Minimally Invasive Techniques for the Treatment of Primary Spinal Column Lesions

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ABSTRACT
Minimally invasive spine surgery is becoming more prevalent as surgeons seek to provide definitive treatment without the morbidity and dysfunction associated with traditional, open surgical procedures. Minimally invasive surgery has been applied with success to the treatment of degenerative disease and traumatic injuries of the spine. Approaches to metastatic and primary spinal column tumors have also evolved rapidly as clinicians seek to minimize tissue disruption, postoperative pain and blood loss in these susceptible patient populations who may also require adjuvant therapies. The various noninvasive and minimally invasive techniques available for the treatment of these primary spinal tumors are reviewed, and their indications, benefits, and limitations discussed.

Keywords: Corpectomy, Minimally invasive spinal surgery, Percutaneous, Vertebral tumors.

INTRODUCTION
The spinal column represents the most common site for bony metastatic spread and consequently metastatic disease of the spine is encountered far more frequently than primary tumors. Primary tumors of the vertebral column are relatively rare comprising 10% or less of all vertebral column tumors. Benign primary lesions of the spine include osteoid osteoma, osteoblastoma, osteochondroma, chondroblastoma, giant-cell tumor, aneurysmal bone cyst, eosinophilic granuloma and cavernous hemangioma. Malignant or locally aggressive primary tumors include osteosarcoma, Ewing’s sarcoma, soft tissue sarcoma, chordoma, chondrosarcoma, solitary plasmacytoma and multiple myeloma. A thorough knowledge of the spectrum of lesions that can affect the vertebral column is essential in providing the appropriate work-up and therapeutic interventions. Also, knowledge of their radiological appearance on computerized tomography (CT) and magnetic resonance imagining (MRI) scans are essential to initiate a treatment plan.

Minimally invasive techniques have been devised to treat a myriad of conditions affecting the spine. Decompression, arthrodesis and instrumentation are now performed routinely with minimal access spinal technology (MAST) through the use of tubular retractors and percutaneous instrumentation systems. The demonstrated benefits include less tissue dissection, decreased postoperative pain, reduced length of hospital stay, and earlier mobilization and return to work.

TREATMENT GOALS
The realistic objectives of the surgical treatment for any spinal tumor must be clearly defined. In some cases, diagnosis may be the primary goal, which can be achieved by a percutaneous method of CT guided biopsy. For many extradural tumors this can be accomplished by CT-guided biopsy with 71 to 96.5% diagnostic accuracy. A lasting cure is the goal of surgery for most primary spinal column tumors. As such, the choice of surgical technique is critical in achieving access and definitive excision. Numerous studies have demonstrated that negative margins with en bloc resection of primary malignant tumors of the spine significantly decrease recurrence rates and prolong survival. The surgical approach must be tailored to meet this goal. The important objectives involved are:

- Diagnosis
- Tumor removal for local control and/or cure
• Circumferential spinal cord decompression
• Symptomatic pain relief and
• Spinal stability.

Where indicated, treatment options should incorporate arthrodesis, deformity correction, and fixation for levels that have been destabilized either by the tumor or by the treatment itself.2,17,18,29,34,35,53-55,92,102

METHODS

A comprehensive literature search using the Ovid gateway of the MEDLINE database from 1950 to December 2009 was performed. The following keywords were queried individually and in combination: ‘minimally invasive spine surgery,’ ‘vertebral tumors,’ ‘primary spinal tumors’ ‘lumbar,’ ‘thoracic,’ ‘spinal metastasis’ and ‘endoscopic spinal surgery.’ The search was limited to human studies published in English. A manual hand search of references from the identified papers was then also performed. All studies were carefully scrutinized for patient clinical characteristics, type of spinal tumor, radiographic characteristics, and treatment modality employed. The data are all presented in this extensive review.

DRAwBACKS OF TRADITIONAL SURGICAL APPROACHES

Traditional open surgical procedures for spinal tumors can carry an up to 30% complication rate, including neurological deterioration, severe medical complications, massive hemorrhage, wound complications including infection and dehiscence, hardware complications, cerebrospinal fluid leaks and death.2,17,18,29,34,35,53-55,63,86,96,102,105-107

If a patient has had previous radiation treatment to the surgical site, the rate of wound complications can be as high as 40%.2,26,76,107 There are numerous potential complications that accompany an open thoracotomy including atelectasis, pulmonary contusion, pleural effusion, hemotorax, chylothorax, intercostal neuralgia or significant postoperative pain due to rib resection and chest wall retraction (post-thoracotomy syndrome). These complications affect at least 11% of patients.8,17,22,97,99 During an anterior or posterior thoracic approach, an incidental durotomy can cause a subarachnoid-pleural fistula. This rare complication is seen in 2.4% patients with anterior approach and 0.23% from a posterior approach. Eight out of nine patients required surgical repair of the fistula in one series.34

Traditional open posterior laminectomy, requires a subperiosteal dissection resulting in denervation and devascularization of the paraspinal muscles. This ultimately results in diminished postoperative axial muscle strength and performance.42,44-48,62,79,90,91,95,104 In the cervical spine, injury to the semispinalis capitis and cervicis muscles along with disruption of the bony and ligamentous components of the posterior tension band can result in a post-laminectomy kyphosis. This has been shown to negatively affect outcome.10,94 It can be seen in 10 to 40% of adults and 24 to 100% of pediatric patients undergoing posterior laminectomy and is most commonly seen after intradural tumor surgery.3,10,94

MINIMALLY INVASIVE TECHNIQUES

The aim of any minimally invasive intervention for the treatment of spinal neoplasms is to minimize the collateral damage to normal surrounding spinal anatomy.6,56,67,69 This should ultimately translate into shorter operative times, less blood loss, fewer complications, decreased postoperative pain, shorter hospital stays and decreased medical resource utilization.20,23,40,41 For this review, we have categorized them into percutaneous, noninvasive techniques and minimally invasive surgical techniques.

PERCUTANEOUS AND NONINVASIVE TECHNIQUES

Percutaneous radiofrequency ablation (RFA) is a minimally invasive option for the treatment of certain tumors of the vertebral column.6,13,30,80,85 Radiofrequency ablation is a CT or fluoroscopically guided method by which thermal energy is delivered to a target. Asteroid stomas have been treated successfully in this manner with success rates of 79 to 89%.83,100 Most of these lesions were treated with single fraction radiation with similar success rates.13,26,32,100 There have also been reports of its successful use in the treatment of metastatic disease of the spine.90 Given the use of thermal energy in RFA, it is limited by lesion size and proximity to neural structures.26 Most authors recommend that the target for treatment is no closer than 1 cm to a sensitive neural structure (i.e. theca sac, nerve root) and require the presence of a layer of cortical bone between the lesion and neural structures in order for patients to be considered for RFA.13,26,32,33 Although this treatment modality comes with significant limitations it offers an attractive treatment option, i.e. relatively simple, economically feasible and avoids the morbidity associated with traditional surgical resection.

Vertebroplasty and kyphoplasty are additional minimally invasive therapeutic options for the treatment of compression fractures due to vertebral column tumors. These techniques both involve the injection of acrylic cement into the vertebral body. Kyphoplasty is meant to provide a greater restoration of vertebral height than injection of cement alone by creating a cavity, prior to
injection of the cement. These are minimally invasive techniques meant to provide pain relief and improved stability of the vertebral body. Vertebroplasty and kyphoplasty are ideal options for patients with intractable pain, more extensive disease involving multiple vertebral bodies, patients with a poor prognosis and limited life span and patients that would not tolerate more invasive surgical options, such as en bloc resection and instrumentation.43 Both of these procedures have been widely used in multiple myeloma compression fractures.57 Improvement in Oswestry Disability Index (ODI) of 86% and partial restoration of vertebral height was achieved in the anterior and middle columns in 76 and 91% of levels treated, respectively.57 A randomized controlled trial of 300 patients published by Wardlaw et al in the Lancet in 2009 found that patients with vertebral compression fractures treated with balloon kyphoplasty had significant improvements in quality of life, function, mobility, and pain relief when compared to patients treated non-surgically.103 A more recent randomized controlled trial of 131 patients published by Kallmes et al in the New England Journal of Medicine in 2009 comparing vertebroplasty to a sham procedure for osteoporotic compression fractures disputes the aforementioned results.43

As with any invasive procedure, vertebroplasty and kyphoplasty carry their own potential complications. These include as follows:

- Leakage of cement and fracture of adjacent vertebral bodies. Cement may leak into one of several compartments including the disk space, paravertebral tissue, paravertebral venous plexus (potentially leading to a pulmonary embolism) or the epidural space (potentially compressing neural elements).75 Kyphoplasty appears to carry a negligible leak rate when compared to vertebroplasty.6 Adjacent level fracture is a greater concern in osteoporotic patients than patients with euplastic lesions and can be as high as 25%.25

Percutaneous techniques and non-invasive therapies have also been used in combination.27,30,33,39,70 Radiofrequency ablation has been used in conjunction with vertebroplasty through the same bone biopsy needle port for the palliative treatment of malignant bone lesions, particularly metastases.30,70 In one series, 19 spinal tumors were treated in this fashion with a 100% rate of significant decreases in VAS scores and post-procedural tumor necrosis seen in a mean of 71% of total tumor volumes.78 Neural injury was seen in four of these patients, in whom the tumor had violated the cortex of the posterior vertebral body or pedicle, emphasizing the need for intact cortex between RFA electrodes and neural structures.85 It has been theorized that RFA may reduce intravascular cement leakage during subsequent vertebroplasty via thrombosis of the intravertebral venous plexus.33 Combination therapy of kyphoplasty and spinal radiosurgery (SRS) for metastatic spinal lesions27 has been reported with 92% of patients who experienced pain relief, in the absence of cement leakage. To date, no such studies have been performed on primary spinal lesions.

The percutaneous injection of pharmacological agents, under CT or fluoroscopic guidance, has been used in the treatment of vertebral column tumors. Aneurysmal bone cysts have been injected under CT or fluoroscopic guidance with sclerosing agents or calcitonin and methylprednisolone to induce ossification in patients with pain but without neurological compression or spinal instability.16,31,78

**MINIMALLY INVASIVE SURGICAL TECHNIQUES**

A number of minimally invasive surgical approaches to the spine have been developed to minimize surgical morbidity. When adopting the following approaches for the treatment of primary spinal column tumors, the surgeon must carefully weigh the benefits of these techniques vs the risk of failing to achieve the defined surgical objectives. Insufficient exploration during a minimally invasive approach can lead to an incomplete and, therefore, noncurative resection, inadequate decompression of the neural elements and unsatisfactory stabilization.

Thoracoscopic surgery represents a major advance in minimizing the morbidity associated with resection of tumors of the thoracic spine.15,80,83 This technique involves placement of 3 to 4 ports through small incisions in the chest and placement of a rigid endoscope, allowing visualization of the anterior thoracic spine (T3–T12). Corpectomy and reconstruction is performed using specialized long instruments.40 The advantages of this approach over the traditional thoracotomy include decreased incisional pain, earlier ambulation, shorter hospital stays, decreased incidence of intercostals neuralgia, shoulder girdle dysfunction and post-thoracotomy syndrome.6,18,80,83 As with a traditional thoracotomy, this approach requires lung deflation and subsequent chest tube drainage, and hence the potential for postoperative pulmonary complications, and consequent prolonged hospital stay, remains. The rate of pulmonary complications has been reported to be 10 to 29%.15,37,63 Moreover, the surgical learning curve for thoracoscopic techniques and equipment costs can be prohibitive for some surgeons and centers.15,22,80,84

Endoscopic systems have also been applied to traditional surgical approaches with the objective of reducing incision size and tissue dissection while maintaining or enhancing visualization. Endoscopes have been used
in the ventral cervicothoracic and upper thoracic spine (C7–T3) while sparing the sternum, clavicle and ribs.50 This was performed through a 6 to 8 cm anterior incision and multiple ports through which the endoscope and specialized instruments were used to perform a corpectomy and reconstruction. The endoscope has also been utilized in performing a posterolateral thoracic corpectomy using a transpedicular or costotransversectomy approach.55,65,66 The angled endoscope allows for safe, complete ventral decompression and reconstruction under improved visualization when compared to traditional transpedicular or costotransversectomy approaches. This approach also spares the patient the morbidity of a lateral extracavitary (LEC) or transthoracic approach.

Several authors have described a mini-transthoracic or mini-retroperitoneal approach for thoracolumbar corpectomy.36,56,69 Six vertebral tumors out of 65 spinal tumors were removed in this manner.56 A 5 cm skin incision was used but otherwise were similar to traditional anterolateral techniques. In general, these approaches take advantage of specialized retractor systems that permit continued visualization through the constrained working space.56,69 These studies report modest improvements in blood loss, length of stay, complications, and operative times.36,56,69

Extreme or direct lateral minimally invasive approaches to the thoracic and lumbar spine have been developed to achieve interbody fusion. With the same approach current tubular retractor systems allow for enough exposure to perform corpectomy and stabilization from T4 to L4. These procedures still typically require separate positioning and incisions for posterior fixation and arthrodesis. A case of successful T6 corpectomy and T5 to T7 anterior fusion utilizing an extreme lateral minimally invasive approach for the management of a T6 metastatic lesion has been reported.49

Posterolateral approaches to the thoracic and lumbar spine in the prone position avoid the morbidity associated with a transthoracic or abdominal approach and allow for the placement of instrumentation without the need for repositioning.59,58,64,81 In 2007, a mini-open posterior approach for lumbar corpectomies was reported. This was done through bilateral 2 to 3 cm incisions extending from the superior aspect of the rostral disk space to the inferior aspect of the pedicle of the vertebral body of interest.61 Through this incision they performed a complete facetectomy, and discectomy of the superior disk space. The corpectomy was subsequently performed with the disk space serving as a space for extractions of bone fragments. This was done bilaterally. An underbody graft was placed within the superior disk space. Subsequently, percutaneous pedicle screws and rods were placed caudal and rostral to the vertebral body of interest. In their series, corpectomies were performed for the management of traumatic lumbar burst fractures with retropulsed bone. This can, however, be applied to certain euplastic conditions, particularly in patients that cannot tolerate a more invasive anterior approach. This technique is limited in its ability to assure complete ventral decompression of the theca sac as well as the ability to perform dorsal decompression if indicated. In 2008, a series of 8 patients with metastatic disease to the thoracic spine with acute neurologic compromise that underwent minimally invasive transpedicular vertebral without instrumentation. Five of eight (62.5%) patients improved at least 1 grade on the Nurick scale and had significant pain relief postoperatively. This method may be an attractive option for palliative treatment of malignant lesions of the thoracic spine.14

Percutaneous pedicle screw fixation alone is a palliative minimally invasive option for rigid fixation in the treatment of spinal instability. Many patients with vertebral column tumors will require fusion in conjunction with other therapeutic options, such as vertebroplasty/kypophoplasty or RFA. This can be done with or without stereotactic image-guidance.1,20 This technique is ideal for patients with spinal instability and limited life-expectancy or poor candidates for open surgical fusion.

Our group recently studied the feasibility of minimally invasive posterolateral thoracic corpectomies in cadavers beginning 3, 6 and 9 cm lateral to the midline72 (Fig. 1). We studied the extent of bony removal and degree of ventral decompression. The specimens were placed in the prone position. A 3.5 cm longitudinal skin incision was made at varying distances off of the midline. Dilators were used to spread the fibers of the alissimo dora and serratus anterior muscles until the rib was in view. The rib was dissected in the typical subperiosteal...
fashion, followed as far medially as possible, stripped of the intercostals neurovascular bundle and underlying pleura and respected. A tubular retractor was then placed at the medial extent of our dissection and the rib was dissected medially to the transverse process (TP), which was then drilled away. The pedicle was removed exposing the lateral dural and exiting nerve roots. The vertebral body was then dissected and the segmental vessels and sympathetic chain ligated. Using a drill, rongeurs and curettes the vertebral body was removed as far medially as could be performed safely. The endplates were then prepared and an appropriate underbody strut was inserted. Using post-procedure fine cut CT scans the average percentage of corpectomy was found to be 81.5% and the extent of ventral decompression was 92% (Fig. 2). We found an approach 6 cm off midline to be ideal for proper exposure and vertebral body resection. Lateral

**Figs 3A to D:** A 59-year-old man presented with chronically progressive myelopathy from thoracic plasmacytoma despite radiation therapy. (A) Sagittal T2-weighted MRI reveals plasmacytoma of the T4 and T5 vertebral bodies with collapse and epidural spinal cord compression. (B) Sagittal reconstruction of the CT scan of the same patient demonstrates replacement of the T4 and T5 bodies with tumor, (C) anteroposterior radiograph of same patient after a right-sided minimal access LEC corpectomy of T4 and T5. The defect was reconstructed using an expandable titanium cage and ipsilateral vertebral body and pedicle screws with rod fixation and (D) postoperative axial CT images show the extent of bone removal from a right-sided approach, with satisfactory placement of the autograft-filled intervertebral cage. The rods connecting the screws are seen on the right side of the defect, and a surgical drain is seen overlying the laminectomy site (A: anterior; R: right)
vertebral body screws can be placed if additional anterior fixation is desired. Alternatively, posterior instrumentation can be inserted at the same setting through the same incision ipsilaterally and percutaneously on the contralateral side. A gentleman with T4 to T5 plasmacytoma was managed using this surgical technique with adequate decompression and reconstruction (Figs 3A to D). We also recently described several other cases of patients operated upon using this technique.52

Finally, in 2009, a thoracolumbar neurofibroma was successfully removed using a transdiaphragmatic robotic assisted laparoscopic approach utilizing the da Vinci robot (Intuitive Surgical, Sunnyvale, CA). Minimally invasive retroperitoneal laparoscopic access was obtained, the urologic surgeons opened the diaphragm and the robot was docked. The neurosurgeon then operated the robot and excised the neurofibroma from its nerve origin. The mass was completely resected without complications.68 The use of robotics in spine surgery is not commonplace but represents yet another potential therapeutic application that warrants consideration.

RECOMMENDATIONS

Based on the assessment of the literature and our own experience, several conclusion and recommendations can be made. The most important of all is achieving the goals of treatments that are laid out in the paper. Treatment should be tailored to each individual patient's general condition, preoperative comorbidity, prognosis of the tumor if pathology known, surgeons and patient preference and availability of resources and technology. No specific treatment modality can be recommended unless these issues are considered. The available techniques based on the clinical goal of treatment related to pain or palliative control, neurological compromise, stability or curative treatment is summarized in Flow Chart 1.

CONCLUSION

Minimally invasive techniques for the removal of spinal column tumors are continuing to evolve. Many of these approaches compare favorably with the more traditional operations in their ability to achieve adequate neural decompression and recovery of function.1,6,12,13,15,20,23,24,36,66,69,71,89,93 The surgeon must carefully weigh the benefits of reducing operative morbidity vs the risks of failing to achieve surgical objectives, notably curative resection. The application of these techniques is of particular use for the palliative care of the medically compromised patient who would otherwise not tolerate a more traditional surgical approach. Further advances in retractor systems, surgical instrumentation, targeted chemotherapeutic delivery systems and osteobiologic agents hold great promise as we continuously strive to improve the quality of life of patients with neoplastic disease.

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