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Adjunct and Minimally Invasive Techniques for the Diagnosis and Treatment of Vertebral Tumors

Oren N. Gottfried, MD[a], Andrew T. Dailey, MD[a], Meic H. Schmidt, MD[a,b,*]

[a]*Department of Neurosurgery, University of Utah Medical Center, 175 North Medical Drive, Salt Lake City, UT 84132, USA*

[b]*Spinal Oncology Service, Huntsman Cancer Institute, University of Utah, Salt Lake City, UT 84112, USA*

Although, historically, many primary vertebral tumors were diagnosed and treated through open surgical approaches, many new minimally invasive options are now available that can avoid some of the problems associated with open procedures. The problems that may be encountered with open procedures include identifying the lesion during surgery and ensuring its complete removal. In addition, the surgeon must be careful to avoid creating instability secondary to a wide resection, requiring a fusion or causing nerve root and spinal cord injury. Many new percutaneous options have incorporated image guidance that allows for focused attention on the tumor; this enables the surgeon to avoid excessive bony removal and soft tissue trauma. At times, open surgical intervention is clearly indicated, and newer surgical options are available with advances in image guidance and intralesional resections. Surgery is also facilitated by transarterial and intralesional embolization techniques, which devascularize tumors, and new ablation techniques. In this article, the authors focus on advances in minimally invasive nonoperative and operative treatments of primary vertebral tumors.

Diagnosis of primary spine tumors

As asymptomatic lesions are identified more frequently during the workup of patients for spinal tumors, the need for biopsies is increasing. Modern radiologic techniques, such as MRI, CT, and bone scintigraphy are allowing for the earlier diagnosis and localization of smaller lesions [1]. Percutaneous biopsy of the spine was first described in 1935, but these investigators noted that they could not easily obtain soft tissue samples with their instruments [2]. In 1956, Craig [3] described a technique for percutaneous core needle biopsy using a paravertebral approach under general anesthesia with new instruments, including cutting needles and guide cannulas. Earlier percutaneous procedures required guidance on anatomic landmarks or radiographs and used large-bore needles; thus, they were limited to the lower thoracic and lumbar levels [4].

Advances in the design of specialized thin-walled and cutting biopsy needles allowed adequate biopsy at all spinal levels [5], and increasing numbers of researchers have described procedures using percutaneous biopsy of the spine with accurate CT guidance (Fig. 1) [4–8]. Image-guided percutaneous approaches are considered safe, accurate, and relatively inexpensive for obtaining tissue samples of spine lesions; in many cases, the use of these approaches eliminates or reduces the need for open biopsy [4]. Today, the diagnostic accuracy of an image-guided percutaneous

* Corresponding author. Department of Neurosurgery, University of Utah Medical Center, 175 North Medical Drive, Salt Lake City, Utah 84132.

E-mail address: meic.schmidt@hsc.utah.edu (M.H. Schmidt).

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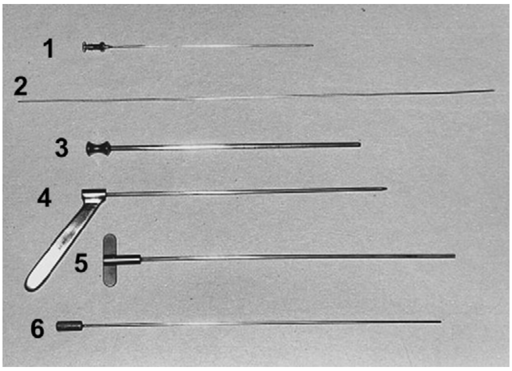

Fig. 1. Advances in the design of specialized, thin-walled, and cutting biopsy needles allow adequate biopsy at all spinal levels. Pictured is a trephine set for transpedicular biopsy of thoracic and lumbar lesions: (1) fine needle, (2) rigid guidewire, (3) graduate external sheath, (4) hollow intermediate piece with handle, (5) serrated cannula, and (6) obturator. (*From* Pierot L, Boulin A. Percutaneous biopsy of the thoracic and lumbar spine: transpedicular approach under fluoroscopic guidance. AJNR Am J Neuroradiol 1999;20(1):23–5; with permission. Copyright © 1999 American Society of Neuroradiology.)

biopsy has been reported to be between 71% and 100% [4,6,7]. 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 a lower risk for the complications associated with open-core needle biopsy.

Kornblum and colleagues [4] 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. These investigators included biopsies obtained at all levels of the spine. To get a well-preserved core specimen in each case, they used (1) thin-walled cutting needles, including the cut-biopsy needle or core biopsy instrument, for primarily lytic lesions with paraspinal extension; (2) a needle with a trephine cutting tip to cut through bone for mixed lesions or lytic lesions with intact overlying cortex; and (3) a transpedicular trephine needle for lesions within the central portion of the vertebral body. Significantly lower diagnostic yield rates have been reported by several researchers for thoracic-level spinal biopsies. This is thought to be attributable to the proximity of vital structures ventral to the thoracic spine and to problems with accurate access [4,6,7,9].

Several variables are thought to be important for diagnostic accuracy after percutaneous biopsy of spine lesions. Higher accuracy rates may occur for metastatic disease (96%) than in primary neoplasms (82%) [10]. In several series, biopsy of osteolytic lesions more frequently yielded a diagnosis than biopsy of osteosclerotic ones [6,7,9]. Obtaining biopsies within sclerotic lesions is difficult because of how hard the overlying bone can be, and it is recommended that the biopsy involve the least dense area and that the surgeon use trocar needles for the procedure.

The transpedicular approach is valuable for thoracic and lumbar lesions that are in the central or anterior aspect of the vertebral body [5,11,12]. It avoids the complications associated with the paraspinal approach, including paraspinal hematoma, pneumothorax, or neuropathy, which occur in up to 26% of cases [12,13]. The transpedicular approach is performed safely with CT or with fluoroscopic guidance and is reported to yield diagnosis in 89% to 96.5% of cases [5,11,12]. Although CT is more accurate and ideal for smaller lesions, fluoroscopy provides real-time control of the position of the needle in the anteroposterior and the cephalocaudal directions. It can thus be safer and quicker in the hands of a familiar operator [5,11]. The transpedicular biopsy is safe and efficacious as an outpatient procedure for obtaining biopsy material of deep vertebral body lesions and can be performed with no complications as compared with the posterolateral approach [5,11,12]. The main indication to use the transpedicular approach is to differentiate a primary vertebral body lesion from metastatic disease [11]. If a patient has a vertebral body fracture, this approach can be used to differentiate tumor from osteoporotic collapse [11]. Also, a patient who experiences a vertebral body collapse without a known tumor can have a vertebral body lesion biopsy and undergo vertebroplasty or kyphoplasty at the same session [11]. The coaxial technique allows the surgeon to obtain several biopsy specimens with only one tract, to contain bleeding within the cortical bone, to prevent inadvertent spread of tumor cells, and to place cement if needed after the biopsy [5,11].

Of note, lesions located at the inferior part of the body may require the posterolateral approach [5]. The authors of a recent report on a series of 20 patients detailed an alternative CT-guided percutaneous transforaminodiscal approach for biopsy of vertebral body lesions that did not have the high complication rate associated with the posterolateral approach. The principle of this technique is to puncture the vertebral body through the intervertebral disc. Eighteen (90%) of 20 lesions were successfully accessed using this approach without procedure-related complications [14].

Needle aspiration cytology with CT guidance is another minimally invasive method for diagnosis of vertebral lesions, and a diagnosis can be rendered in approximately 90% of cases [15,16]. In two large series, the overall sensitivity of fine-needle aspiration biopsy by cytology in detecting vertebral and paravertebral lesions was 90% to 93% and the specificity was 94% to 95% [17,18]. Fine-needle aspiration biopsy was accurate in differentiating malignant and benign disease and in differentiating primary bone from metastasis [17]. Overall, it is a safe, accurate, reliable, and cost-effective method to diagnose vertebral and paravertebral tumors, and cell blocks, core biopsies, and ancillary studies can be used as adjuncts when necessary [17].

Percutaneous treatments

Vertebroplasty/kyphoplasty

Percutaneous vertebroplasty is a minimally invasive radiologically guided procedure originally developed in 1987 in France for the treatment of painful vertebral hemangiomas [19]. The technique was expanded for the treatment of hematologic malignancies and metastatic lesions of the spinal column and other primary bone tumors. It consists of percutaneous puncture of the affected vertebral body and injection of an acrylic polymer [20]. The polymer provides vertebral body stabilization and 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 over an untreated control group. In patients who have 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 vertebral body height while creating a cavity to be filled with cement. Kyphoplasty is associated with a lower risk for cement leak and better restoration of vertebral body height and sagittal spine alignment compared with vertebroplasty.

Patients with significant focal mechanical pain unresponsive to analgesia because of osteolytic tumors are candidates for vertebroplasty and kyphoplasty [21]. Patients who have cortical osteolysis should be excluded from treatment because of the risk for causing canal compromise if there is significant epidural involvement. 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.

Although there is extensive literature describing the use of vertebroplasty and kyphoplasty for pathologic fractures secondary to metastasis and osteoporotic fractures, the use of these techniques for treatment of primary vertebral tumors is limited. Hemangiomas remain one of the few primary tumors that result in fractures and benefit from these treatments [22–24]. Patients who had symptomatic hemangiomas were treated with vertebroplasty before laminectomy and epidural tumor resection, which resulted in excellent outcomes with reduced pain and lack of instability or evidence of vertebral collapse after the procedure [22,25].

Radiofrequency/thermocoagulation tumor ablation

Radiofrequency ablation is a percutaneous image-guided technique of tumor reduction using a thermal energy source. It has been used in the musculoskeletal system for the treatment of low back pain secondary to facet osteoarthritis, herniated discs, or failed back [26]. There has been wide success for the treatment of osteoid osteomas of the appendicular skeleton; however, recently, this technique is being applied for the treatment of pain and local tumor control for spinal osteomas [26]. A theoretic concern in this location is the proximity of neural structures to the heat-generating source and risk for injury. Experimental studies suggest that radiofrequency to vertebral bodies does not result in cytotoxic temperature elevations recorded in the spinal canal [27], and it is thought that tissue is affected in a sphere of 5-mm diameter from the tip of the probe [28]. Other investigators have noted that the risk for spinal cord damage is low because of the shorter time and lower power needed to achieve total ablation of the small spine lesions [26]. Generally, it is recommended that the probe be kept greater than 5 mm from neural structures and, if possible, to retain a rim of cortical bone protecting neural structures [26]. Although radiofrequency has primarily been used for osteoid osteomas, new electrodes that allow larger regions of thermocoagulation have been developed for other spinal tumors, including metastasis [26].

CT guidance is used for localization of lesions and to measure the size of the lesion and determine the energy necessary to ablate the tumor. Cove and colleagues [29] described the treatment of two patients who had osteoid osteomas located on the posterior structure of the lumbar lamina that were treated with percutaneous CT-guided thermocoagulation. Under general anesthesia, a bone biopsy cannula was introduced into the center of the tumor, a biopsy sample was sent for histologic evaluation, and a thermocoagulation probe was then inserted into the lesion (confirmed on CT) and heated at 90°C for 4 minutes (Fig. 2). Both patients had complete pain relief, no evidence of clinical recurrence at 2 years, and no evidence of osteoma on follow-up CT scans. Other investigators have treated patients who had osteoid osteomas located in the cervical, thoracic, and lumbar spine with radiofrequency coagulation without evidence of recurrence at greater

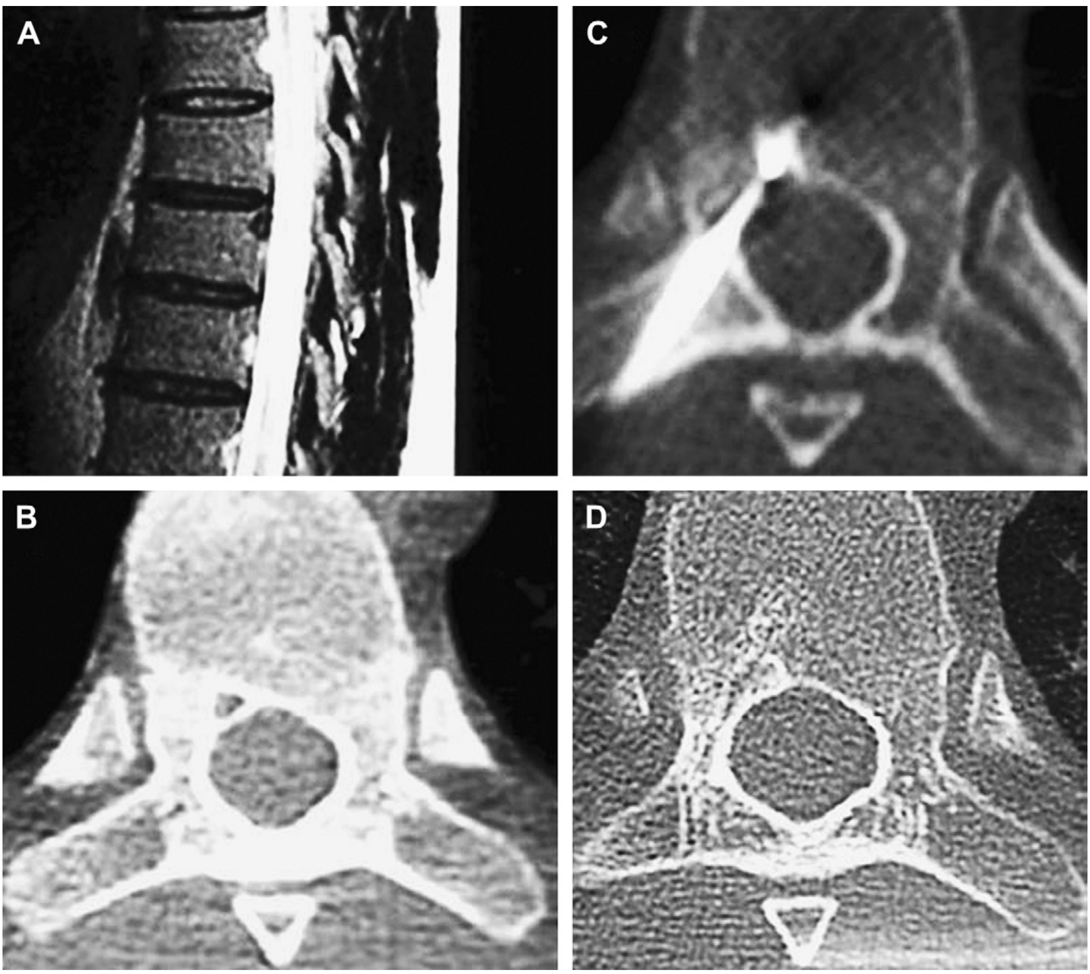

Fig. 2. An example of percutaneous radiofrequency coagulation of a T8 osteoid osteoma. (*A*) MRI T2-weighted image with a low T2 intensity round lesion at T8. (*B*) Axial CT with a small lytic lesion surrounded by a thin sclerotic rim. (*C*) Tip of the electrode in the center of the nidus during percutaneous radiofrequency coagulation. (*D*) Image obtained 2 years later shows spongiose healing of the lesion contiguous to the electrode tract. (*From* Samaha EI, Ghanem IB, Moussa RF, et al. Percutaneous radiofrequency coagulation of osteoid osteoma of the "Neural Spinal Ring." Eur Spine J 2005;14(7):702–5; with kind permission from Springer Science and Business Media.)

than 1 year of follow-up and with symptomatic relief (see Fig. 2) [30–32]. Even osteomas that are difficult to access, including one in the C5 vertebral body, have been treated with CT guidance and unique approaches, including a transthyroid trajectory, for successful radiofrequency ablation [33]. Gangi and colleagues [26] have treated a series of spine osteoid osteomas with radiofrequency ablation and interstitial laser photocoagulation. The radiofrequency ablation is similar to that described previously, and the laser photocoagulation involves placement of optical fibers producing controlled coagulative necrosis around the fiber (Fig. 3) [26]. Of note, only small osteomas (1.5 cm) can be treated with this technique [26].

Pain relief after thermocoagulation ablation for all osteoid osteomas, including appendicular ones, was between 77% and 100%, with complication rates ranging between 0% and 24% and recurrence rates of 5% to 12% [26,32]. The most frequent complication was mild skin burns, but some vertebral fractures and peripheral nerve injuries occurred. The interstitial laser photocoagulation technique has been used with a clinical success rate ranging from 91% to 100% and a minor complication rate of 4% to 33% [26,34,35].

Other percutaneous treatments

The goal of percutaneous techniques may be to reduce intraoperative blood loss with injection of alcohol-embolizing emulsions or N-butyl cyanoacrylate (NBCA) or to serve as a definitive tumor

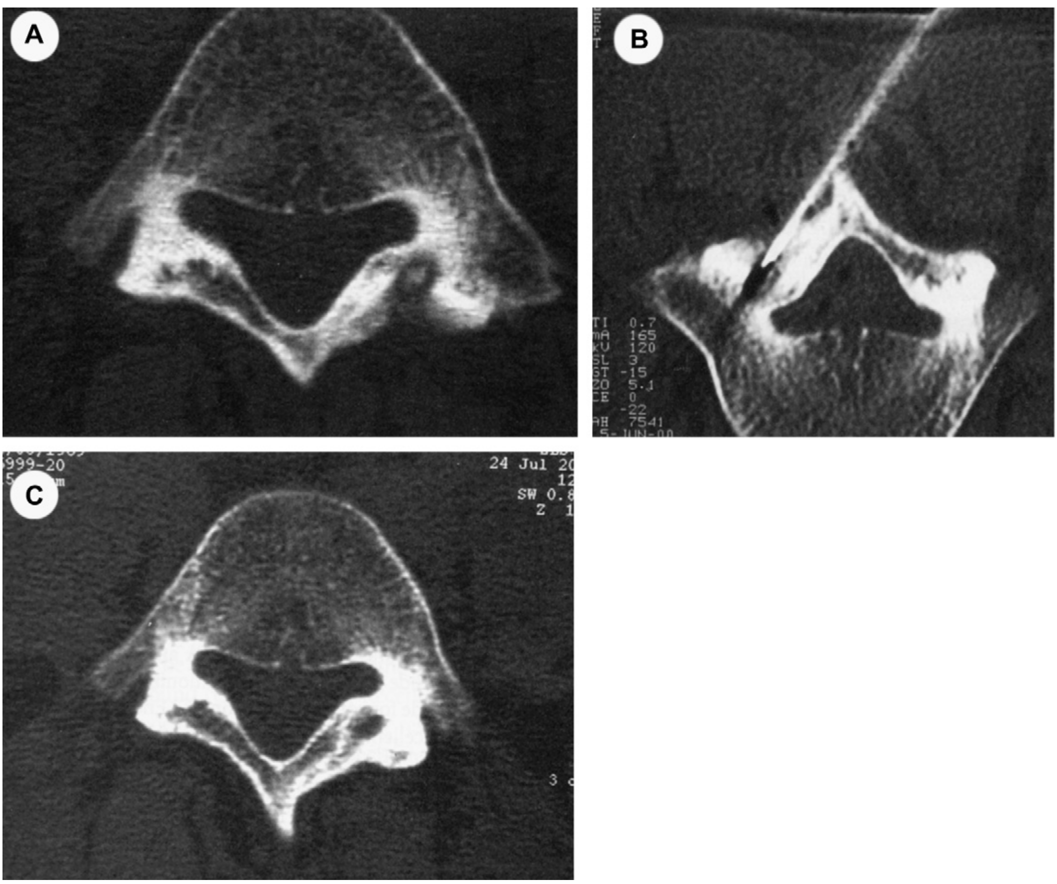

Fig. 3. Percutaneous laser photocoagulation of spinal osteoid osteoma. (*A*) CT scan of the nidus at the L5 lamina. (*B*) An 18-gauge needle is positioned in the nidus with coaxial insertion of the optical fiber; 1000 J of energy was delivered. (*C*) CT 1 year later in a patient with complete symptomatic improvement. (*From* Gangi A, Basile A, Buy X, et al. Radiofrequency and laser ablation of spinal lesions. Semin Ultrasound CT MR 2005;26(2):89–97; with permission.)

treatment [22]. Direct percutaneous intralesional techniques offer an alternative to transarterial vascular embolization when the latter has too high a risk because of proximity between the tumor's blood supply and the vasculature supplying neural tissue [22,36,37]. Tumor devascularization occurs by filling of the intratumoral vessels rather than by occluding the supplying pedicle. After percutaneous injection, angiograms can be used to confirm whether tumor vascularity is reduced or eliminated as in transarterial treatments [36]. Use of preoperative intralesional injection to reduce blood loss in treatment of hemangiomas and other hypervascular tumors has been described [22,36–39]. Cotten and colleagues [22] injected NBCA into the posterior arch of patients who had hemangiomas before they underwent laminectomy and epidural tumor resection, with good operative hemostasis.

Direct percutaneous puncture can also be used to ablate lesions as a primary treatment option. Several investigators have described relief from spinal cord compression by vertebral hemangiomas after treatment with intralesional injection of absolute alcohol [40–42]. Goyal and colleagues [41] injected absolute alcohol (by means of a transpedicular approach) with a long lumbar puncture needle under CT guidance into 14 patients who had symptomatic vertebral hemangiomas: 13 with neurologic symptoms (including paraparesis) and 1 with back pain. Before the alcohol injection, contrast dye was injected to enable visualization of the opacified soft tissue component and to assess inadvertent extravasation. Although all patients had transient deterioration in neurologic symptoms after the procedure for up to 5 days, 86% of patients had clinical improvement at long-term follow-up of 5 to 31 months. Five patients had excellent improvement with resolution of their symptoms, 8 had good results, and the remaining patient had an incomplete treatment. Improvement correlated with a significant reduction of the epidural soft tissue mass on MRI, but cord signal change, when present before the procedure, did not change. One patient developed a recurrent hemangioma within a month and required intra-arterial embolization with polyvinyl alcohol (PVA) and radiotherapy, and 1 patient had deterioration after collapse of the involved vertebral level, which required surgical intervention. The direct injection of alcohol into hemangiomas has the benefit of reducing the size of the lesion and potentially destroying the lesion. Alternatively, transarterial injection occludes the feeding vessel but does not ablate the lesion. Radiotherapy may be effective for residual tumor but usually shows delayed results. One concern with alcohol ablation is the risk for delayed vertebral collapse, which can occur in up to 20% of cases; however, it is thought that the risk can be reduced with decreased alcohol or preventive vertebroplasty/kyphoplasty [40–42].

A novel treatment was used in the case of two patients who had aneurysmal bone cysts of C1 that were treated with a CT-guided percutaneous injection of calcitonin and methylprednisolone [39,43]. At 6 months and 2 years of follow-up, each patient had complete sclerosis and ossification of the cyst and improvement in pain. Calcitonin was selected because of its promotion of bone formation, and the steroid was selected for its antiangiogenic properties. By using this approach, the surgeon can avoid the standard treatment with curettage and bone grafting or other alternatives, such as radiation therapy or embolization.

Gabal and colleagues [44] used percutaneous injection of ''sclerosant'' directly into vertebral hemangiomas under CT guidance to induce shrinkage of the whole tumor mass and release of the compressed spinal cord. In the five patients who had vertebral hemangioma and neurologic symptoms, sclerotherapy was the only treatment given in three patients and sclerotherapy was preceded by transcatheter embolization in the other two patients. Decompressive surgery, radiation therapy, and stabilization were not required with this technique, and all patients had good outcomes.

It is also possible to perform percutaneous CT-guided drilling of osteoid osteomas with biopsy needles, toothed drills, and curettes, eliminating the need for open surgery [45,46]. The disadvantage of open surgery is the need for wide exposures disproportionate to the small size of the lesion to ensure complete tumor removal. In one series in which percutaneous CT-guided drilling of osteoid osteomas was used, complete resection was confirmed pathologically and radiographically in all cases and clinical success was obtained in 17 (94.5%) of 18 patients, with only 1 patient experiencing disease recurrence that required open surgery [45]. Other investigators have argued that percutaneous drilling of osteoid osteomas of the spine is dangerous because of the risk for penetration of the drill into the spinal canal caused by the toughness of the sclerotic bone. The exact localization of the lesion may also make drilling more difficult because of scattering on the CT image from the metal tools [47].

Intraoperative ablation techniques

It is also possible to perform intraoperative direct injection of an embolic agent or cement [48,49]. For example, direct intraoperative injection of cement into a hemangioma provided immediate hemostasis and allowed easy decompression of the epidural component of the tumor [49]. As mentioned previously, hemangiomas also respond to intralesional injection with alcohol [40], and this can be done at the time of surgery.

Lonser and colleagues [48] successfully treated three patients who had epidural spinal tumors, including a sarcoma, by slow incremental injections of small amounts of ethanol (0.1–0.2 mL) into the tumor. Intraoperative direct injection of ethanol facilitated visualization and resection of spinal tumors by rapid devascularization and reduction of blood loss in patients with incomplete preoperative embolizations or in those who were unable to undergo embolization. The end point for injection at a specific site was arrest of active hemorrhage with visible tumor blanching. The ethanol caused necrosis of the tumor, and the injected tissue instantly became soft and easy to resect.

Intraoperative cryosurgery is another method of devascularizing spinal tumors [50,51], and it also causes cell death, eliminating residual tumor [52] Cryosurgery causes direct injury to cells by tissue ice crystal formation and microcirculatory breakdown associated with thawing. As the temperature increases, these crystals coalesce and mechanically disrupt the cell membrane, causing cell death [52]. Freezing of the tumor causes immediate cessation of intratumoral blood flow and allows better delineation of tumor planes [50]. Cryocoagulation is performed after adequate exposure of the tumor and separation of the tumor from any nearby neural element. Typically, liquid nitrogen is the circulating agent with which freezing is induced. A probe is placed into the tumor, and the extent of cryocoagulation is evaluated by intraoperative real-time ultrasonic imaging [50,51]. Alternatively, cryosurgery can be performed with the open-pour technique with liquid nitrogen or with the argon-helium–based heat freeze system [52]. In general, the neural elements must be protected from the cryosurgery. Interestingly, Maroon and colleagues [50] demonstrated safe resection of an intramedullary tumor with the aid of cryocoagulation; thus, focused tumor cryocoagulation may be tolerated by the adjacent neural elements.

Cryocoagulation has been used successfully in treating lesions to the thoracic spine with significant reductions in blood loss and without complications attributable to the use of cryocoagulation, but freezing-related injury to the spinal cord remains a risk [51]. Kollender and colleagues [52] treated 15 sacral tumors, including giant cell tumors, aneurysmal bone cysts, and several sarcomas, with cryosurgery as an adjunct after surgical debulking. They had a low rate of disease recurrence with only two local recurrences, and all patients had resolution of chronic pain. In this series, the remaining bony sacrum protected the neural elements from the cryosurgery; thus, this procedure is ideally suited for bone tumors (Fig. 4). Nader and colleagues [51] treated an aneurysmal bone cyst of the T2 and T3 vertebral bodies with a thoracotomy, followed by insertion of a 3-mm cryotherapy probe into the vertebral body/lesion. A cryogenic lesion was created for 9 minutes at −180°C (Fig. 5). Ultrasonography was used to evaluate the extent of cryocoagulation and the formation of an iceball lesion. Cryotherapy facilitated resection and corpectomy without significant blood loss. These investigators also noted reduced blood loss and clearer resection planes for two metastatic spine lesions treated with cryocoagulation.

Transarterial embolization

Embolization of spinal tumors is a useful adjunctive therapy and aids in the surgical management of these lesions to reduce intraoperative blood loss [53]. It also facilitates resection, improves visualization, decreases operative times, and may decrease the size of the tumor. Embolization can also be used as a primary and definitive treatment modality for hypervascular lesions, including giant cell tumors and aneurysmal bone cysts. Several primary bone tumors can be highly vascular, and if this is suspected based on presentation and imaging features, preoperative angiography should be performed to determine whether the lesion would benefit from embolization. Selective vascular delivery of an embolic agent is desired to minimize unwanted collateral vessel occlusion and subsequent tissue infarction and necrosis. If selective vascular delivery is not possible, direct percutaneous puncture techniques may be necessary to obtain selective embolization placement [36]. The choice of embolic material is based on the territory embolized, the permanence of

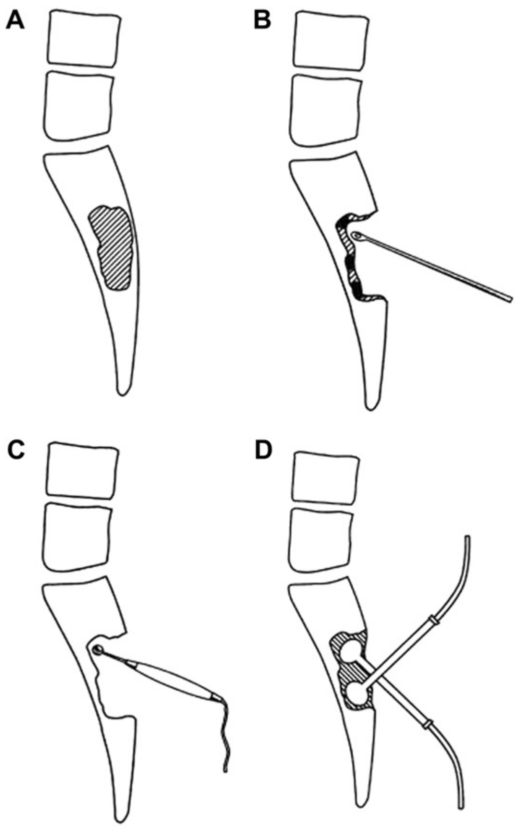

Fig. 4. Cryosurgery as an adjuvant technique for surgery of sacral tumors, including giant cell tumors and aneurysmal bone cysts, as described by Kollender and colleagues [52]. Fenestration of the tumor (*A*), manual curettage (*B*), burr drilling (mechanical curettage, *C*), and cryosurgery procedure with remaining bone protection (*D*). (*From* Kollender Y, Meller I, Bickels J, et al. Role of adjuvant cryosurgery in intralesional treatment of sacral tumors. Cancer 2003;97(11):2830–8; with permission. Copyright © 2003 American Cancer Society.)

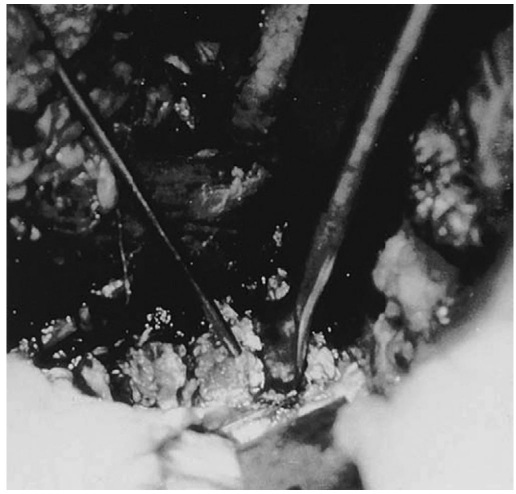

Fig. 5. Intraoperative photograph demonstrates cryocoagulation with the probe tip in an aneurysmal bone cyst of the thoracic vertebral body. Ice formation developed at the probe tip after 9 minutes at −180°C, facilitating the tumor resection and with reduced blood loss. (*From* Nader R, Alford BT, Nauta HJ, et al. Preoperative embolization and intraoperative cryocoagulation as adjuncts in resection of hypervascular lesions of the thoracolumbar spine. J Neurosurg 2002;97(3 Suppl):294–300; with permission.)

occlusion needed, and the ability of selective delivery of an embolic agent by means of a transcatheter or direct percutaneous puncture route. Typically, Gelfoam (Pharmacia & Upjohn, Kalamazoo, Michigan), PVA particles, and coils are used, but other agents include tissue adhesives, ethanol, and microfibrillar collagen [54].

Embolization can be used as a primary treatment to treat pain and, in some cases, as definitive treatment of aneurysmal bone cysts and giant cell tumors. These hypervascular lesions can be embolized before surgical resection to reduce blood loss; however, in some cases, surgery can be avoided with successful embolization with relief of pain, sclerosis or calcification of the lesion and a decrease in the size of the tumor mass. De Cristofaro and colleagues [54] treated 14 aneurysmal bone cysts and five hemangiomas with selective arterial embolization. Seventeen patients had complete symptomatic relief, 11 had complete ossification of their tumors, 3 had a moderate decrease in size, and only 2 had clinical or radiologic recurrences. Lackman and colleagues [55] found that 4 of 5 patients who had giant cell tumors treated exclusively with embolization had resolution of their symptoms, arrested tumor growth, and no recurrence, whereas Lin and colleagues [56] had similar results in patients who had giant cell tumors treated with serial embolization, reporting that 14 of 18 patients had improvements in pain and neurologic symptoms with some late recurrences. Chuang and colleagues [57] treated a series of 10 patients who had unresectable giant cell tumors, of whom 70% had complete pain relief after embolization. Overall, the recurrence rate after embolization for aneurysmal bone cysts and giant cell tumors lesions is low and can be managed with repeat embolization [54,55,57]. Serial embolization of these lesions is typically performed at 4- to 6-week intervals until symptomatic improvement occurs or the tumors' vascularity disappears [55].

There are other primary spine tumors that are treated with embolization therapy, including osteoblastomas and hemangiomas, and several reports note that preoperative embolization significantly reduced blood loss in the surgery of spinal hemangiomas and osteoblastomas (Fig. 6) [22,23,58–61]. In two series of hypervascular cervical spine osteoblastomas treated with preoperative embolization, radical resection was achieved and there were no cases of tumor recurrences [60,61]. In a recent series of primary bone tumors of the spine in children, 8 of 11 surgically treated patients underwent preoperative embolization and the investigators noted a low average blood loss of 305 mL in these cases [62]. They treated patients who had diagnoses of aneurysmal bone cyst, eosinophilic granuloma, fibrous dysplasia, osteoblastoma, and chordoma, which suggests the range of tumors that may benefit from embolization before surgery is broad.

Most primary malignant tumors of the spine demonstrate increased vascularity, although chordomas display variability in their vascularity. Angiography is useful to determine whether a chordoma is hypervascular and to evaluate whether embolization is beneficial as a preoperative measure. Wang and colleagues [63] performed selective arterial embolization before tumor resection on 15 primary malignant thoracolumbar spinal tumors, including a chordoma, a fibrous xanthosarcoma, a malignant fibrohistiocytoma, an osteosarcoma, a Ewing's sarcoma, and a leiomyosarcoma. All patients showed satisfactory results after embolization and had reduced intraoperative blood loss and shortened operative time; in each case, there was a clear operative field for tumor resection.

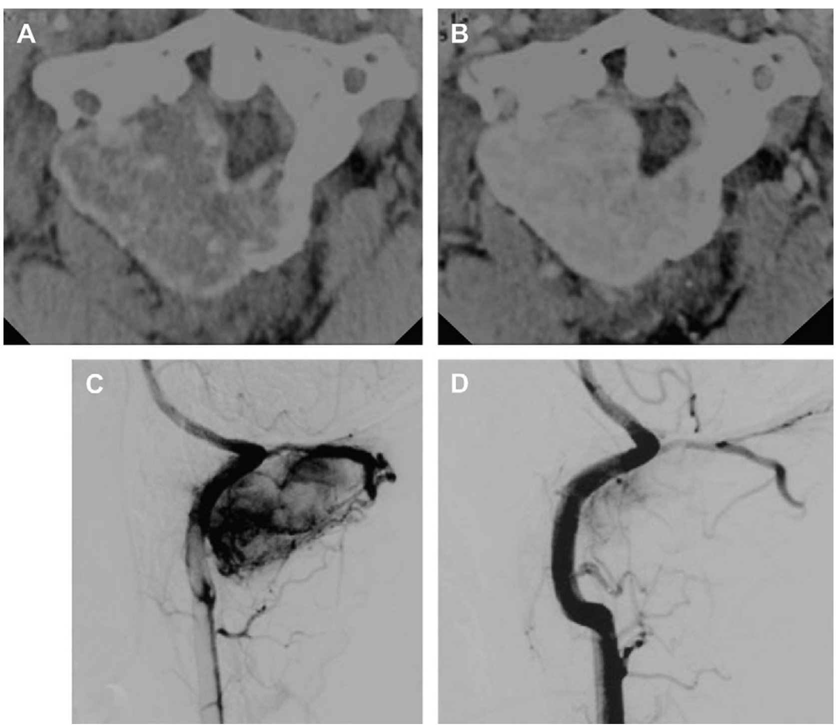

Fig. 6. Successful embolization of a C2 osteoblastoma that facilitated surgical resection. CT scans before (*A*) and after (*B*) contrast administration show extensive enhancement of the large expansive lesion with extension into the spinal canal. (*C*) Selective injection of the right vertebral artery (*lateral view*) shows a highly vascular tumor with most of its supply from the feeding vessels of right vertebral artery. (*D*) Selective injection after embolization shows only minimal residual tumor blush, and surgery was performed soon after with only moderate bleeding. (*From* Trubenbach J, Nagele T, Bauer T, et al. Preoperative embolization of cervical spine osteoblastomas: report of three cases. AJNR Am J Neuroradiol 2006;27(9):1910–2; with permission. Copyright © 2006 American Society of Neuroradiology.)

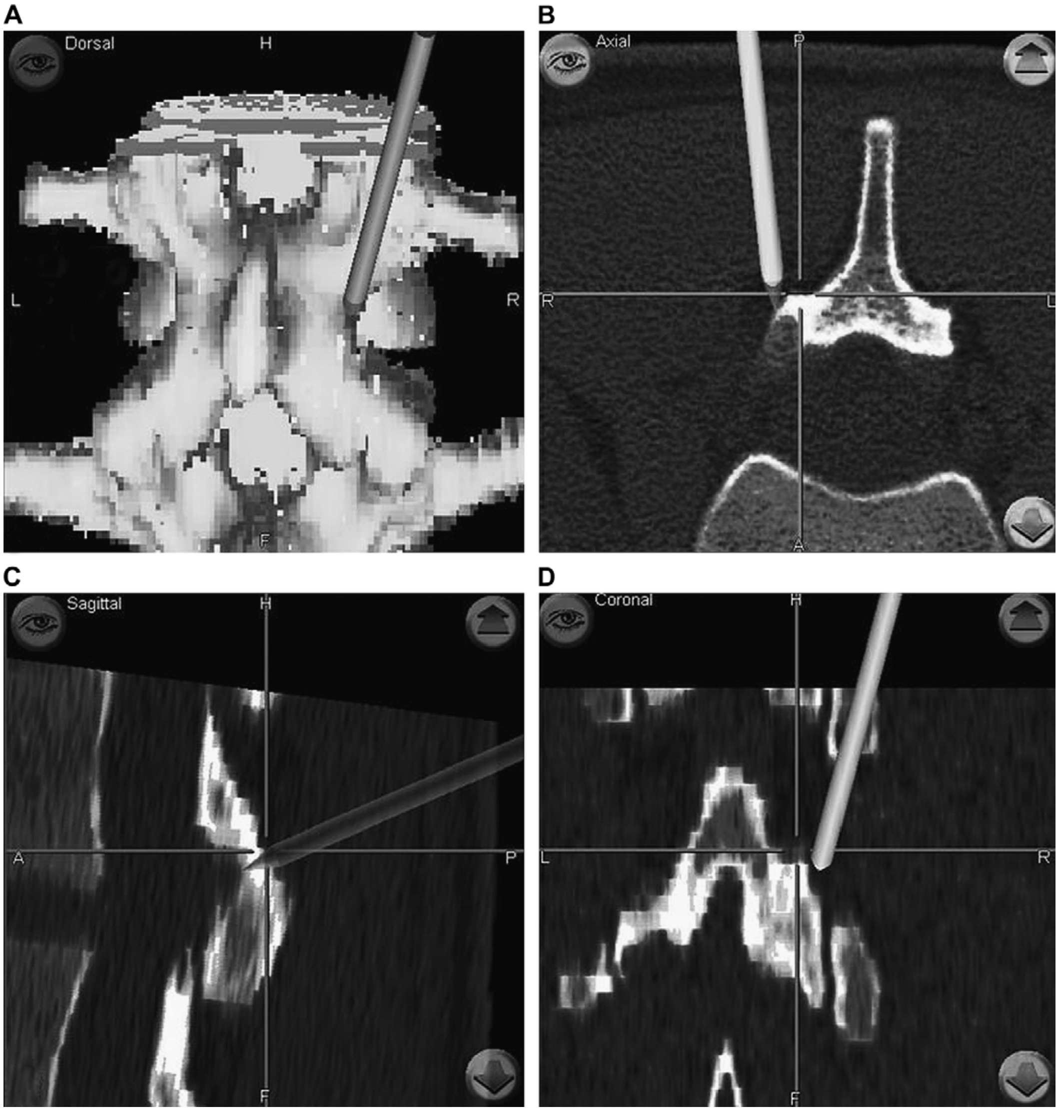

Fig. 7. (*A*) Three-dimensional reconstruction of CT data of an osteoid osteoma of the L1 right inferior articular process. Computer-assisted surgery with CT images in real time in the surgical field during excision of the nidus. The position of the tip of the standard probe and high-speed drill is monitored in transverse (*B*), sagittal (*C*), and coronal (*D*) planes. (*From* Van Royen BJ, Baayen JC, Pijpers R, et al. Osteoid osteoma of the spine: a novel technique using combined computer-assisted and gamma probe-guided high-speed intralesional drill excision. Spine 2005;30(3):369–73; with permission.)

Minimally invasive surgery

The use of a minimally invasive approach to a primary spine tumor was described in 1936; a transpedicular approach was used to diagnose and resect a giant cell tumor of the fourth lumbar vertebra [64]. Overall, the common goal of minimally invasive approaches to primary vertebral tumors is complete tumor resection, having an adequate access to the tumor, and minimizing adjacent normal bone resection and soft tissue injury. These measures allow for shorter hospital stays, quicker return to normal level of function, and symptomatic relief, without the morbidities of larger, more extensive operations. Image guidance or preoperative localization can accurately localize and guide excision of primary spine tumors. Image guidance in the spine has been previously described for pedicle screw placement [65,66], and use of the same technology is now being described for spine tumor resection.

Reports of techniques to localize tumors accurately have been growing. For example, Magre and Menendez [67] described a technique for the preoperative localization of an osteoid osteoma nidus. The lesion was localized with CT, a needle was advanced into the cortex, methylene blue was injected, and a self-retaining localization wire was then left in place. The site of marking was identified during surgery by following the guidewire to the cortical mark, permitting nidus excision with minimal resection of bone.

Other methods to help localize tumors include repeated intraoperative technetium Tc 99m bone imaging to localize and completely resect a sacral osteoblastoma [68] and technetium labeling combined with an intraoperative radiation probe for the localization of osteoid osteomas [69]. Van Royen and colleagues [47] described a technique used in five patients who had thoracolumbar osteoid osteomas that combined computer navigation and a gamma detection probe for high-speed drill excision to localize and excise this lesion with minimal bone resection. One day before surgery, patients were injected with radioactive ^{99m}Tc-oxidronate. Real-time images of the lesion were generated using a CT-based electro-optical navigation system by matching the intraoperative surface with preoperative CT images (Fig. 7). The reference frame with attached passive markers of the navigation system was mounted on the spinous process of the affected vertebrae, and surface registration of the posterior structures was performed. The osteoid osteoma was excised with the use of an image-guided high-speed drill, and complete excision was confirmed with a gamma detection probe. All five patients reported immediate complete relief of characteristic pain, there was no evidence of recurrence after 6 to 33 months of follow-up, and there were no complications.

Moore and McLain [70] used stereotactic image guidance to resect an osteoid osteoma from the pedicle of C7 and an osteoblastoma of the T1 and T2 vertebral bodies. Fine-cut CT images were loaded into the stereotactic workstation, the images were registered to the exposed vertebral anatomy by identifying three distinct nonlinear points on the bony surface (Fig. 8), and the wand was used to select the entry point and trajectory to the tumors that minimized the bone resection. Only a small laminar osteotomy was needed on the first case, and a hemilaminectomy was required for the other case. No outrigger assembly was needed with this system, and these investigators noted that "surgical excision can be performed without dissecting normal, uninvolved anatomy to acquire visualization, locate landmarks or apply an outrigger. The neoplastic lesion can be approached directly through the least destructive corridor and excised to the margin without disrupting the adjacent facets or surrounding bony architecture" [70]. Other researchers have also described stereotactic techniques with intraoperative guidance using preoperative CT for successful resection and drilling of osteoid osteomas [71].

Fig. 8. Use of CT image-guided stereotactic localization of benign osseous cervicothoracic tumors without an outrigger system. Fine-cut CT images were loaded into the stereotactic workstation, the images were registered to the exposed vertebral anatomy by identifying three distinct nonlinear points on the bony surface, and the wand was used to select the entry point and trajectory to the tumors that minimized the bone resection. (*From* Moore T, McLain RF. Image-guided surgery in resection of benign cervicothoracic spinal tumors: a report of two cases. Spine J 2005;5(1):109–14; with permission.)

Summary

This review demonstrates a wide range of innovative techniques used in the diagnosis and nonoperative and operative treatment of primary spinal tumors. Many of these procedures are performed percutaneously or through open approaches that minimize soft tissue trauma and the need for bony resection. Some techniques facilitate actual tumor resection, whereas others provide symptomatic relief and clinical improvements.

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