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Minimally invasive treatments for metastatic tumors of the spine

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The most common lesions of the spinal axis represent metastatic disease [1]. Metastatic disease involving the spinal axis has been estimated to affect 5% of the cancer population per year, or about 61,000 individuals, although not all these diagnosed lesions become symptomatic [2]. The most common primary cancers to metastasize to the spine include lung, breast, and prostate cancer as well as lymphoma and multiple myeloma. Pain is the presenting symptom in 95% of patients with spinal metastases and can be focal or radicular pain or pain from a pathologic fracture.

With new high-resolution imaging, many spine lesions are found before they become clinically relevant. Many patients, however, present to their physician's office with complaints of pain or the sequelae of compression from symptomatic spinal metastases. Traditionally, spinal metastases were treated with a combination of radiation therapy, decompressive laminectomy, or chemotherapy. As more minimally invasive modalities for the diagnosis and treatment of spinal metastases are developed, patients increasingly have the option of procedures that put them at less risk for the morbidity and mortality associated with larger and more invasive procedures. Tissue diagnosis of spine tumors can now be done percutaneously as an outpatient procedure to help guide further management of the patients with new lesions often found on imaging. Patients with significant pain and instability also have the option of a variety of percutaneous procedures for improvement of pain and stabilization, including vertebroplasty, radiofrequency tumor ablation, and percutaneous pedicle screw placement. Tumor resection can be accomplished through a variety of less invasive modalities, such as endoscopic resection, reconstruction, and stabilization, as well as through a host of minimally invasive surgical approaches.

This article details the many minimally invasive modalities available to patients with spinal metastatic disease. As the use of these treatments becomes more widespread, the resection and palliation of spinal metastases can be accomplished with less morbidity and mortality and improved quality of remaining life.

Diagnosis of spine tumors

The need for vertebral biopsies is increasing as asymptomatic lesions of the vertebral body are identified more frequently during the staging workup of patients with malignant tumors. Modern radiologic techniques, such as magnetic resonance imaging (MRI), computed tomography (CT), and bone scintigraphy, are allowing for the earlier diagnosis of smaller lesions [3]. In 1956, Craig [4] described the technique and developed a needle for open core needle biopsy using a paravertebral approach under general anesthesia. Although commonly used, this paravertebral approach has been associated with hemorrhage and, less frequently, nerve damage.

More recently, several reports have described percutaneous biopsy of the spine using fluoroscopy or CT guidance [5–15]. Kornblum et al [6]

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published a retrospective study of 103 patients who underwent CT-guided biopsies of the spine and found that the specimen was adequate for pathologic examination in 87% of cases, with definitive diagnosis made in 71% of patients.

Most of the patients in these series had paraspinal lesions or lesions located in the far lateral area of the vertebral body in which a paravertebral approach was feasible. Lesions that are found early are often in the central or anterior aspect of the vertebral body, however, and require a transpedicular approach, because the paraspinal approach carries an increased risk of paraspinal hematoma, pneumothorax, or neuropathy [3]. In their experience with transpedicular biopsy in 32 patients, Jelinek et al [3] concluded that transpedicular biopsy under CT or fluoroscopic guidance was safe and efficacious as an outpatient procedure for biopsy of deep vertebral body lesions. Minart et al [15] described the use of this technique during vertebroplasty under fluoroscopic guidance. In this series, biopsies contributed to diagnosis in 55 of 57 (96.5%) cases without any of the above-mentioned complications.

A recent series of 20 patients details a CT-guided percutaneous transforaminodiscal approach for biopsy of vertebral body lesions. Eighteen of 20 lesions were successfully accessed using this approach without procedure-related complications [16].

Needle aspiration cytology with CT guidance is another minimally invasive method for diagnosis of vertebral lesions. Gupta et al [17] demonstrated a diagnosis in all but 7 patients in a series of 70 patients undergoing fine needle aspiration. The information obtained was not only diagnostic but was able to help guide appropriate management of the patients. Carson et al [18] reported similar results in their series of 57 cases, with a diagnosis in 81% of 57 cases of patients undergoing fine needle aspiration biopsy.

These minimally invasive diagnostic techniques have been shown to provide tissue diagnosis in most patients and do not require general anesthesia or an overnight hospital stay. In addition, they carry less risk of the complications associated with open core needle biopsy.

Percutaneous vertebroplasty/kyphoplasty

Extensive multifocal metastatic disease of the spinal column is often treated by radiation therapy or conservative measures, such as bed rest, bracing, corticosteroids, and analgesia. With radiation therapy, however, pain relief is often delayed by 2 weeks and bone strengthening is minimal and not seen for up to 4 months after treatment if it occurs at all [19]. Conservative treatment is often associated with the complications of long-term immobilization, such as pneumonia, deep venous thrombosis, and pulmonary embolism [20].

Percutaneous vertebroplasty is a minimally invasive radiologically guided procedure originally developed in 1987 in France for the treatment of painful vertebral hemangiomas [21]. The technique was expanded for the treatment of hematologic malignancies and metastatic lesions of the spinal column [22–28]. The technique consists of percutaneous puncture of the affected vertebral body and injection of an acrylic polymer. The polymer provides vertebral body stabilization as well as prompt pain relief. Polymethylmethacrylate (PMMA) is an acrylic polymer known for its excellent compressive strength that has long been used for vertebral packing after tumor debulking. PMMA injected into osteoporotic vertebral bodies demonstrates an increase of 195% in the maximal force required to compress treated vertebrae compared with an untreated control group [29]. In patients with osteolytic fractures, however, vertebroplasty is associated with an increased rate of cement leak and less predictable pain relief. Kyphoplasty is an extension of vertebroplasty that uses an inflatable balloon to restore the vertebral body to its original height while creating a cavity to be filled with bone cement (Fig. 1). Kyphoplasty is associated with

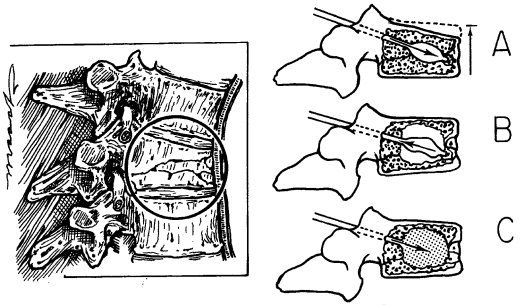

Fig. 1. Kyphoplasty. (*A*) The collapsed vertebral body is accessed through a transpedicular route. The balloon at the end of the instrument is inflated, thus restoring the height of the body. (*B, C*) The balloon is removed, and the defect is filled with bone cement (polymethylmethacrylate), which re-establishes structural integrity to the vertebral body.

a lower risk of cement leak as well as with restoration of vertebral body height and sagittal spine alignment [30].

In North America, vertebroplasty and kyphoplasty have been limited largely to the treatment of benign osteoporotic compression fractures, but they are being used increasingly for the treatment of metastatic disease in the spine. In 2003, Fourney et al [31] reviewed the results of kyphoplasty and vertebroplasty in a group of 56 cancer patients with intractable pain secondary to vertebral body fractures. Of these patients, 84% had marked or complete pain relief and no patient had worse pain after treatment. The patients had significant reductions in pain scores up to 1 year. Asymptomatic leakage occurred in 9.2% of levels during vertebroplasty and not at all during kyphoplasty. In this series, the absence of cement leakage was thought to be a result of the high-viscosity cement, the small volume injection, and the use of kyphoplasty in selected cases [31].

The decision to treat a patient with vertebroplasty/kyphoplasty is based on the extent of the disease, the patient's medical condition, and the patient's response to previous treatments. In general, patients with significant focal mechanical pain unresponsive to analgesia because of osteolytic metastases or myeloma are potential candidates for the treatment [20]. Patients with cortical osteolysis should be excluded from treatment because of the risk of causing canal compromise if there is significant epidural involvement [24]. Extensive destruction and significant collapse with 70% or greater loss of height may also be a contraindication, because displaced fracture fragments can compress the cord or nerve roots when PMMA is injected. Absolute contraindications include uncorrected coagulation disorders, infection involving the affected vertebra, and the lack of surgical support in cases of a complication [20].

Radiofrequency tumor ablation/thermocoagulation

Radiofrequency tumor ablation is a percutaneous image-guided tumor ablation with a thermal energy source. It has been used in the musculoskeletal system for the treatment of low back pain secondary to facet osteoarthritis or failed back syndrome and for the percutaneous treatment of osteoid osteomas [32–34]. This technique is gaining attention for the treatment of pain in focal spine metastases as well as for providing local tumor control. Although radiofrequency tumor ablation has primarily been used for osteoid osteomas, new electrodes that allow larger regions of thermocoagulation have been developed for spinal metastases [33]. Gronemeyer et al [35] reported a series of 10 patients with unresectable osteolytic spine metastases who underwent radiofrequency ablation under combined CT and fluoroscopic guidance. In this study, radiofrequency ablation was used as a palliative measure to reduce back pain and pain-related disability in patients who could not benefit from chemotherapy, radiotherapy, or surgery. Patients had a relative pain reduction of 74% and an average reduction in pain-related disability of 27%, with preservation or improvement of neurologic function in all patients.

Minimally Invasive Surgical Techniques

Surgery is indicated in selected patients with single- or adjacent-level disease with neurologic symptoms from tumor compression or vertebral collapse who are otherwise in good health with a life expectancy of 6 months or greater. Many minimally invasive approaches to spine tumors have been described in the literature, however, and are increasingly being used for the surgical treatment of spinal metastases.

Endoscopy

Spinal endoscopy has been used in spine tumor surgery for diagnosis by either direct visualization or biopsy as mentioned previously as well as by decompression of structures and delivery of therapeutic agents. Video-assisted thoracoscopic surgery (VATS) has been used corpectomies for the treatment of vertebral body tumors [36,37]. Thoracoscopy can be used to access the entire spine from T1 to T12, providing visualization of the disks, vertebral bodies, and ipsilateral pedicle [38]. VATS can also be used for decompression of nerve roots and the spinal cord, spine stabilization via internal fixation devices for pathologic fractures, and tumor resection [38]. It is associated with a lower rate of pulmonary morbidity than open thoracotomy; reduces the approach-related trauma on skin, muscles, and ribs; avoids shoulder girdle dysfunction and minimizes the incidence of intercostal neuralgia; and allows for earlier ambulation and shorter hospital stays. Thoracoscopy has a steep learning curve that requires the surgeon to acquire knowledge of segmental surgical anatomy [39] as well as the

technical skills needed to use the long working arms of the equipment [38].

In 1996, Rosenthal et al [40] took a transthoracic microsurgical endoscopic technique originally used for thoracic discectomy and modified it for vertebrectomy, reconstruction, and stabilization. Four of the 28 patients in their series had metastatic disease treated with this technique. In this modified technique, patients receive general anesthesia via a double-lumen endotracheal tube inserted endoscopically. A trocar is inserted 3 to 4 cm paramedial in the seventh intercostal space. After insertion of the 30° rigid scope, one-lung ventilation is started, allowing exposure of the anterolateral portion of the spine. After release of pleural adhesions and identification of the affected segment, the next trocars are placed along the midaxillary line—one above each healthy vertebra and the third above the tumor. The parietal pleura is then sectioned cranially and caudally until healthy structures have been reached, followed by discectomy of the segments above and below the tumor to give the surgeon orientation with regard to distance to and position of the spinal canal and dural sac. Tumor removal begins at the periphery and continues toward the center of the vertebral body. When the posterior longitudinal ligament has been reached, the resection includes the head and approximately 2 cm of the proximal rib, most of the right pedicle, and the infiltrated part of the vertebral body. The posterior longitudinal ligament is then opened and resected so that full decompression of the dural sac and spinal cord is achieved. Reconstruction is performed with homologous bone or PMMA. Stabilization is accomplished with a ventral plating device. All the patients in this study were ambulatory and pain-free at the time of discharge (7–8 days) and at an 11-month follow-up examination. Regan et al [41] demonstrated similar results in their small series of patients treated for various disorders (including tumor) with VATS.

McLain [42,43] described a technique for thoracoscopic vertebrectomy and anterior decompression followed by formal anterior column reconstruction. The indications he used for surgery were patients with radioresistant metastases of the thoracic spine or patients with pulmonary disease who could not tolerate a standard thoracotomy. He also had good neurologic results as well as low morbidity and short hospital stays (average of 6.5 days).

Laparoscopic approaches can also be used for retroperitoneal approaches for decompression and corpectomy [38]. This approach to L1 to L4 is a combination of thoracoscopic and laparoscopic techniques. The patient is placed in the lateral decubitus position. The right lung is deflated, and the thoracoscope is inserted along the right midaxillary line. After incision, the retroperitoneal space is dissected using a balloon and insufflated with carbon dioxide. The thoracoscope then visualizes the diaphragm, which is transected using Endoshears (United States Surgical Corp., Norwalk, CT), allowing the thoracoscopic instruments to be used on the lumbar spine.

Le Huec et al [44] described an endoscopic approach to the cervicothoracic junction for two patients with vertebral metastases. After decompression and corpectomy, the patients underwent reconstruction by strut graft through small trocar incisions, avoiding sternotomy. The approach begins with a standard Smith-Robinson incision with blunt dissection of the posterior face of the manubrium with the finger. The endoscope is inserted through 10-mm trocars, one above the manubrium and a second through the second rib space. After dissection and decompression of the spinal cord, a strut graft is fixed anteriorly. Levels T1 through T3 are well exposed with this approach, allowing complete vertebral body removal at T1 or T2 with reconstruction and stabilization.

Minimally invasive surgical approaches

When endoscopic techniques cannot be used, surgeons are developing less invasive approaches and techniques for accessing spinal tumors. Traditionally, anterior spinal tumors have been accessed through an anterior vertebrectomy, followed by bone graft reconstruction. Recently, many microsurgical minimally invasive approaches have been developed to gain access to the anterior spine.

Anterior decompression and fusion for thoracolumbar spine tumors are considered effective but are associated with considerable surgery-related trauma. Muhlbauer et al [45] described a minimally invasive retroperitoneal approach (MIRA) for lumbar corpectomy and anterior reconstruction in 5 patients with osteoporotic compression fractures and metastatic L4 disease. In all patients, the MIRA was shown to allow for complete decompression and anterior reconstruction, verified by follow-up radiographic studies [45]. A larger series by Huang et al [46] demonstrated good results in 23 patients with various

indications for anterior lumbar surgery, including vertebral tumors. In this series, at a mean follow-up of 39.6 months, 9 patients had excellent outcomes, 11 had good outcomes, 2 had fair outcomes, and 1 had a poor outcome [46]. This approach does not require an endoscope or microscope and necessitates only a 5-cm skin incision [46].

Jho and Ha [47] describe a minimally invasive microsurgical technique in which a microforaminotomy is used for tumor resection for cervical spine lesions anterior to the cord. Tumor resection was accomplished through a flask-shaped hole. The authors describe using a hole with a smaller outer opening and a larger inner opening to accommodate the extent of the tumor. With this technique, bone fusion and postoperative immobilization could be avoided. Spinal stability was well maintained at 6 weeks after surgery, and postoperative imaging confirmed tumor resection [47].

Although they did not specifically describe anterior approaches for tumor resection or stabilization of spines with metastatic disease, Mayer and Wiechert [48] and Mayer [49] recently published their experience with microsurgical anterior approaches to the lumbar spine for fusion. They describe retroperitoneal as well as transperitoneal microsurgical techniques to approach the anterior lumbar spine from L2 to S1. We include this report because these approaches can be performed through limited skin incisions and could potentially be used for various forms of anterior lumbar interbody fusion and stabilization in patients with spinal metastases. The first described approach is a retroperitoneal lateral microsurgical approach to L2 to L5. This approach is performed on the left side of the patient with the table tilted between 20° and 40° toward the surgeon. The orientation of the disk space is projected onto the skin by lateral fluoroscopy. A 4-cm skin incision is made above this projection obliquely. The retroperitoneal space is exposed by blunt splitting of the muscle fibers. Once the spine and psoas muscle are exposed and the genitofemoral nerve is identified and preserved, the anterolateral attachments of the psoas muscle are sharply dissected from the lateral circumference of the disk space to expose the anterior longitudinal ligament. The disk space is identified under fluoroscopy, and blunt dissection is continued to expose 5 to 10 mm of adjacent vertebral bodies. The frame type retractor is then applied to expose the anterolateral segment to be fused.

The second approach is a midline microsurgical approach to L5 to S1. The patient is in the Trendelenburg position with the lumbar spine hyperextended and both legs in maximum abduction. Again, the orientation of the disk space is marked with fluoroscopy. A 4-cm incision is made in the midline of the abdomen centered over L5 to S1. The anterior circumference of L5 to S1 is exposed via blunt retroperitoneal dissection along the abdominal wall on the right side in thin patients or via a transperitoneal approach in obese patients. In both of the described approaches, anterior lumbar interbody fusion with bone graft and titanium cages can be accomplished through small incisions with less tissue trauma than traditional anterior approaches.

Minimally invasive approaches to posterior spine stabilization and fusion

Percutaneous fixation of the lumbar spine was first described by Magerl [50], who used an external fixator. Mathews and Long [51] first described and performed a wholly percutaneous lumbar pedicle fixation in which they used plates as the longitudinal connectors. Lowery and Kulkarni [52] described a similar procedure in which rods were placed. The advent of computer-aided image guidance has allowed surgeons to perfect these techniques to help make spine surgery increasingly less invasive for patients. Although most of these techniques were not developed for patients with metastatic spine disease, the applications can easily cross over for patients who need stabilization.

Foley and Gupta [52] used their technique of percutaneous pedicle screw fixation in the lumbar spine of 12 adults. They placed lumbar pedicle screws and rods through percutaneous stab wounds using fluoroscopic image guidance. Again, the pedicle screws were attached to screw extenders to connect the screw to the rod. The authors found many advantages to this technique, including avoidance of a large midline incision and significant paraspinous muscle dissection, minimal blood loss and tissue trauma, and easier realization of an ideal screw trajectory.

Holly and Foley [53,54] recently described their experience using an isocentric C-arm fluoroscope to guide the placement of percutaneous thoracic and lumbar pedicle screws. Their results were promising, with 94.7% of pedicle screws placed without cortical breakthrough. They used the same technique as described previously but found that with image guidance and three-dimensional fluoroscopy, minimally invasive spinal navigation was more accurate.

Summary

Minimally invasive approaches are finding their way into all aspects of metastatic spinal disease from diagnosis to treatment of patients who are diagnosed early in their course as well as patients with multifocal metastases. For patients who are found to have asymptomatic spinal metastases, diagnosis is important to guide management and treatment so as to prevent future morbidity. These patients also now have the option of less invasive techniques for resection, reconstruction, and stabilization, including endoscopy and less invasive surgical approaches. Patients who are treated later in their course, with multifocal metastatic disease also have more options for palliation of pain and for stability, including vertebroplasty/kyphoplasty and radiofrequency tumor ablation as well as some of the percutaneous methods of stabilization described previously. As techniques evolve and improve, patients will continue to have more access to less invasive options for treatment of spinal metastases.

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