Minimally Invasive Techniques for Spinal Tumors Both Primary and Metastatic: A Review of Surgical Considerations and Techniques

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ABSTRACT
Minimally invasive surgery (MIS) for spinal procedures is an evolving field and is a promising therapeutic treatment option for patients with both primary and metastatic spinal column tumors. This paper is a review of the literature on MIS surgical techniques and considerations for resection or decompression of patients with neoplastic pathologies within the spinal column.

KEY WORDS: Metastatic spine tumor, minimally invasive spine surgery, MISS, primary spine tumor

INTRODUCTION
Traditional approaches to surgical treatment of spinal column tumors typically involve midline incisions, subperiosteal muscle stripping, and in many cases bilateral laminectomies and facetectomies, particularly for large tumors. Post-operative instability and deformity are significant concerns when aggressive bone and soft tissue dissection is utilized to approach the tumor. Minimally invasive surgery (MIS), which often involves the use of tubular retractor systems, has recently become an option in the surgical treatment of both primary and metastatic spinal tumors. In addition to fixed tubular retractors of various diameters, expandable tubular retractors have been utilized when more extensive exposure is needed, essentially amounting to a “mini-open” technique. While initially only reported by a few surgeons considered masters of both minimally invasive spine surgery and spinal tumor surgery, these techniques are gaining wider acceptance. Increasing numbers of case series and case reports have discussed the utility of MIS for both extradural and intradural primary and metastatic spinal tumors.

Currently however, only Class III evidence exists regarding MIS spine tumor surgery. Favorable reports have shown decreased operative blood loss, reduced post-operative pain levels, earlier ambulation, and comparable recovery of neurologic function when compared to open techniques. Reports to date are limited to case reports and retrospective case series. Further randomized prospective studies are required to delineate the equivalence or superiority of minimally invasive versus open resection of spinal tumors. A challenge to initiating quality prospective trials is the evolving nature of minimally invasive surgery. Further, the goals of surgery vary with type of pathology, and whether gross total resection / en bloc resection is planned, versus simple debulking and stabilization of the spine. Approaches, techniques, and outcomes are highly variable and dependent on surgeon experience, a steep learning curve and the patient's functional status and medical comorbidities. The authors present here a discussion of current minimally invasive approaches for metastatic and primary spinal tumors.
There are currently more published clinical reports using expandable retractors compared to fixed tube retractors for tumor resection. Table 1 provides a review of case series for primary spinal tumors and perioperative data including operative time, blood, loss, length of hospital stay, complications, and outcomes. Haji et al. reported successful resection in 22 cases of intradural-extradural and extradural tumors using an expandable retractor (22 mm to 52 mm) with equal success in gross total resection, complication rate and outcomes when compared to open procedures (12). Lu et al. also report 18 patients with intramedullary tumors who underwent resection using an expandable retractor with successful gross total resection in all of their patients (18). Mannion et al. used expandable retractor systems for treatment of 11 patients with 13 intradural extramedullary tumors with 100% gross total resection except in 1 patient who required a conversion to an open procedure after localization to the wrong level. Their article highlighted a significant learning curve with increasing experience. Average operating times in the first three cases were 3.8 hours compared to the last three cases which averaged 1.8 hours in length. Estimated blood loss was 280 cc compared to 80 cc respectively (43). One of the few prospective studies on this subject described 54 patients with intradural tumors that were resected using an expandable retractor (6). This retrospective review of prospectively collected data failed to publish the raw data so analysis is difficult. Perioperative factors (length of stay, blood loss, neurologic signs and symptoms pre and post operatively and pain scores) were not reported. The authors did, however, report decreased length of stay and decreased complications when compared with patients who underwent open procedures (6).

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**SPINAL TUMOR**

**Intradural**

Intradural tumor resection has progressed from bilateral laminectomies to a more limited hemilaminectomy, laminotomy, or laminoplasty approach in selected cases. Studies have shown that extensive removal of posterior elements can lead to increased pain and deformity (3, 15, 29). In some populations laminoplasties have been performed with intent to decrease the risk of post surgical kyphotic deformities (29). Iacoangeli et al. report the use of hemilaminectomies performed in an elderly population with intradural extramedullary meningiomas. Their
<table>
<thead>
<tr>
<th>Study</th>
<th>Patients</th>
<th>Retractor Type</th>
<th>Tumor Location</th>
<th>Operative Time (min)</th>
<th>Estimated Blood Loss (mL)</th>
<th>LOS mean (days)</th>
<th>Complications</th>
<th>Improved Neurologic Symptoms</th>
<th>Gross Total Resection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tredway 2006</td>
<td>6</td>
<td>Hinged expandable</td>
<td>ID-EM</td>
<td>247</td>
<td>56</td>
<td>3</td>
<td>84%</td>
<td>84%</td>
<td>100%</td>
</tr>
<tr>
<td>Haji 2011</td>
<td>20 with 22 tumors</td>
<td>Mini-open expandable</td>
<td>ED - 7 ID-EM - 14, ID-IM 1</td>
<td>210 (120-285)</td>
<td>428 (60-1250)</td>
<td>3 (1-9)</td>
<td>1 - CSF leak, 1 - Foot drop and urinary retention</td>
<td>95%</td>
<td>68% (15)</td>
</tr>
<tr>
<td>Mannion 2011</td>
<td>11 with 13 tumors</td>
<td>Both hinged and mini-open</td>
<td>ID-EM</td>
<td>150 (90-252)</td>
<td>155 (&lt;50-600)</td>
<td>3 (1-5)</td>
<td>2 - wrong levels</td>
<td>NA</td>
<td>100%</td>
</tr>
<tr>
<td>Lu 2011</td>
<td>18</td>
<td>Mini-open expandable</td>
<td>ID</td>
<td>239</td>
<td>153</td>
<td>5 (2-7)</td>
<td>1 - pseudo-meningocele</td>
<td>83%, 50% improved ASIA score, 89% improved VAS score</td>
<td>100%</td>
</tr>
<tr>
<td>Lu 2009</td>
<td>3</td>
<td>Mini-open expandable</td>
<td>ED</td>
<td>200</td>
<td>250</td>
<td>4</td>
<td>None</td>
<td>100%</td>
<td>66% (2)</td>
</tr>
<tr>
<td>Dahlberg 2012</td>
<td>54</td>
<td>Mini-open expandable</td>
<td>ID</td>
<td>126 (65-218)</td>
<td>NA</td>
<td>NA</td>
<td>None</td>
<td>NA</td>
<td>100%</td>
</tr>
<tr>
<td>Gandhi 2013</td>
<td>14</td>
<td>Mini-open expandable</td>
<td>ID-EM, ID-IM 2</td>
<td>218 (92-344)</td>
<td>280 (20-900)</td>
<td>2 (1-5)</td>
<td>1 wound dehiscence</td>
<td>71% (29% stable)</td>
<td>79% (11)</td>
</tr>
<tr>
<td>Nzokou 2013</td>
<td>13</td>
<td>Fixed tube</td>
<td>ED - 9 ID-EM - 4</td>
<td>215 (75-355)</td>
<td>219 (25-500)</td>
<td>3 (1-6)</td>
<td>None</td>
<td>30% improved ASIA score, 77% improved VAS score</td>
<td>92% (12)</td>
</tr>
</tbody>
</table>

**ED** - extradural, **ID** - intradural, **EM** - extramedullary, **IM** - intramedullary, **ASIA** - American Spinal Injury Association, **VAS** - visual analog scale for pain
team argues that this procedure decreases risk of post laminectomy kyphosis, provides increased cord protection from post operative hematoma or seroma formation, causes less dural constriction from epidural scarring and preserves anatomical planes should a second procedure be required (13).

From a posterior approach, a paramedian incision is made through skin, subcutaneous tissue and fascia. Serial dilators are used to pass through paraspinal musculature and ultimately dock onto the hemilamina from the spinolaminar line medially to the edge of the facet capsule laterally (43). Soft tissue is removed with electrocautery and a hemilaminectomy is performed with undercutting of the spinous process and removal of the contralateral ligamentum flavum to allow for a midline durotomy. This approach allows for access to both dorsal and ventral pathology (43, 44, 45). A limited facetectomy may be performed to allow for further visualization of the contralateral side. Hemilaminectomies preserve the contralateral lamina, maintain the midline tension band and preserve the integrity of the supraspinous/ interspinous ligaments and contralateral musculature (13).

Two-level hemilaminectomies can be performed using expandable retractors, thus avoiding the need for re-adjustment of a fixed tubular retractor (43). With current technologies, anything of more significant length than two vertebral levels would likely benefit more from an open approach. Tumors that involve the contralateral lateral recess, are bilateral extradural lesions, have poorly defined borders, or have a high risk of hemorrhage, may require a full laminectomy at that level (13).

**Intraluminal Intramedullary**

In the case of intramedullary tumors, it is important to locate midline in order to enter into the cord between the dorsal columns to reduce dorsal column dysfunction postoperatively. Lateral lesions can be accessed via the dorsal root entry zone with minimal cord injury. In the case of superficial lesions, the tumor may be accessible through the shortest, most direct route to minimize cord damage (45). Ultrasound may be helpful in identifying lesions before and after removal to gauge degree of resection. Numerous series report the use of hemilaminectomy approaches for extramedullary pathology. There are fewer reports published on intramedullary tumors. Ogden and Fessler expound upon their previous case series by Tredway to describe resection of an ependymoma using a tubular retractor system. A midline myelotomy approach was utilized. Poor tumor margins required piecemeal removal of the tumor. While the tumor itself was small, Ogden and Fessler argue for a full exposure of the dorsal surface of the spinal cord to allow for a more accurate determination of midline for the myelotomy. In a hemilaminectomy approach, the exposure is the same as a conventional laminectomy except for a more oblique working angle, higher risk of injury to the ipsilateral posterior column, as well as potentially more difficult hemostasis. Neurological and radiographic outcomes were similar to an open case. Patient mobilization occurred earlier, however (23).

**Intradural Extradural**

Several case series report the successful use of tubular retractor systems for the treatment of intradural extradural spinal pathology. Using an approach similar to what is described above, hemilaminectomies with a minimally invasive approach can be done for tumors within the span of two vertebral levels (9, 45, 43). For tumors with foraminal extension, part of the ipsilateral facet may be removed with a high-speed drill for exposure of the full tumor margin. If a sufficient percentage of the facet has been removed causing concern for destabilization, percutaneous pedicle screw fixation and transforaminal interbody fusion may be performed (43).

**Extradural**

In primary spinal tumors, a small subset of nerve sheath tumors can be entirely extradural. Dakwar et al. describe the use of a minimally invasive lateral extracavitary approach done for thoracolumbar and lumbar intraforaminal neurofibromas. Dissection was done in an open fashion with a 6 cm oblique incision at the ribs and finger dissection performed to mobilize pleura and expose the lateral surface of the spine. An expandable retractor was then placed along the corridor to perform the actual tumor resection (5). Weil et al. describe the successful use of a fixed tubular retractor for the resection of an L3-4 large dumbbell schwannoma with resolution of the patient's chronic leg pain, paresthesias, and weakness (38).

**METASTATIC SPINAL COLUMN TUMORS**

Due to new and evolving therapeutics, cancer patients are living longer and the prevalence of metastatic disease to the spine is increasing. Approximately 5-10% of all cancer patients will develop metastatic spine disease. In fact, more than 90% of spinal tumors in the United States...
are metastatic, with breast, lung and prostate as the most common pathology. Seventy percent of spinal metastases are located in the thoracic spine followed by 20% in the lumbar spine, and the remaining 10% in cervical and sacral regions. A third of cases will have multiple levels affected (1, 17, 29).

The goal of spine surgery in the setting of metastatic disease is not oncologic cure but as a palliative measure to preserve quality of life and neurologic function (39). The well-known randomized study by Patchell found that a combination of modern surgical intervention with radiation therapy improved outcomes compared to patients treated with radiation alone.

Intradural and intramedullary metastases are rare and often due to cerebrospinal fluid (CSF) seeding (26). Osseous vertebral column invasion followed by extradural cord compression is more common. Metastases tend to localize most frequently to the anterior column and may extend into the posterior elements, paravertebral regions, or epidural space. Procedures done to decompress from a posterior column approach via midline laminectomy alone increase the risk of destabilization, spinal cord vascular insufficiency and radicular compression (39, 40). Patients thus often require stabilization in addition to decompression (39).

Anterior approaches to the cervical spine for tumor resection are not unfamiliar to the spine surgeon. Thoracic and lumbar approaches however, are more challenging and open approaches are associated with significant morbidity and mortality due to involvement of the cardiopulmonary system, bowel, and great vessels. Open surgeries typically include extensive incisions with muscle detachment and/or denervation, significant postoperative pain, risk of infection, and muscle atrophy, and often lead to a prolonged rehabilitation course. MIS arguably diminishes the severity of many of these issues. Establishing a working corridor to the anterior column using MIS techniques has been difficult but the development of expandable tubular retractors and transmuscular dilators has created improved access for thoracic and lumbar corpectomies.

MIS decreases the degree of dead space and soft tissue injury associated with a more open procedure and might allow for earlier initiation of adjuvant radiotherapy or chemotherapy due to faster wound healing times. Traditionally, chemotherapy is not recommended earlier than a month after surgery, although this might vary from case to case. At some institutions with the MIS procedures adjuvant therapies are started as early as a week after surgery (39).

SURGICAL APPROACHES

Limitations of MIS increase with increasing severity of metastatic burden to the spine. Decompression of the spine at multiple levels is more difficult to achieve with a MIS approach. Taghva reports a two level corpectomy with percutaneous pedicle screws from T1-T3 and T6-T8 and a T4-T5 expandable cage placed for a circumferential metastatic adenocarcinoma at the T4-T5 level. Bilateral tubular retractors were used simultaneously for a posterior decompression as well as corpectomies and tumor resection in the anterior column. The right sided approach for the vertebrectomy was via a transpedicular approach with concomitant removal of the right paracentral and ventral epidural tumor. The left side was addressed via a costotransversectomy approach for corpectomy and tumor resection with pleural and intercostal muscle dissection and rib osteotomies. Removal of the facet, transverse process, and costotransverse and costovertebral joints were done at two levels on the left side. The patient had resolution of his myelopathy and his weakness. But using MIS to expand beyond two levels is rare and this case report demonstrates one of the more extensive approaches for treatment of metastatic epidural spinal cord compression (MESCC) (31).

For metastatic tumors, approach is significantly dependent on the anatomic pathology. A right sided thoracotomy minimizes risk to great vessels and aortic arch with access to mid- and lower thoracic (T5-12) levels. The thoracolumbar region may require a thoracotomy or retroperitoneal approach. The lumbar spine is accessible via both posterior and anterior approaches. Corpectomies require reconstruction with bone graft, cages, plating, or polymethylmethacrylate. Taghva et al. demonstrate the successful use of costotransversectomies and transpedicular approaches done through a tubular retractor system to perform tumor resection and spinal stabilization procedures.

Thoracic Spine

Thoracic spine metastases are frequently highly symptomatic due to anatomic proximity to metastases from nearby viscera as well as the intrinsic narrow diameter of the spinal canal. However, the thoracic spine is one of the most difficult regions to access. Minimally invasive surgery has changed thoracic spine approach techniques in particular due to the significant morbidity associated with traditional
anterior and posterolateral open approaches. The majority of thoracic MESCC cases can be treated through various approaches adapted to a minimally invasive retractor system: transthoracic, lateral extracavitary, lateral extrapleural and transpedicular. Numerous cadaveric studies and subsequent case series have demonstrated the feasibility of minimally invasive approaches for thoracic corpectomies and osteotomies (19, 21, 36).

**Anterior transthoracic:** The transthoracic approach include the need for a thoracotomy, which is associated with numerous risks including atelectasis, pleural effusions, hemothorax, pneumothorax, chyle leaks and visceral injuries. Open procedures in patients with metastatic tumors to the thoracic spine undergoing an open thoracotomy are associated with a morbidity rate of 29.5% and mortality of 8.2% (37). The open transthoracic approach involves significant intercostal and transversalis muscle and fascia dissection and often post operative chest tube placement. Minimally invasive anterior approaches have been developed utilizing endoscopy that allows for access and exploration of the thoracic spine without the need for rib excision, long diaphragmatic incisions or significant muscle dissection associated with open thoracotomies. Kan et al. reported in 2008 successful treatment of five patients with thoracic metastases with an endoscopic approach. Using the endoscope they were able to successfully achieve a ventral decompression via a corpectomy with inter-body reconstruction and an anterolateral plating system. A standard 4-portal setup was utilized, including suction, retractors, and camera ports. The working portal was 3-4 cm in length in order to accommodate expandable cage insertion. Blunt dissection was used for placement of the first portal and trocar to minimize lung injury. Exposure of the vertebral bodies and intervertebral discs required elevation of a pleural flap and Karl et al. recommend use of the harmonic scalpel for reduced smoke production compared to bovie electrocautery for better visualization within the cavity. Exposure of the pathology and corpectomy were performed in standard fashion. Vertebral body reconstruction was performed with an expandable cage placed with fluoroscopic visualization and then allograft bone placed around the cage. An anterolateral plate was fixed over the cage with screws placed in the superior third of the first non-affected vertebral body caudally and the inferior third of the cranial vertebral body to avoid injury to the segmental arteries in the mid-portion of the vertebral body. A chest tube was left in place and the lung was reinflated under direct visualization to ensure proper lobe inflation (15). Kan et al present one of the few surgical technique case series on endoscopic thoracic vertebral reconstructions for spine metastases. Ragel et al. recommend the use of thoracoscopic surgery for anterior decompression between levels from T4 to L2. Below L2 a retroperitoneal exposure is more strongly indicated while there do exist reports of successful endoscopic retroperitoneal L2 and L3 corpectomies (27). Drawbacks to anterior thoracotomies include lack of access to the posterior elements and limited exposure of the contralateral pedicle. Reduction of deformities is difficult to achieve and may require a posterior approach. Drawbacks to this approach include a limited availability of internal fixation systems that can be applied endoscopically (15, 20).

**Transpedicular:** Mini-open and minimally invasive posterolateral corpectomies were performed in cadavers using tubular access by Musacchio in 2007 (21). Deutsch, Kim, and Chou demonstrate varying transpedicular minimally invasive techniques for resection of vertebral body tumors (16). Deutsch and Kim utilized percutaneous pedicle screws with cage placement in a paramedian unilateral approach with rib head resection. For Deutsch, none of their 8 patients with acute neurologic compromise experienced complications. Five were noted to have improvement neurologically. Two were independently ambulatory after surgery and 62.5% experienced post-operative pain improvement (7). Chou differed in the use of a direct midline approach for circumferential decompression with preservation of the rib head. Chou's mini-open technique could be performed with or without a tubular retractor system but during cage placement they utilized self-retaining retractors and an expandable cage (2). The Tancioni group reports the successful placement of transpedicular screws with transpedicular vertebral body augmentation with kyphoplasty after minimally invasive decompressive laminectomies (33). Zairi reports ten patients with thoracolumbar metastasis and neurologic injuries who underwent transpedicular corpectomies with percutaneous stabilization. No complications were noted and 80% of patients improved by at least 1 Frankel grade (39).

**Lateral Retropleural Approach:** MIS lateral retropleural approach to the thoracolumbar spine allows for a ventral decompression while remaining outside the pleura and compared to a transthoracic approach reduces the risk of injury to the aorta, vena cava, sympathetic plexus and lowers risks of duropleural cerebrospinal fistula (24). It also allows
for preservation of the anterior and posterior longitudinal ligaments to preserve stability after a corpectomy. MIS differs from open with a smaller amount of rib resection and a smaller incision. A disadvantage is the long working distance in a narrow working space as well as the risk that dissection through the retropleural space could be seeded by tumor. The dissection can be difficult when extensive adhesions are present. Further, if posterior instrumentation is required, another incision must be made. Uribe reports the treatment of 21 patients with thoracic spine tumors treated with a minimally invasive lateral approach, 13 of whom required corpectomies. All patients remained neurologically stable to improved (35).

Lateral extracavitary approach:

The lateral extracavitary approach allows for optimal exposure while avoiding high risk anatomic obstacles (8, 11). This approach allows for both an anterior and posterior decompression as well as posterolateral fusion if necessary (11). The approach involves resection of 2 cm of rib distal to the transverse processes at the level of the vertebrectomy as well as the part of the rib at the level below. A plane is subsequently developed between pleura and rib with dissection of the tissue away from rib head and lateral vertebral body. Pedicles are removed and vertebrectomy or corpectomy is performed from the right to avoid the aorta. An expandable cage is placed and then posterior arthrodesis is performed (14). Smith et al. report successful use of the lateral extracavitary MIS approach using a 24 mm tubular retraction system on a series of cadaveric models and then ultimately three patients with vertebral body pathology at T4-5, T7, and T11 who underwent vertebrectomies and cage placement. For tumor at high thoracic levels an anterolateral approach is inhibited anatomically by the axilla and mediastinum (24). The upper thoracic spine, specifically T1-T6 is challenging anatomically due to the scapula, narrow spinal canal, thoracic cage, and pleural and mediastinal cavities. In these cases a lateral retropleural approach may be indicated.

Spinal instability, pre operative evaluation and surgical decision making

Spinal instability with worsening deformity with risk of progressive nerve root or spinal cord injury is a concern in any spine tumor case. Though such pathology may not present in the acute perioperative period, patients undergoing extensive or destabilizing procedures risk requiring further stabilization surgery in the future unless pre-operative planning accounts for this issue. One study in Finland found a 6% rate of delayed spinal deformity after 187 cases of open spinal meningioma resection (28). The introduction of the hemilaminectomy technique has resulted in reduced rates of postoperative deformity in addition to decreased complication rates and shorter hospital stays (12, 22, 23). In cases where there is extension laterally to beyond the facet joint, percutaneous screws as well as transpedicular fusions may be performed concurrently with tumor resection to mitigate the risk of postoperative instability.

Metastatic tumors can be severely destabilizing to the spinal column. Biomechanical studies demonstrate that the vertebral body supports up to 80% of the axial load, explaining why osteolytic vertebral body lesions are particularly injurious. With metastatic invasion, patients risk compression or burst fractures with retropulsion into the spinal canal or neural foramina. Pedicle screw instrumentation is indicated in high stress areas, if the patient is undergoing two or more vertebrectomies, or if there is significant kyphosis or circumferential tumor involvement (29). The cervicothoracic and thoracolumbar junctions may also be subject to pathologic fractures with less tumor burden relative to other spinal levels. (41) Taneichi and colleagues determined that 35-45% lysis of the thoracolumbar spine and 50-60% lysis of the thoracic spine were strong positive predictors of collapse (42). In corpectomies and significant destabilizing procedures, most surgeons recommend fusions at least two levels above and below the affected levels in order to ensure stability. In patients with MESCC and bony invasion, both bone quality and degree of bony and ligamentous invasion will likely influence the levels of fixation required.

In consideration of a surgical intervention for MESCC numerous scoring systems have been devised in order to predict patient outcomes. The Tokuhashi scoring system incorporates functional status, spinal and visceral tumor burden, neurologic deficit, and tumor pathology to determine patient outcome and prognosis. See Table 2: Tokuhashi Scoring System and Tokuhashi Treatment Strategy. Higher scores are assigned to good prognostic indicators including less aggressive tumor, solitary lesions, absence of other visceral metastases, and good functional status without neurologic deficits. Those with higher scores were recommended for surgical resection of their lesions. Lower scores, associated with worse prognosis, were
recommended for palliative intervention involving a limited decompression and stabilization. This scoring system can help guide surgeons in determining the appropriate candidates for aggressive surgical intervention versus palliation (34). A recent paper on separation surgery has argued for the surgical intervention prior to radiation or chemotherapy to decrease the risk of neurologic deficit from post-radiation edema. For centers, such as ours, adoption of these guidelines results in an increasing number of referrals of patients with metastatic spine disease not necessarily at the point of symptomatic spinal cord compression (2).

**Table 2: Tokuhashi Revised Scoring System for Prognosis of Metastatic Spine Tumors**

<table>
<thead>
<tr>
<th>Score</th>
<th>General condition (performance status)</th>
<th>Number of extraspinal bone metastases foci</th>
<th>Metastases to major internal organs</th>
<th>Primary cancer site</th>
<th>Palsy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor (10-40%)</td>
<td>≥3</td>
<td>Unremovable</td>
<td>Lung, osteosarcoma, stomach, bladder, esophagus, pancreas</td>
<td>Complete (Frankel A,B)</td>
</tr>
<tr>
<td></td>
<td>Moderate (50-70%)</td>
<td></td>
<td>Removable</td>
<td>Liver, gallbladder, unidentified</td>
<td>Incomplete (Frankel C, D)</td>
</tr>
<tr>
<td></td>
<td>Good (80-100%)</td>
<td></td>
<td>No metastases</td>
<td>Others, Kidney, uterus, Rectum</td>
<td>None (Frankel E)</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
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</table>

**Tokuhashi Treatment Strategy**

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Management</th>
<th>Predicted Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8</td>
<td>Conservative</td>
<td>&gt; 6 months</td>
</tr>
<tr>
<td></td>
<td>Palliative</td>
<td></td>
</tr>
<tr>
<td>9-11</td>
<td>Palliative</td>
<td>&lt; 6 months</td>
</tr>
<tr>
<td></td>
<td>Excisional if Single lesion No mets to major organs</td>
<td></td>
</tr>
<tr>
<td>12-15</td>
<td>Excisional</td>
<td>&lt; 1 year</td>
</tr>
</tbody>
</table>

**Limitations of MIS**

For tumors greater than two spinal levels using a minimally invasive approach makes visualization difficult. At this time, if tumors span greater than two levels craniocaudally, an open approach is typically used. In spinal tumor surgery whether a durotomy is intended and required or unintended, repair is more difficult through a tubular system than through an open repair. Tan describes where the tack up sutures holes are incorporated into the repair with 4-0 Neurolon, 5-0 Prolene, or 6-0 Gore-Tex running sutures (31). Modified needle drivers and knot pushers are utilized to simplify suture tying through smaller tubular openings. If the seal is not satisfactorily water tight after valsalva maneuver then harvested paraspinal muscle can be sutured in place to buttress the defect. Fibrin glue is often layered over the defect. An alternative to dural sutures is the U-clip device previously used in cardiac surgery, which has been adapted for dural closures in endonasal approaches and now with minimally invasive spine approaches The use of the U-clip avoids having to push knots down the tubular system (9, 24).

**FUTURE DIRECTIONS**

Minimally invasive spine surgery is an exceptionally broad category with an ever-evolving definition. From the use of the endoscope, to tubular retractor systems to percutaneous screws and vertebroplasty – the definition remains in flux. The utility of minimally invasive procedures for tumor resection whether for a primary or a metastatic tumor are arguably improving outcomes for patients and are increasingly in demand. However, the level of evidence still remains Class III and further studies with prospective data and with larger patient numbers remain needed to establish how these techniques compare to the “gold standard” open techniques (31). It remains to be seen exactly what role emerging technologies such as computer-assisted navigation, 3-D intraoperative imaging, robotic surgery, motion preservation, and others might or might not play in future MIS treatment of spinal tumors.
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