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Minimally Invasive Approaches to Vertebral Column and Spinal Cord Tumors

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Advances in diagnostic imaging and systemic therapies for oncologic disease have brought ever greater numbers of spinal tumors to surgical attention. Further advances in surgical and microsurgical techniques have made resection of tumors from all compartments of the spine and spinal cord increasingly safer and more efficacious. Continuing efforts at minimizing surgical morbidity and making at least palliative therapies available to even the most medically compromised patient with a tumor have led to the development of a wide array of minimally invasive techniques to treat tumors and space-occupying lesions throughout the spine. This article reviews the types of lesions that are amenable to minimally invasive approaches and the various modalities currently available to treat them.

Epidemiology

Of all spinal tumors, 50% to 55% are extradural, 35% to 40% are intradural-extramedullary (IDEM), and 5% to 10% are intramedullary [1,2]. The following section outlines the epidemiology of neoplastic lesions within each compartment.

Extradural tumors

Spinal column tumors

In the United States, at least 90% of spinal column tumors are metastases, and 30% to 70% of patients with cancer have evidence of vertebral disease [3–6]. Approximately 5% to 20% of patients with cancer and vertebral metastases develop neurologic deficit or spinal instability, equating to approximately 18,000 to 25,000 cases annually [3–5,7–9]. Multilevel involvement is seen in up to a third of cases [3,10]. Breast, lung, and prostate carcinomas are responsible for more than half of the spinal metastases seen each year [3,10–12].

Primary tumors of the vertebral column, conversely, are quite rare compared with metastatic lesions of the spine [5,13–19]. Benign lesions include osteoid osteoma, osteoblastoma, osteochondroma, aneurysmal bone cyst, eosinophilic granuloma, and cavernous hemangioma. Malignant or locally aggressive lesions include giant cell tumor, plasma cell tumors, lymphoma, osteosarcoma, chondrosarcoma, chordomas, and Ewing's sarcoma.

Intradural tumors

Intradural-extramedullary tumors

The annual incidence of intradural tumors is approximately 1 in 10,000 [20]. Extramedullary tumors comprise approximately 66% to 75% of these intradural tumors in adults [2,12,21], whereas their prevalence is nearly equal to that of intramedullary tumors in children [22].

Approximately 25% of all intradural spinal tumors and 40% of IDEM tumors derive from the nerve sheath [1,23] and are schwannomas or neurofibromas. Most form from dorsal rootlets [12],

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but they may arise from ventral rootlets in up to 23% of cases [24]. Approximately 1% of nerve sheath tumors present as a purely intramedullary mass, and even more rarely, they may form in a midline ventral position, deriving perhaps from Schwann cells of the nervi vasorum of the anterior spinal vasculature [25].

The second most common IDEM tumor type is spinal meningioma. These typically affect the thoracic segments in women in the latter half of life and comprise approximately 35% of IDEM tumors [1,12,23]. Filum terminale ependymomas make up 40% of all intradural spinal ependymomas and approximately 15% of IDEM neoplasms [26]. The remaining 10% of IDEM lesions include sarcomas, dermoids or epidermoids, germ cell tumors (primary and drop metastases), and, rarely, solid organ metastases [1,12,23].

Intramedullary tumors

Intramedullary neoplasms account for approximately one quarter of all intradural tumors [1,12,23,26,27]. Intramedullary astrocytomas are slightly less common (40%) than ependymomas (45%) in adults but comprise 60% to 90% of intramedullary tumors in the pediatric population [1,28]. The remaining intramedullary lesions include hemangioblastoma (5%), metastatic tumors, and other rare lesions [12,27,29].

Evaluation of the patient with a spinal tumor

The evaluation of the patient with a known or suspected spinal tumor begins with a thorough history and physical examination. Patients with vertebral column tumors most frequently present with back pain but may also manifest spinal deformity, neurologic symptoms, and systemic symptoms related to malignancy [5]. Patients with intradural tumors less often have radicular or back pain but may present with neurologic deficit from spinal cord or root compromise.

The radiologic evaluation of the patient with a spinal tumor includes MRI for nearly all lesions. CT is particularly helpful for spinal column tumors in assessing the degree of vertebral bone destruction and osteopenia as well as for surgical planning. CT myelography may be useful in patients who are unable to undergo MRI. Plain and dynamic radiographs should also be obtained to assess deformity and instability. Radioisotope bone scanning is highly sensitive for spinal column tumors that demonstrate osteolytic or osteoblastic activity and is most frequently used when searching for small lesions, such as osteoid osteoma, or for metastases in patients with known malignancy [5,30]. Finally, angiography delineates the vascular supply of a tumor and may also be used to perform embolization to reduce intraoperative blood loss from hypervascular lesions, such as an aneurysmal bone cyst, hemangioma, renal cell carcinoma, melanoma, or chordoma [5,31–33].

Principles of treatment

The realistic objectives of the surgical treatment for any spinal tumor must be clearly defined. In some cases, diagnosis may be the primary goal. For many extradural tumors, this can be accomplished by CT-guided biopsy, with 71% to 96.5% diagnostic accuracy [11]. Intramedullary spinal cord tumors, however, require open exploration to obtain a biopsy safely for diagnostic certainty.

For most IDEM tumors and a number of primary spinal column tumors, lasting cure is the goal of surgery, and 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 [13–19,34]. The surgical approach must be tailored to meet this marginal goal.

Conversely, for most metastatic lesions, symptomatic relief and palliation are the most common goals of surgical intervention; therefore, the effects of any selected treatment on the patient's quality of life must be carefully considered [3,5,12,35–37]. In fact, for carefully selected patients with spinal metastases, surgical intervention may offer the best chance of improved quality of life [38,39]. In 2005, Klimo and colleagues [40] analyzed the available literature on neurologic function after treatment for metastatic epidural cord compression and found that stabilization or improvement of ambulation was seen in 85% of patients who underwent surgery versus 64% of patients who received radiation. Patchell and coworkers [7] reported a prospective trial in 2005 in which patients with metastatic epidural cord compression were randomized to surgical circumferential decompression followed by radiation or to radiation alone. Of note, these patients were generally high functioning and had a life expectancy of at least 3 months. Posttreatment ambulatory rates were 84% in the surgery group and 57% in the radiation group, and median time to loss of ambulation was longer in the surgical group (122 versus 13 days). For patients who were nonambulatory at study entry, 62% in the surgical group and only 19% in the radiation group regained the ability to walk. Spinal cord function as measured by the Frankel scale, American Spinal Injury Association score, and urinary continence all showed more improvement in the surgical group compared with the radiation group. These results are compelling and demonstrate a primary role for surgical decompression in certain patients with metastatic epidural spinal cord compression [7,38,40].

In addition to the goals of (1) diagnosis, (2) tumor removal for local control or cure, (3) circumferential spinal cord decompression, and (4) symptomatic pain relief, any approach to spinal tumors must take into account the stability of the spinal segments involved. Where indicated, treatment options should incorporate arthrodesis, deformity correction, and fixation for levels that have been destabilized by the tumor or by the treatment itself [3,5,25,36,37,41].

Complications of traditional approaches

The motivation to develop minimally invasive strategies to treat spinal tumors is driven by the significant complication rates associated with established surgical approaches to neoplastic spinal disease.

Traditional circumferential open decompressive operations for spinal metastases can carry up to a 30% complication rate, including neurologic deterioration, severe medical complications, massive hemorrhage, wound infections and dehiscence, hardware complications, cerebrospinal fluid (CSF) leaks, and death [3,6,9,35–39,42–49]. Wound complications after open surgery can affect up to 40% of patients who have been irradiated previously [6,7,50]. At least 11% of patients undergoing open thoracotomy experience one of a number of approach-related complications, such as atelectasis, pulmonary contusion, pleural effusion, hemothorax, chylothorax, intercostal neuralgia, or significant postoperative pain from rib resection and chest wall retraction (postthoracotomy syndrome) [42,51–54]. If unintended durotomies occur during thoracic corpectomy or when intradural tumors are removed from an anterior or posterolateral approach, a subarachnoid-pleural fistula may uncommonly develop. Hentschel and coworkers [45] reported nine patients with this troublesome complication after resection of thoracic tumors, the largest series to date. They reported a 2.4% incidence of this complication after anterior approaches but only a 0.23% incidence after posterior approaches. Interestingly, eight of the nine patients had completely extradural tumors, but eight of nine cases were reoperations and the tumors had been irradiated previously. As expected, eight of nine leaks developed after anterior approaches, and eight of nine patients required operative repair of the fistula, with four needing a vascularized muscle flap to seal the leak. Two of the patients manifested pneumocephalus, a complication indicating both subarachnoid-pleural and bronchopleural fistulae [45].

Typical open posterior laminectomy approaches also have significant drawbacks. First, subperiosteal dissection is required; therefore, denervation and devascularization of the paraspinal musculature ensue. This iatrogenic injury has been shown to lead to significant diminishment in postoperative axial muscle strength and performance [55–66]. Second, in addition to sacrificing the bony and ligamentous portions of the posterior tension band, open laminectomy in the cervical spine injures the semispinalis capitis and cervicis muscles, which are thought to provide the primary force for maintained extension of the head and cervical spine [67]. These untoward effects can produce iatrogenic sagittal plane destabilization that may lead to a progressive spinal deformity, most frequently seen in the cervical spine [67,68]. Also known as postlaminectomy kyphosis, such deformity may occur in up to 10% to 40% of adults and 24% to 100% of children after laminectomy and is most common after intradural tumor surgery [67–71]. Such deformity has been shown to affect outcomes negatively [67,70,71].

Finally, wound dehiscence and CSF leaks are the most common complications after IDEM tumor surgery [1]. Persistent CSF leak after IDEM tumor resection can even lead to intracranial hypotension and the development of an infratentorial or supratentorial intracerebral or subdural hematoma [72].

Minimally invasive techniques

The factors that influence the decision to use minimally invasive techniques in the treatment of spinal tumors are the same as those affecting the decision to initiate surgical therapy in the first place, namely, life expectancy; health status of the patient; tumor type, location, and extent; symptomatology; prior therapies; and spinal stability [3,5,11,37,73]. The indications for intervention are as mentioned previously, intractable pain, neurologic deficit, spinal deformity, need for diagnosis, and tumor cure or control.

The surgeon must critically appraise the impact that any given treatment is likely to have on postoperative function [73] for benign lesions in young active patients as well as for metastatic tumors in debilitated patients with limited life spans. To that end, the primary objective of minimally invasive surgery is to reduce approach-related injury to normal spinal anatomy around the lesion of interest [1,2,11,68,73–75]. Ultimately, this should translate into shorter operative times, reduced blood loss, shorter hospital stays, fewer complications, less postoperative pain, reduced medication use, decreased medical resource use, and faster recovery times [2,76–79].

Approaches based on compartment

Extradural (spinal column)

Percutaneous and noninvasive techniques

Percutaneous radiofrequency ablation (RFA) is a fluoroscopic or CT-guided technique for accurate delivery of destructive thermal energy that has been applied to tumors in the vertebral column [11,80–82]. To avoid the iatrogenic injury associated with open en bloc resection, percutaneous RFA has been safely and effectively used to treat osteoid osteomas. As described by Rosenthal and colleagues [82], RFA was performed on osteoid osteomas in 263 patients in the appendicular skeleton and spine, with an overall 89% pain relief success rate and with two major and two minor complications. Smaller series of patients with strictly spinal osteoid osteomas treated with RFA have reported similar success rates with few or no complications [80,83,84]. In 2002, Gronemeyer and coworkers [81] presented a series of 10 patients with metastatic tumors of the spine that underwent RFA using a larger electrode array than that used for smaller osteoid osteomas. They reported a 90% rate of pain relief, no complications, and arrest of tumor growth in all cases on follow-up MRI. RFA is currently limited by lesion size and proximity to neural elements [83]. To prevent thermal injury to these sensitive structures, most authors recommend that RFA be performed only if the lesion is no closer than 1 cm to the thecal sac or closest nerve root and that a layer of cortical bone be interposed between the tumor and the neural structures [80,83–85].

For radiosensitive tumors of the vertebral column, standard external beam radiotherapy (EBRT) of 25 to 40 Gy delivered over many sessions successfully provides pain relief in 66% to 80% of cases [4,5,85–87]. However, the effects of radiation may be delayed by weeks, are usually not definitive in the unstable spine, and are not useful for radioresistant tumors (eg, melanoma) [11,85,86,88]. Moreover, the sensitivity of surrounding structures to radiation-induced injury (eg, spinal cord, esophagus, small bowel) precludes repetitive EBRT for recurrent disease [89]. Stereotactic radiosurgery (SRS), conversely, focuses high doses of radiation on a neoplasm under frameless image guidance in a single stage or hypofractionated stages with minimal exposure to surrounding tissues [4,88,90–92]. Current systems, including the Novalis (BrainLab, Heimstetten, Germany) and the robotic Cyberknife (Accuray, Sunnyvale, California), register preoperative imaging (MRI and CT) to intraoperative radiographs using internal skeletal anatomy, surface markers, or implanted fiducial markers [88,90]. Patients are typically immobilized in a temporary body cast apparatus, and real-time corrections can be made for patient movements during the treatment, producing a treatment accuracy of approximately 1 mm [88,91]. Single-fraction treatment doses range from 8 to 25 Gy [3,88,90,93]. The highest treatment doses have been found to cause transient radiculitis and parotitis [88,90]. The success rates for pain relief and neurologic stabilization or improvement range from 90% to 94% and from 63% to 89%, respectively [88,90]. SRS has been recommended for the treatment of patients who cannot tolerate surgery; for previously irradiated tumors; or as adjunct to other methods, including surgery [92]. Currently, precise dosing protocols for various types of lesions and long-term studies on toxicity are still lacking. Moreover, it remains to be seen from future prospective comparative studies how clinical outcomes and complications from SRS stand up against surgery, conventional radiation, and other combinations of modalities as discussed below.

Another minimally invasive option for the palliation of vertebral column tumors is vertebroplasty or kyphoplasty. The details of these procedures are discussed elsewhere in this issue but are briefly reviewed here with respect to their use in tumor treatment. Vertebroplasty involves the percutaneous injection of acrylic-based cement directly into a vertebral body and was originally used for the treatment of vertebral hemangiomas [94]. Kyphoplasty similarly uses percutaneous techniques under fluoroscopic guidance to inject acrylic cement but only after a balloon has been inflated within the diseased vertebral body in an attempt to restore body height and create a cavity for the cement. The intent of these procedures is to provide immediate lasting pain relief and some degree of stabilization to the affected vertebral segment. These techniques are ideal in patients who have intractable pain, multiple levels of disease, or a limited life expectancy (less than 3–6 months) or in patients who cannot otherwise tolerate other surgical interventions [3,11,95].

In 2003, Fourney and colleagues [95] presented the results of 97 vertebroplasty or kyphoplasty procedures on 56 patients with painful vertebral compression fractures from metastatic disease. Eighty-four percent demonstrated marked or complete pain relief that was durable up to at least the mean 4.5-month follow-up interval. Lane and coworkers [96] prospectively reviewed the use of kyphoplasty for painful pathologic compression fractures in 19 patients with multiple myeloma. Although the follow-up end point was short (3 months), 16 of the 19 patients demonstrated meaningful improvements in the their Oswestry Disability Index (ODI) scores, and partial restoration of body height was achieved in the anterior and middle columns in 76% and 91% of levels treated, respectively. These investigators compared their results with those of a historical control cohort of patients treated with kyphoplasty for osteoporotic compression fractures and found no significant differences in symptomatic (ODI) improvements. Two major concerns arise in the use of vertebroplasty or kyphoplasty: cement leakage and adjacent level fracture. During injection, cement may leak into the disc space, paravertebral tissues, epidural space (possibly causing neural compression), or paravertebral venous plexus (possibly causing pulmonary embolism) [86]. It seems that kyphoplasty has a negligible leak rate compared with vertebroplasty [11]. Adjacent level fracture may be of greater concern in the osteoporotic population than in the patients with neoplasia and shorter life spans.

Perhaps the most novel and intriguing use of these percutaneous and noninvasive therapies is in their combination [81,85,86,93,97]. RFA has been used in conjunction with vertebroplasty through the same bone biopsy needle port for the palliative treatment of malignant bone lesions, particularly metastases [85,97]. Nakatsuka and colleagues [97] reported on 19 spinal tumors treated in such a fashion, with a 100% rate of significant decreases in visual analog scale (VAS) scores and postprocedural tumor necrosis seen in a mean of 71% of total tumor volumes. Neural injury was seen in 4 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 [97]. It has been theorized that RFA may reduce intravascular cement leakage during subsequent vertebroplasty via thrombosis of the intravertebral venous plexus [85]. In 2005, Gerzsten and coworkers [93] reported on the combination therapy of kyphoplasty and SRS for metastatic spinal lesions. Twenty-six patients underwent kyphoplasty followed by SRS after a mean of 12 days. Ninety-two percent of patients experienced pain relief, and no cement leaks occurred.

Percutaneous injections of pharmacologic agent have also been used in the treatment of vertebral column lesions. 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 neurologic compression or spinal instability [98,99]. Duncan and colleagues [100] similarly described the percutaneous direct injection of a cervical angiosarcoma metastasis with bleomycin as a purely palliative measure. In the latter case, the treatment-resistant tumor shrank sufficiently in size to allow some neurologic recovery over the remaining short life span of the patient.

Varga and coworkers [101] have described a narrow tubular guide sleeve system for image-guided percutaneous biopsy or evacuation of spinal column tumors. Primarily applied to the sacrum, the system makes use of a percutaneous automated discectomy vacuum system to remove tumor once the guide sleeve is docked in the bone. This system requires implantation of fiducial markers and attachment of a reference array to the patient's spine. The indications clearly are for cases in which the diagnosis of the lesion is unknown, and the goal of intervention is palliative relief of low back pain attributable to sacral metastases in patients not suitable for surgery [101].

Finally, percutaneous pedicle screw fixation presents another potentially attractive tool in the palliative treatment of painful and unstable vertebral body tumors. With [102] or without [77] stereotactic image guidance, systems like the Sextant (Medtronic Sofamor-Danek, Memphis, Tennessee) allow pedicle screws to be placed at up to three vertebral bodies and then joined by a rod via percutaneous stab-type incisions. For patients with painful instability and limited life expectancy or an inability to tolerate larger open surgery, such fixation could be performed in conjunction with RFA or vertebroplasty or kyphoplasty. This type of approach may confer immediate pain relief partnered with rigid fixation to prevent progressive spinal deformity [103].

Surgical techniques. Thoracoscopic surgery represents a major advance in minimizing approach-related morbidity in the treatment of spinal tumors [104–106]. The general technique is discussed elsewhere in this issue; however, essentially, three to four ports placed via small incisions in the chest wall allow visualization of the ventral thoracic spine from T3 to T12 using a rigid endoscope and specialized long instruments to perform a corpectomy and reconstruction [78]. The advantages of this technique include less incisional pain, earlier ambulation, and shorter hospital stays as well as decreased incidences of intercostal neuralgia, shoulder girdle dysfunction, pulmonary complications, and the postthoracotomy syndrome [11,43,105,106]. Nevertheless, obligatory intraoperative lung deflation and postoperative chest tube drainage carry risks of postoperative pulmonary complications in 10% to 29% of patients and may prolong the length of hospitalization [47,104,107]. Moreover, the surgical learning curve for thoracoscopic techniques and equipment costs can be prohibitive for some surgeons and centers [11,104,105,108].

Endoscopes have also been used to perform open operations less invasively while still ensuring complete decompression [107]. LeHuec and colleagues [109] described a "mini-open" retrosternal approach to the upper thoracic spine (C7–T3) in two patients through a 6- to 8-cm anterior incision that does not require manubrial, clavicular, or costal resection. Endoscopic ports and instruments are inserted around these bony obstacles to visualize and perform the corpectomy and reconstruction in this region, which can be anatomically difficult to access. The structures most at risk in this approach are the recurrent laryngeal nerve and the thoracic duct. Indeed, one of the two patients in this study experienced a temporary recurrent laryngeal nerve injury [109].

Another use of the endoscope, endoscope-assisted posterolateral thoracic corpectomy, permits access via a transpedicular or costotransversectomy approach instead of a potentially more morbid lateral extracavitary (LEC) or thoracotomy approach [3,110,111]. The angled endoscope within the corpectomy defect provides light, magnification, and visualization for safe completion of ventral dural decompression and vertebral reconstruction that may have to be done blindly during typical transpedicular or costotransversectomy approaches.

A number of authors have sought to minimize approach-related injury for thoracolumbar corpectomy through the use of mini-thoracotomy or mini-retroperitoneal approaches [74,75,112]. In some cases, these have been supplemented with thoracoscopic and laparoscopic techniques [74,79]. In 2001, Kossman and colleagues [74] and Huang and coworkers [112] reported their experiences with these mini-open techniques on heterogeneous groups of 65 and 25 patients, respectively, including six and two vertebral tumors, respectively. Their "minimal access" approaches were performed through an approximately 5-cm skin incision but were otherwise similar to traditional anterolateral techniques. In general, these approaches take advantage of specialized retractor systems that permit continued visualization through the constrained working space [74,75]. The authors of these studies report modest improvements in blood loss, length of stay, complications, and operative times [74,75,112]. These procedures still typically require separate positioning and incisions for posterior fixation and arthrodesis.

In 2004, Maciejczak and colleagues [113] reported a mini-open purely posterior approach for lumbar corpectomy and fixation that involves four 2- to 3-cm paraspinal incisions made over the pedicles above and below the body of interest. Through these incisions, they performed a transpedicular "keyhole" corpectomy and instrumented the pedicles of the adjoining bodies. This technique is limited in its ability to ensure complete ventral decompression of the thecal sac as well as the ability to perform dorsal decompression if indicated.

Our group recently presented a technique for minimally invasive posterolateral thoracic corpectomy and reconstruction in a cadaveric and clinical case study [76]. The approach is a modification of the LEC approach [114,115] and can be used at any level of the thoracic spine [41]. Posterolateral approaches have the advantage of avoiding injury to structures within the thoracic and abdominal compartments and allow posterior fixation to be performed in the same positioning as the ventral decompression and reconstruction. Nevertheless, tissue dissection and blood loss can be substantial during LEC cases [116]. Therefore, we applied current minimal access technologies to six cadaver specimens and two clinical cases to perform thoracic corpectomy. The Quadrant (Medtronic Sofamor-Danek) 22-mm tubular retractor system (Fig. 1) is used to gain access to the thoracic spine from a posterolateral position. Specifically, a 4- to 5-cm incision is made approximately 6 cm off the midline over the appropriate spinal level. Under fluoroscopic guidance, a series of tubular dilators is placed through the paraspinal musculature and the Quadrant retractor is docked on the lateral transverse process. The retractor is expanded in a longitudinal direction, and the ends of the tubular blades may be angled outward to expand the field further at the depth of the retractor. Additional retractor blades may be added to allow for retraction of soft tissues in a medial and lateral direction. The operation then proceeds, as with open posterolateral approaches, to the thoracic spine. Briefly, 4 to 6 cm of the proximal ribs at the affected and immediately caudal level are resected after careful subperiosteal stripping of the intercostal neurovascular bundle and underlying pleura. The transverse processes, facets, and pedicles are removed, and the neural foramen is identified by following the thoracic nerve back to its origin. The intercostal nerves are ligated with long sutures that are used later for gentle retraction. The remaining ipsilateral posterior elements (lamina and undersurface of spinous process) are removed with rongeurs and high-speed drill, exposing the thecal sac. Subperiosteal dissection along the lateral aspect of the vertebral bodies allows identification of the segmental vessels and sympathetic chain, both of which are ligated. The intervertebral discs above and below the affected body are also identified in this manner. After complete removal of the relevant discs, the corpectomy and tumor removal are performed using rongeurs, curettes, and a drill (Fig. 2). The end plates of the adjacent bodies are prepared, and an appropriate interbody strut (eg, structural allograft, expandable cage, titanium mesh, methacrylate) is inserted. Lateral vertebral body screws may also be placed through this approach to provide supplemental anterior fixation. Finally, if posterior fixation is also required, pedicle screws may be inserted under direct vision ipsilaterally and with a new incision and dilation contralaterally, or they may be inserted using percutaneous techniques, such as with the Sextant pedicle screw system. If the pleura is intact, no chest tube is required. Patients may be mobilized immediately. Of note, a double-lumen endotracheal tube is not required for this technique.

In the six cadavers studied, six one-level and one two-level corpectomies were performed and post-procedural fine-cut CT scans were obtained. These images revealed a mean removal of 93% of the ventral spinal canal and a mean corpectomy volume of 80% of the original body. There were no dural or pleural violations in any of the cadaver cases. Two clinical cases were performed in this manner for a T6 burst fracture and a T4 and T5 plasmacytoma (Fig. 3), with satisfactory decompression and reconstruction in both cases [76].

Intradural (extramedullary and intramedullary)

Percutaneous and noninvasive techniques

Percutaneous procedures for intradural pathologic processes are currently limited. IDEM arachnoid cysts have been drained and fenestrated

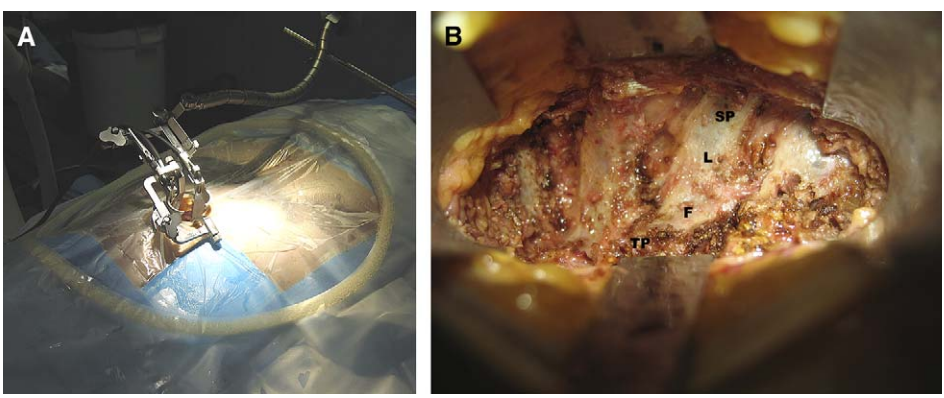

Fig. 1. (*A*) Photograph demonstrates the Quadrant (Medtronic Sofamor-Danek, Memphis, Tennessee) retractor in position to perform a minimal access LEC thoracic corpectomy in a prone cadaver from a left-sided approach. (*B*) View through the retractor after expansion demonstrates multilevel exposure of the posterolateral elements of the thoracic spine. Left is rostral, and the top is medial. F, facet; L, lamina; SP, spinous process; TP, transverse process.

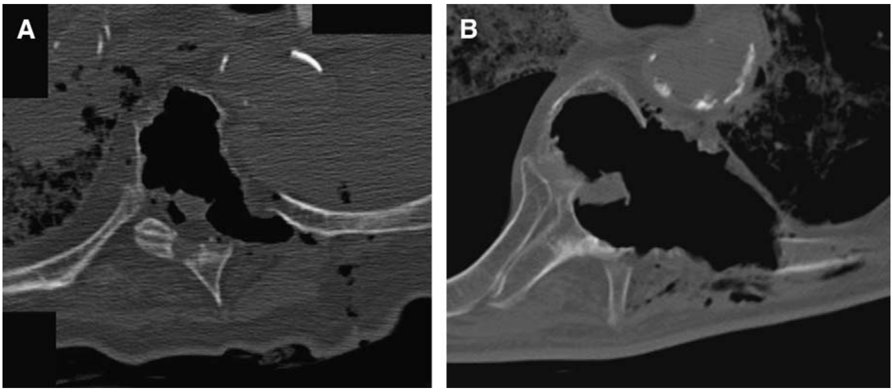

Fig. 2. Postprocedural axial CT scans after a minimal access LEC thoracic corpectomy in a cadaver model demonstrate satisfactory spinal canal decompression and vertebral body resection from 6-cm (*A*) and 9-cm (*B*) starting points off of the midline. Note the longer rib resection required with the 9-cm approach.

percutaneously under intraoperative MRI guidance in the ventral cervical and dorsal thoracic spine [117,118]. The use of such a technique in tumor cysts would be purely palliative in nature.

SRS has also been used in the treatment of intradural tumors [88,90,91]. SRS typically has been used to treat IDEM nerve sheath tumors and meningiomas but has also been applied to some hemangioblastomas, paragangliomas, and hemangiopericytomas [88,90,91]. In 75% to 100% of benign IDEM tumors, growth arrest or a decrease in tumor size has been seen on follow-up imaging after SRS [88,90]. In 2005, Bhatnagar and colleagues [91] reported 59 cases of benign extracranial tumors, 45 of which were spinal, treated by SRS with the Cyberknife. The median treatment time was 59 minutes. Tumor doses (80% isodose line) ranged from 9 to 31 Gy, with a median of 16 Gy. Symptomatic improvement was seen in 78% of patients, and the local control rate with a median follow-up of 8 months was 96%. No toxicity from the treatments was observed. Interestingly, 42% of the lesions had undergone prior surgery, and 20% had received prior EBRT [91]. Although these types of studies show promise for this modality in the treatment of benign intradural tumors, dosing has yet to be defined, the follow-up periods are far too short for lesions with benign histology, and comparative studies are lacking. For the time being, SRS of benign intradural tumors should likely be reserved for those patients who are unable to undergo more definitive surgical treatment or for whom other treatments have failed [88]. SRS may be of particular benefit in patients with phakomatoses and multiple tumors, such as neurofibromatosis and von Hippel-Lindau disease.

Surgical techniques. In an effort to reduce the morbidity associated with the resection of ventrolateral cervical IDEM tumors, Jho and Ha [119] described anterior cervical IDEM tumor removal through a flask-shaped bony opening in the lateral aspect of the spine in two patients. Through a standard 3- to 5-cm anterior cervical incision and soft tissue approach, a portion of the longus colli overlying the affected level is excised unilaterally and the uncovertebral joint is resected. The lateral portion of the uncinate process must be dissected away from the vertebral artery. A partial lateral corpectomy of the vertebral bodies above and below the involved level is performed, which is widest at the depth of the defect and narrowest at the surface of the spine. The posterior longitudinal ligament is removed, and a curvilinear durotomy is performed to allow tumor removal. Dural closure is challenging and requires 7-0 or 8-0 suture. The authors were able to completely resect two ventrolateral tumors (meningioma and neurofibroma) without complication. Neither patient underwent fusion or external bracing. The authors claim no instability was present after surgery, but no objective evidence (ie, delayed dynamic radiographs) was presented to confirm this. The extent of bone resection in this procedure is concerning for delayed instability, and until long-term follow-up data are presented on a larger number of patients, this technique should be used cautiously and likely only by those with experience in performing anterior cervical microforaminotomies [119].

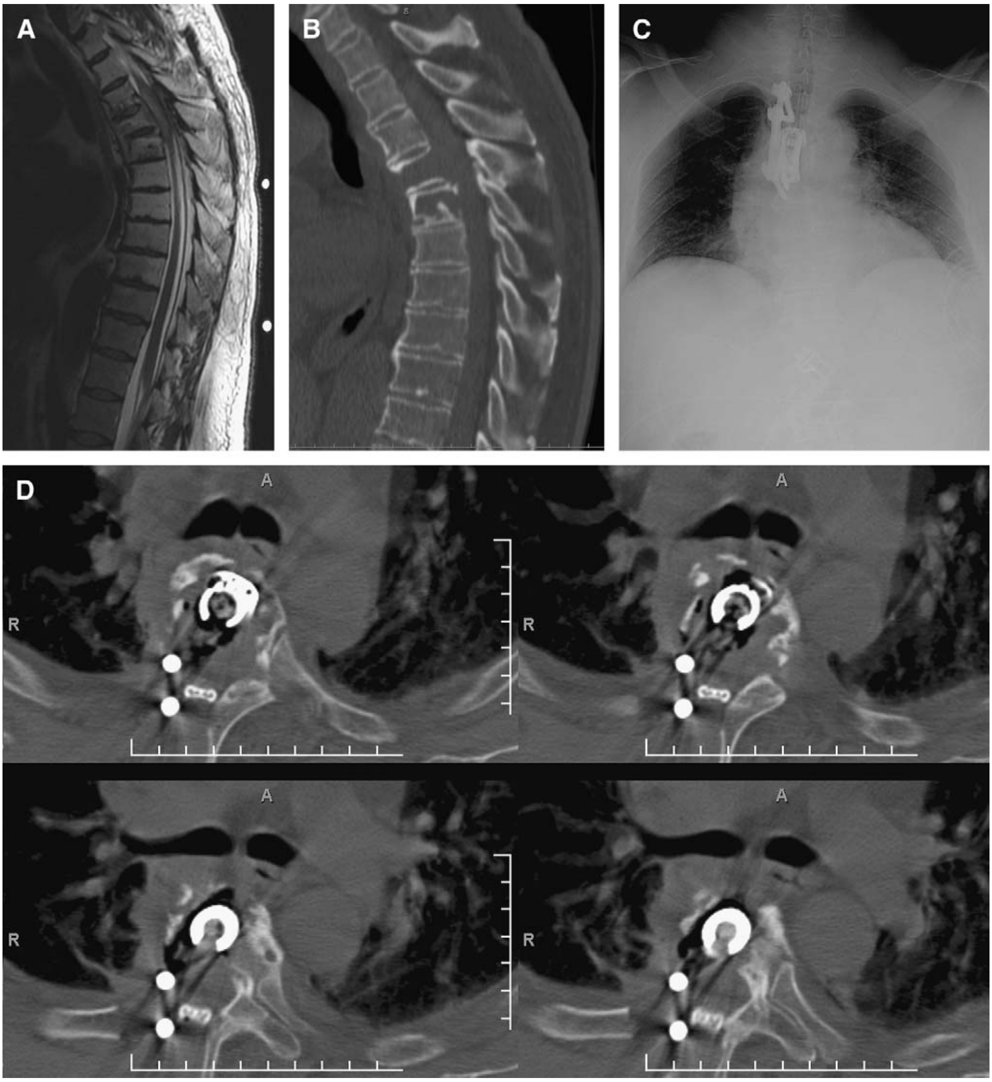

Fig. 3. A 59-year-old man presented with chronically progressive myelopathy from thoracic plasmacytoma despite radiation therapy. (*A*) Sagittal T2-weighted MRI reveals plasmacytoma of the T4 and T5 vertebral bodies with collapse and epidural spinal cord compression. (*B*) Sagittal reconstruction of 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. (*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.

In the decompressive treatment of cervical spondylotic disease, laminoplasty represents an attempt at maintaining cervical motion and the posterior tension band. In an effort to apply this to patients with tumors, Casha and coworkers [70] reported a series of 28 subjects treated with "suspended" laminoplasty, in which the laminae are divided from the lateral masses bilaterally over a variable number of levels and the intervening ligaments connecting the removed laminae are left intact. This osteoplastic construct was then reattached bilaterally using titanium mini-plates without a bone graft. Nine of their 28 patients harbored intradural lesions: eight intramedullary lesions and one IDEM lesion. All lesions were successfully resected, and the laminoplasty constructs were placed without difficulty. In this technique, however, the posterior tension band is still deficient where it is sectioned at the most rostral and caudal extents of the laminoplasty. Casha and coworkers [70] reported that of the 8 patients with intramedullary tumors, 1 went on to develop a kyphotic deformity after surgery and 1 developed straightening of the cervical spine from preoperative lordosis. The 11% incidence of kyphosis and overall 25% incidence of worsening of cervical alignment represent a possible improvement over traditional laminectomy rates, but comparative studies are not yet available.

Unilateral posterior approaches to the spinal canal represent an attempt to preserve at least portions of the posterior tension band and musculature [21,68,120–124]. A unilateral laminectomy allows access to dorsal and lateral tumors, and with the addition of a partial facetectomy, access to ventrolateral tumors [1]. A unilateral laminectomy with [21] or without [124] a partial facetectomy has been used for some time in the resection of combination IDEM/extradural ("dumbbell") nerve sheath tumors in the cervical spine. Sarioglu and colleagues [122] reported on the unilateral laminectomy approach in 40 patients with predominantly IDEM tumors at all levels of the spinal canal. Complete resections were achieved in all cases, and patients were mobilized 24 hours after surgery. As with other smaller series of unilateral approaches [68,121,123], no spinal deformity was seen at a mean of 32 months after surgery [122]. These techniques do seem to reduce iatrogenic approach-related complications by preserving the spinous process and contralateral lamina, the interspinous ligament, and the contralateral part of the ligamentum flavum [68]. Nevertheless, these open procedures still dissect the paraspinal musculature in a subperiosteal fashion on one side, which may contribute to more postoperative pain and poorer long-term axial function.

We have recently reported on the use of minimal access techniques using the unilateral laminectomy approach for the resection of IDEM tumors through a tubular retractor [2]. A 2.5-cm incision is made approximately 2.5 cm off the midline, and after standard tubular dilation, the X-Tube (Medtronic Sofamor-Danek) retractor (Fig. 4A) is inserted and expanded to achieve a 4-cm long operating field at the depth of the retractor while maintaining a 2.5-cm aperture at the surface (Fig. 4B, C). A unilateral laminectomy is performed, followed by undercutting of the spinous process and removal of the ligamentum flavum. Depending on the location of the tumor and the degree to which the spinous process is undercut, the durotomy is made in the dorsal midline or in a paramedian fashion, as noted in other reports (Fig. 4D) [68,119]. Specialized instruments have been designed for effective dural repair or grafting; otherwise, the remainder of the procedure follows traditional intradural tumor surgery principles. Six patients were originally reported, but at the time of this writing, the cohort comprises 12 patients with IDEM tumors of cervical (n = 1), thoracic (n = 5), and lumbar (n = 5) regions, with pathologic diagnosis that include schwannoma (n = 6), meningioma (n = 4), and filum ependymoma (n = 2) (unpublished data). All lesions were successfully resected in a minimally invasive fashion (Fig. 5). The mean operative time was 235 minutes, the mean blood loss was 75 mL, and mean length of hospital stay was 2.5 days. No CSF leaks and no wound infections have been encountered [2]. We hypothesize that the decreased amount of tissue destruction and reduced dead space after minimally invasive surgery dramatically reduces CSF-related wound complications.

Ultimately, this technique represents the marriage of minimal access technology as applied originally to degenerative spinal disease with the advances made in open microsurgical techniques for the removal of intradural tumors [125]. Currently, this procedure is limited to lesions that are less than three segments in length, but improvements in retractor design may permit larger resections. In theory, this approach can be applied successfully in the treatment of short-segment intramedullary tumors and intradural vascular malformations among other pathologic findings. Future comparative studies should properly demonstrate the postulated benefits of decreased postoperative pain, decreased blood loss, decreased length of hospital stay, decreased incidence of CSF leaks, decreased incidence of postoperative spinal deformities, and faster recovery times.

Outcomes

As with any tumor surgery, neurologic recovery is proportional to the extent and duration of preoperative neurologic deficit [1,3,7,9,12,126].

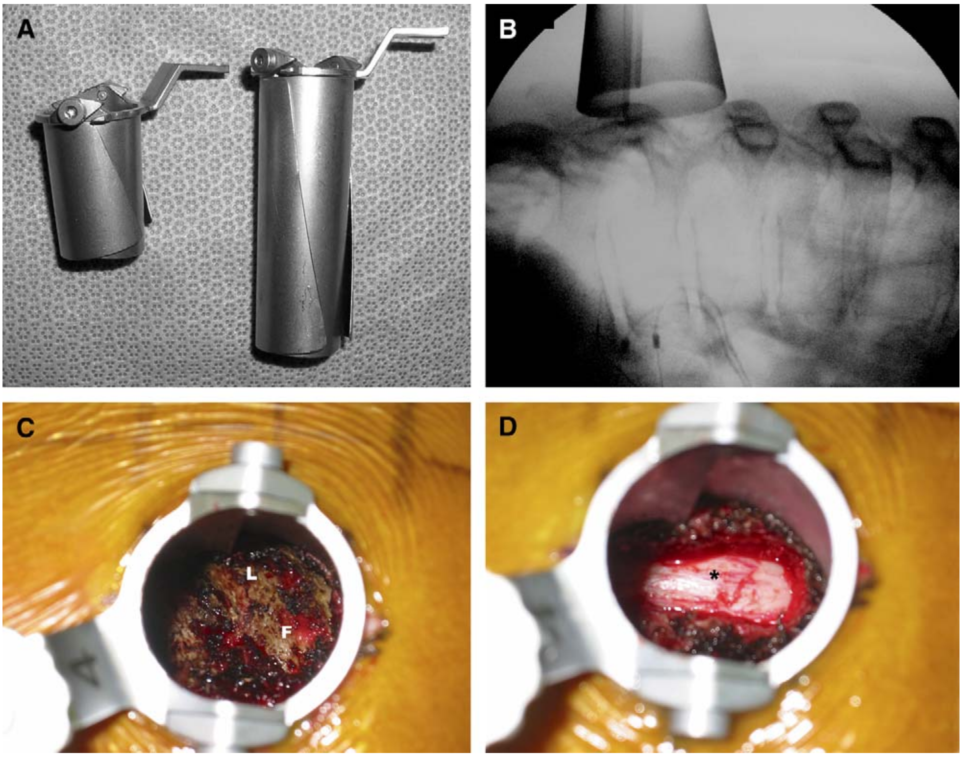

Fig. 4. (*A*) Two examples of the X-Tube retractor (Medtronic Sofamor-Danek, Memphis, Tennessee). The superficial aperture is 2.5 cm in diameter. Note the hinge at the top of the tube that allows the base to be expanded, permitting an approximately 4-cm long field at the depth of the retractor. (*B*) Intraoperative lateral fluoroscopic radiograph demonstrates postexpansion positioning of the X-Tube for a thoracic IDEM tumor resection. (*C*) Photographic view through X-Tube after initial exposure of a right-sided approach reveals a typical appearance of the thoracic lamina (L) and facet (F). Right is rostral, and the top is medial. (*D*) Photographic view through the X-Tube after completion of bony removal shows typical dorsal dural exposure. The midline of the dura is marked (*).

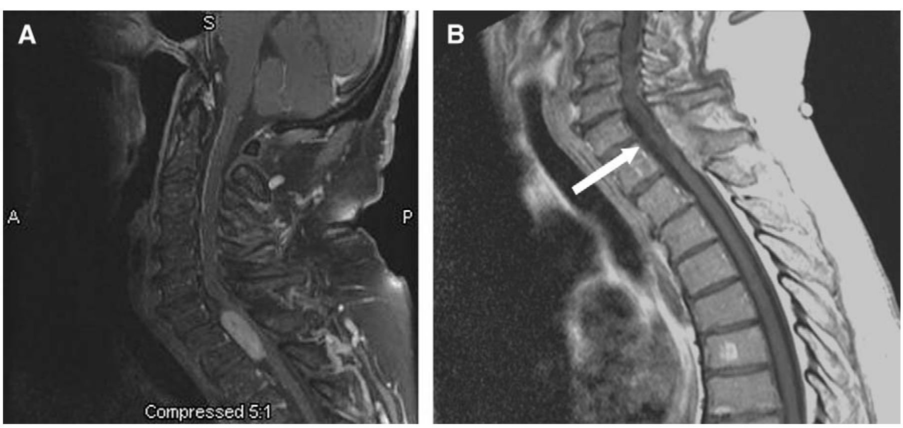

Fig. 5. A 70-year-old man presented with chronic myelopathy secondary to a thoracic schwannoma. (*A*) Sagittal T1-weighted MRI with gadolinium demonstrates a well-demarcated, ventrolateral, enhancing, lobular IDEM mass extending from the level of the C7-to-T1 disc space to behind the T2 body. (*B*) Postoperative T1-weighted MRI with gadolinium reveals complete resection of the tumor (*arrow*) with minimal impact on the posterior spinal structures.

Box 1. Characteristics of minimally invasive surgical approaches to spinal tumors

Advantages
Decreased perioperative pain
Decreased blood loss
Decreased length of stay
Faster recovery
Overall decreased morbidity for medically debilitated patients
Decreased incidence of CSF leak and wound healing problems for intradural cases
Maintenance of biomechanically important spinal anatomy
Decreased incidence of postoperative instability and deformity

Limitations
Unable to perform long-segment resections
Technologic restrictions on percutaneous fixation constructions
Unable to perform complete marginal spondylectomy

In this regard, minimally invasive surgical techniques compare favorably with open techniques in their ability to achieve satisfactory neural decompression and recovery of function [2,11,68,75–77,80,88,91,95,97,102,104,111,112,117,120,122,123]. Ongoing prospective evaluations of patients with tumors treated with various modalities should provide us with more detailed information regarding the utility of various surgical strategies for treating spinal tumors. In the interim, therefore, it is left to the surgeon to weigh the advantages of minimally invasive procedures against the current limitations (Box 1) and conclude what best serves the needs of each patient.

Summary

Minimally invasive approaches to spinal tumors have evolved dramatically over the past 15 years. Their indications, efficacy, and limitations continue to be defined while new technologies concomitantly emerge. Improvements on current techniques should include new instrumentation and retractor systems to permit longer resections and longer fixation constructs as well as refined uses of percutaneous and noninvasive therapies in combination, such as RFA, SRS, and vertebroplasty or kyphoplasty. The next generation of minimal access approaches may include novel biologic and genomic therapies that are implanted in a minimally invasive fashion to treat neoplastic disease of the spine and spinal cord. Ultimately, all these techniques must meet existing standards in efficaciously providing symptomatic relief, tumor control, and spinal stability while continually striving to reduce operative morbidity in an effort to improve quality of life for patients with spinal tumors.

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