tissue damage. Less tissue damage may also allow for quicker pain relief, decreased intake of opioids during the postoperative period, which may translate to early mobilization, functional recovery, and improvement in quality of life [4, 11]. Smaller incisions are also associated with less perioperative blood loss and transfusion requirements [12, 13].

Other benefits of MISS include preservation of the posterior elements, including the multifidus, which is one of the largest contributors of the posterior tension band and overall stabilization of the spine [14]. Given that many patients with spinal metastases frequently have compromised integrity of the spine, preservation of the tension band may prevent postoperative instability, kyphosis, and forms of instrumentation failure including screw pullout [14].

Disadvantages of MISS techniques include difficulty recognizing microsurgical anatomy given distortion by pathology in smaller spaces, as well as highly vascularized pathology that may lead to bleeding that is difficult to control. Both of these difficulties may require conversion to open approach [15]. Furthermore, the intricacy involved with MISS may lead to longer operative times [15]. Despite these risks, the ability for MISS techniques to offer preservation of function, symptomatic and palliative treatment for metastatic cancer with lower perioperative morbidity remains of great interest.

5. Evolving role of radiation

Both cEBRT (conventional external beam radiation therapy) and SBRT (stereotactic body radiation therapy) and SRS (stereotactic radiosurgery) have been heavily involved in the treatment of MESCC (metastatic epidural spinal cord compression). Historically, palliative radiation in the form of cEBRT was used and has been shown to have stronger outcomes in pain relief, neurologic status, and local control in patients with radiosensitive tumors compared with radioresistant tumors [16, 17]. Additionally, the rate of local control was found to be inversely proportional to tumor size for patients undergoing cEBRT [18]. The advent of SRS and SBRT has significantly improved the treatment of MESCC by its ability to deliver high doses of radiation to smaller targets, minimizing damage to adjacent neurologic structures (**Figure 1**). Compared with cEBRT, SRS is able to provide local control independent of tumor histology [19]. Tumor recurrence in patients that have undergone SRS has been shown to be dependent on the amount of radiation delivered rather than radiosensitivity of the tumor [5]. Furthermore, for patients undergoing epidural spine decompression followed by SBRT, the majority of tumor

Figure 1.

(A) Axial, (B) coronal, (C) sagittal images showing a highly conformal stereotactic radiosurgery treatment plan to a C2 metastatic lesion secondary to thyroid cancer. The isodose lines can be seen around C2 and the structures at risk are also outlined (the oropharynx and upper esophagus in green and the spinal canal in purple). (D) Shows the relative isodose lines in graphic form, with the tumor dose curve on the far right and the overlapping green and purple dose curves in the middle of the graph representing the dose to the oropharynx and spinal canal, respectively.

recurrence arose from the portion of the tumor in the epidural space adjacent to the spinal cord that invariably receives an inadequate dose, due to the need to protect the neural structures from the potential damage of radiation [18, 20, 21]. Clearly, the benefits of radiation therapy must be balanced against the risks of damaging normal tissue.

6. Advent and benefits to separation surgery

It has been well established that radiation therapy is highly effective for local tumor control. A landmark study by Patchell et al. showed that direct decompressive surgery followed by conventional radiation for symptomatic epidural cord compression was superior to radiation alone [22]. This finding established the essential role of surgery in the management of MESCC. At the same time, advances in stereotactic radiosurgery made radiation alone an attractive alternative to surgery once again. However, cord tolerance always constrains the dose of radiation delivered to the tumor close to the spinal cord, in order to avoid irreversible neurological damage (radiation myelopathy). Radiation failure and tumor recurrence of epidural metastatic disease most often occur adjacent to the spinal cord and dura mater, given this is where the radiation dose is limited to prevent injury to important neurological structures. Continued advancements in microsurgical and radiosurgery techniques have led to the advent of separation surgery, which has decreased the need for aggressive approaches for gross total resection [3, 8, 12, 21].

The goal of separation surgery is to create space between the neural elements and the tumor, so an adequate radiation dose can be delivered to the tumor. The surgical technique involves circumferential dissection around the dura to create an ablative target for SRS while preserving or restoring neurologic function and

providing local tumor control [8, 21]. This strategy is most beneficial to radioresistant tumors such as metastatic renal cell carcinoma, melanoma, thyroid carcinoma, colorectal carcinoma as well as previously radiated tumors and may decrease surgical-related complications of gross total resection or en bloc resection [11, 23].

The shift toward separation surgery has allowed for the introduction of subtotal resection with tubular or expandable retractors through a minimally invasive approach [8, 12]. Furthermore, the small incisions associated with MIS approaches may allow for earlier radiation therapy [11]. The most common approach for separation surgery is the posterolateral approach, which allows for posterior instrumentation and stabilization as well as circumferential decompression [11, 24]. The use of tubular retractors with ventral decompression via a transpedicular approach is growing in popularity [8]. Surgical access from a tubular retractor has the ability to create enough space ventral to the dura to allow for delivery of an adequate dose of radiation without harming the neural structures. This less invasive technique is also associated with a relatively low rate of hardware failure. Amankulor cited 2.8% incidence of hardware failure that may be associated with inadequate reconstruction of the anterior column following minimally invasive tumor debulking [25].

7. Laser interstitial therapy

Laser interstitial thermal therapy is an alternative method for treatment of epidural cord compression that may be performed via a percutaneous minimally invasive approach. This technique may achieve both epidural decompression and local control when combined with radiosurgery with less morbidity than surgery [26]. However, the time it takes for the tumor to respond to the treatment and shrink away may preclude widespread adoption of this technique. Compared with open decompression, there may be shorter interval to resume systemic treatment averaging 7.8 days [26]. Small, early studies suggest noninferiority of laser interstitial thermal therapy plus XRT compared with open decompression plus XRT in select patients [26].

8. MISS techniques for treating mechanical instability

Metastatic disease to the vertebral column requires assessment for mechanical instability via the SINS criteria. SINS score of 7–12 signifies potential instability and may require bracing, kyphoplasty, percutaneous stabilization, or a combination of the three. Higher SINS scores involve more serious deformity including translation, significant vertebral body collapse, and bilateral pedicle involvement, which require more extensive approaches including vertebrectomy with instrumentation.

8.1 Vertebral augmentation

Compression fractures of the anterior column and combination of anterior and middle columns with preservation of the posterior elements are amenable to percutaneous kyphoplasty. High-level evidence supports kyphoplasty and vertebroplasty as highly effective for stabilizing symptomatic pathologic compression fractures [12, 27, 44] and may be done via an extrapedicular or transpedicular approach. Kyphoplasty may be combined with radiofrequency ablation and biopsy, which allows for diagnosis as well as oncological treatment (**Figure 2**). Minimal incision provides the ability for expedited recovery without interruption of radiation and chemotherapy. Patients often experience improvement in pain and functional status after these minimally invasive outpatient procedures [14].

Figure 2.

(A) MRI shows multiple painful metastatic lesions at T10, T11, T12 despite treatment with fractionated radiation. (B) Lateral and (C) AP intraoperative images showing pedicle cannulation at all three levels and radiofrequency ablation probe in position of the T11 level.

8.2 Percutaneous stabilization

Indications for percutaneous stabilization include mechanical instability or as an adjunct to a decompressive surgery for neurologic deficit [10]. Instability is an indication for surgical stabilization regardless of radiosensitivity of the tumor [10, 23]. Percutaneous instrumentation can be performed via MISS or mini open approach over the levels of interest. MISS and mini-open approaches share the advantages of quicker healing time, decreased pain, and the potential for expedited time to administration of chemotherapy and radiation [28].

When considering components of the SINS criteria, compression fractures in junctional areas, as well as fractures with more than 50% loss in height, are subject to additional mechanical stress that may exacerbate fracture, deformity, and mechanical pain. These lesions may benefit from kyphoplasty with additional percutaneous stabilization. Furthermore, compression fractures with involvement of the posterior elements benefit from percutaneous stabilization and kyphoplasty. Burst fractures with significant retropulsion may require decompression with percutaneous stabilization.

Many cancer patients are predisposed to instrument-related complications given the metastatic nature of vertebral bodies combined with osteoporosis from systemic steroids and prior radiation. Combining fenestrated screws and cement augmentation with shorter constructs may lessen the cantilever effect on the spine and reduce incidence of screw pullout or pedicle fracture and proximal junctional kyphosis [12, 29, 30].

Patients with spinal instability and limited life expectancy may undergo percutaneous fixation without fusion. Silva and colleagues conducted a multicenter retrospective study that observed low implant failure rate in short and medium term without fusion [31]. Percutaneous screws may at times be placed with chemotherapeutic agents in attempt to reduce tumor size prior to resection. A case report describes the use of percutaneous screw stabilization with denosumab 6 months prior to en bloc spondylectomy for a spinal giant cell tumor associated with instability [32]. The tumor shrunk during this period, allowing for easier resection. This may be a consideration for a primary bone tumor, which requires aggressive total resection.

8.3 MISS decompression

Primary indications for surgical decompression of spinal metastasis are cord compression from radioresistant tumors as well as mechanical radiculopathy that can be localized to nerve root compression on imaging studies [6].

Tubular retractors may be used primarily for decompression of the posterior elements, but may also be used for ventral decompression as well as lateral decompression.

Figure 3.
Patient presenting with worsening back pain lower extremity paresthesias. (A) CT axial (B) CT showing lytic lesion with three column involvement, including unilateral pedicle involvement. (C) T1 MRI axial precontrast and T1 MRI sagittal post contrast shows epidural compression. Patient underwent thoracic laminectomy with unilateral transpedicular corpectomy with percutaneous stabilization two levels above and below the affected vertebrae.

Figure 4.
MIS percutaneous screws and expandable retractor system for a unilateral transpedicular corpectomy.

Figure 5.
Some expandable retractor systems used in minimally invasive unilateral decompression may be attached to the spinal fixation system used for percutaneous pedicle screw placement. Pictured is the space-D[®] retractor system by Medtronic.

8.4 Corpectomy with stabilization

Higher-grade SINS criteria involve significant vertebral body and posterior element compromise, which may require corpectomy with stabilization.

Mini-open and MIS approaches have been described for corpectomy with vertebral reconstruction. Such approaches are not as commonly utilized compared with the open approach. The open approach is often met with high morbidity, which has the potential to be especially detrimental to a cancer patient. A retrospective analysis of cohort of 49 adult patients with thoracic metastasis conducted by Lau et al. showed miniopen approach for thoracic transpedicular corpectomy with instrumentation had significantly less blood loss and hospital stay with no significant difference in complications or ASIA grade compared with the traditional open approach [33].

Extension of metastatic disease into pedicle or facet can cause mechanical radiculopathy as well as further destabilization of the spinal column [34]. If the lesion involves the anterior and middle columns and one pedicle, then unilateral approach tubular or expandable retractor may be used (**Figures 3–5**). If more extensive disease involves both pedicles, then bilateral tubular or expandable retractors can be used.

9. Expanding role of MISS management of spine tumors

There is essentially no role for MISS in primary vertebral body tumors, which require an en bloc spondylectomy for wide marginal resection [35]. There are multiple

reports of both expandable and nonexpandable tubular retractors [36, 37] for extradural intraforaminal and intradural extramedullary tumors. Most reports use MISS techniques on lesions that span no more than two vertebral levels [38]. Combined approaches with tubular retractors have also been described to resect thoracic dumbbell-shaped ganglioneuroma in which tubular retractors were used for intraspinal component and robotic-assisted thoracoscopic resection for the extraforaminal intrathoracic component [39].

An interlaminar approach has been described for resection of intradural extramedullary lesions in the lumbar spine. With this technique, the pathology is approached through the center of the interlaminar space, where the space is the largest. This paramedian, bone-sparing approach theoretically preserves the posterior tension band and decreases postoperative instability [40].

Additionally, reports of flexible endoscopes via mini open incisions have been reported for the resection of intradural schwannomas at the cauda equine [41]. UT southwestern reports using a flexible endoscope through a minimal durotomy for aspiration of a dermoid tumor that spanned from T10-sacrum leading to functional recovery and remained asymptomatic at 3 years despite small recurrence [42].

In general, treatment of intramedullary spinal cord tumors is associated with high neurologic morbidity. Given the need for GTR (gross total resection) in many of these tumors compared with metastatic tumors, which may undergo STR with separation surgery, GTR cannot be sacrificed for the previously mentioned benefits of MISS. A review of keyhole approaches for intradural tumors showed that only 5.3% of intramedullary lesions could be accessed [41]. MIS management of intramedullary tumors is limited to mini open approach with hemilaminectomy and laminotomy for which GTR may still be achieved with benefit of smaller incision and preservation of vertebral stability [41, 42]. A retrospective study by Kahyaoglu et al., who treated 168 intramedullary tumors via hemilaminectomy, showed that neurologic complications increased when intramedullary tumors extended greater than three spinal segments, especially in thoracic spine compared with the cervical spine [43].

10. Conclusion

Advances in minimally invasive spine surgery techniques and concomitant advances in highly conformal stereotactic radiosurgery capabilities have revolutionized the approach to symptomatic metastatic disease involving the spine. The role of surgery is to create a safe distance between the tumor and the neural structures for the safe delivery of a tumoricidal radiation dose and to treat mechanical instability of the spine. Versatility in the use of MISS techniques is essential for the modern management of metastatic disease of the spine to protect and restore the patient's quality of life and allow them to resume radiation and systemic treatment when indicated.

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