

Primary osseous tumors of the pediatric spinal column: review of pathology and surgical decision making

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Spinal column tumors are rare in children and young adults, accounting for only 1% of all spine and spinal cord tumors combined. They often present diagnostic and therapeutic challenges. In this article, the authors review the current management of primary osseous tumors of the pediatric spinal column and highlight diagnosis, management, and surgical decision making.

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TUMORS of the spinal canal and vertebral column are classified based on their anatomical location and origin. When considered as a whole, intramedullary, intradural extramedullary, and extradural spinal tumors account for 5%–10% of all pediatric central nervous system tumors.^{85,101,103} Pediatric brain tumors are 6 times more common than pediatric spinal tumors. Among spinal tumors, extradural primary or metastatic tumors account for approximately 50% of cases, followed by intradural intramedullary tumors (40%) and intradural extramedullary tumors (10%).^{85,101,103} Primary osseous spinal column tumors are rare in children and young adults, accounting for only 1% of all spine and spinal cord tumors combined.⁴⁵ These lesions can be benign or malignant and often present diagnostic and therapeutic challenges. In this article, we review the strategies currently used for the management of primary osseous pediatric tumors of the spinal column, including benign and malignant lesions, and highlight clinical diagnosis, imaging, and surgical decision making through the use of illustrative case examples.

Clinical Symptoms

Tumors of the spinal column can present with neurological dysfunction or osseous destruction. In either scenario, the result can be pain, neurological deficit, or rapidly progressive spinal deformity.^{33,45,81} Pediatric patients often

present with axial or radicular symptoms, most commonly pain. The timing of symptoms can vary based on pathology. Acute onset can indicate vertebral collapse and potential epidural spinal cord compression, whereas chronic symptoms can be present in the setting of slow-growing tumors. In either scenario, persistent nocturnal back pain, localized pain, and pain unrelated to activity can all be hallmarks of spinal column pathology and should prompt immediate evaluation.^{33,81} Additionally, back pain in a patient with known malignancy should cause concern and prompt evaluation for metastatic disease.⁶

The presentation of spinal column pathology in children depends on the age of the patient and location of the lesion. Tumors causing extrinsic compression of the neural elements in the cervical and thoracic spine can cause upper motor neuron signs or myelopathy, including weakness, hypertonia, hyperreflexia, Babinski sign, and sensory deficits. Tumors causing compression or invasion in the lumbar and sacral regions can present with lower motor neuron signs including hypotonia, hyporeflexia, and bowel or bladder dysfunction (constipation, retention, or incontinence).⁴⁵ Toddlers and infants can have subtler presentations, with irritability, regression of motor milestones, refusal to bear weight, and poor developmental progression.³³

In the setting of spinal malignancy, nearly 95% of pa-

ABBREVIATIONS CT = computed tomography; MRI = magnetic resonance imaging; NSAID = nonsteroidal antiinflammatory drug; RANKL = receptor activator of the nuclear factor- κ B ligand.

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TABLE 1. Age ranges and presentation of primary osseous tumors in the pediatric spinal column*

Age Range (yrs)	Benign Diagnoses	Malignant Diagnoses
0–5 yrs	Eosinophilic granuloma	
5–10 yrs	Aneurysmal bone cyst	Osteosarcoma
	Eosinophilic granuloma	Ewing sarcoma
	Osteoblastoma	
10–20 yrs	Osteoid osteoma	
	Aneurysmal bone cyst	Osteosarcoma
	Osteochondroma	Ewing sarcoma
	Osteoid osteoma	

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tients can present with nonspecific back pain, which can complicate the diagnostic picture.^{38,56} Some malignancies—Ewing sarcoma and lymphoma in particular—can present with a myriad of constitutional symptoms (for example, fever, night sweats) that can also mislead toward a diagnosis of infection rather than malignancy.⁹⁴ More than 50% of pediatric patients with malignant tumors of the spinal column present with neurological symptoms;⁵⁶ however, this is less common than the presentation of adults with neurological dysfunction in the same context.

Spinal deformity, including kyphosis, scoliosis, and lordosis, can be present in up to 25% of children with spinal tumors, but such deformities are rarely the only presenting signs of a spinal tumor.^{70,102} The severity of the deformity

relates to the extent of osseous erosion and destruction and neurological deficit; however, a small tumor can cause significant spinal deformity.^{33,86} Inspection of the spine with palpation is essential, as painful scoliosis can indicate the presence of underlying pathology;⁵² in these cases, the tumor is typically located in the concavity of the curve, and the deformity can be secondary to vertebral collapse or a muscular reaction to pain. Additional consideration should be given to spinal deformity after treatment because multilevel laminectomy and radiation therapy have been shown to increase the risk for spinal deformity.^{27,52}

A patient’s age at presentation can also provide an indication of the potential pathology as certain lesions are more likely to appear at different ages (Table 1). Additionally, the location of the lesion along the spinal column and its topographic location on the vertebra itself can provide information regarding diagnosis (Figs. 1 and 2). In addition to the warning signs mentioned above, additional patterns of presentation (for example, incidence, location) can be clues to a diagnosis. Specific details of various lesions along with their imaging and treatment specifics are presented in further detail below (Table 2).

Primary Osseous Tumors

Osteoid Osteoma and Osteoblastoma

Osteoid osteoma and osteoblastoma are generally benign osseous tumors and account for almost 3% of all primary bone tumors.^{39,51} Osteoblastomas are larger than 2 cm, more vascular, and more typically involve the vertebral body;⁷⁰ lesions smaller than 1 cm are osteoid osteomas. Lesions between 1 and 2 cm cannot be entirely differentiated

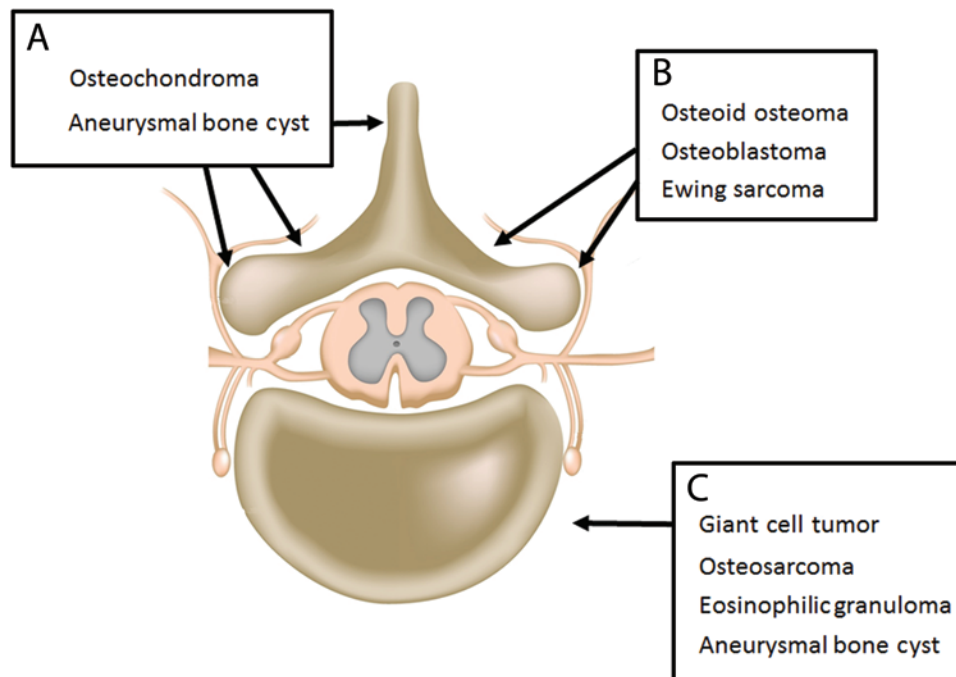


FIG. 1. Most common topographical locations for the occurrence of each of the possible primary osseous lesions in the pediatric spinal column. **A:** Lesions that occur along the facet joint, lamina arch, and spinous process. **B:** Lesions that can occur at the facet joint or pedicle or along the lamina arch or pars interarticularis. **C:** Lesions that occur along the vertebral body. Copyright Fotosearch.com. <http://www.fotosearch.com>.

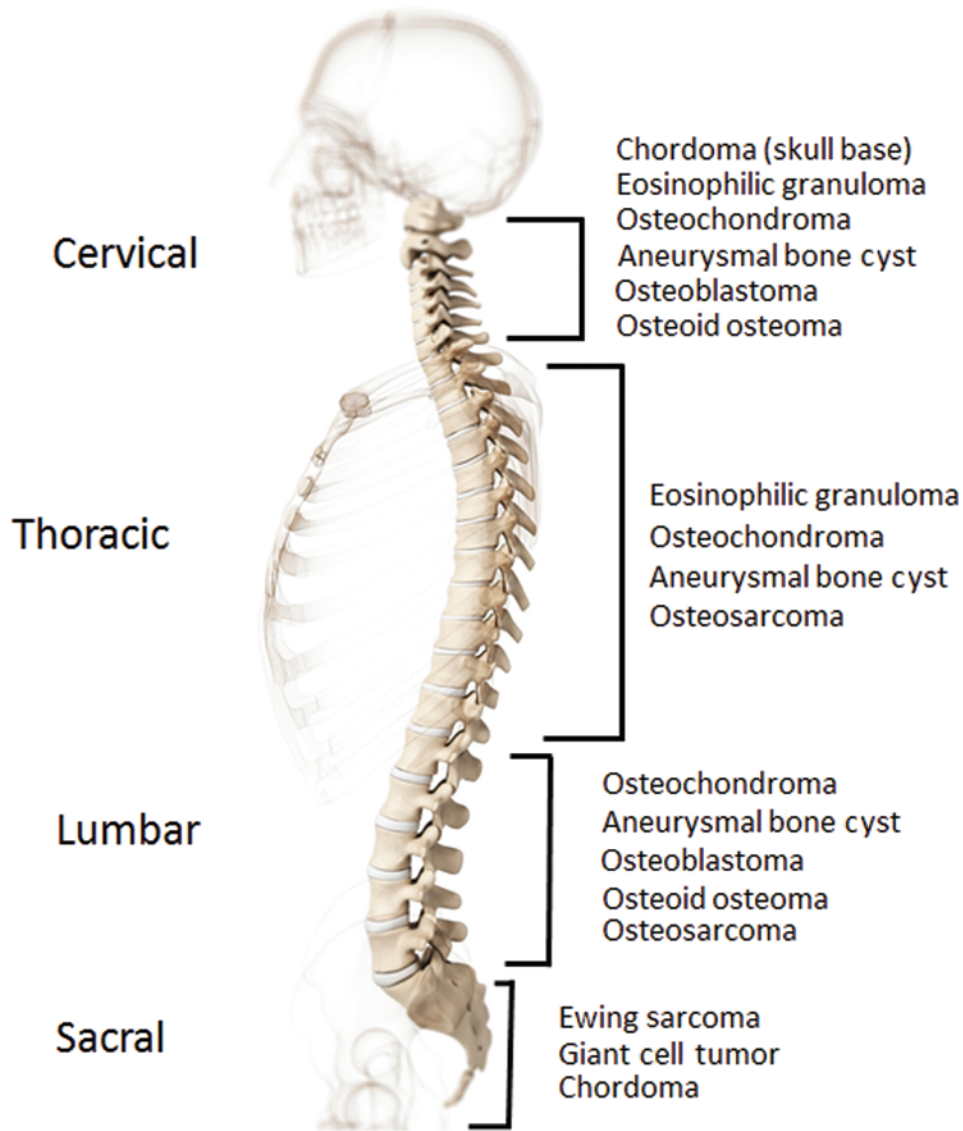


FIG. 2. Distribution of the most common locations for primary osseous lesions in the pediatric spinal column. Copyright Fotosearch.com. <http://www.fotosearch.com>.

based on size alone. Osteoblastoma accounts for less than 1% of all benign vertebral column tumors, whereas osteoid osteoma accounts for 9% of all benign vertebral column tumors.⁴¹ Almost 25% of all osteoid osteomas and 40% of all osteoblastomas are located in the spine.^{1,4,8,18,23,48,55,68} Both of these lesion types are more common in the lumbar spine than in the cervical spine and can occasionally occur in the thoracic spine;⁸⁶ a majority are found in the posterior elements (Table 3). Osteoid osteoma most commonly occurs in the 2nd decade of life, and males are more commonly affected than females.⁸⁰ Osteoid osteomas are benign, latent lesions, whereas osteoblastomas are benign but locally aggressive.²⁷ In fact, osteoid osteomas can “burn out” over a period of time.²⁷ Although osteoblastomas are historically benign lesions, there have been reports of malignant transformation to osteosarcoma.⁴

The pathological findings of osteoid osteoma and osteoblastoma are similar; both demonstrate bone formation

by osteoblasts producing osteoid and woven bone. The primary differentiation is based on size, as mentioned above. However, these lesions can also differ in gross intraoperative appearance and behavior. Osteoblastomas are friable, hemorrhagic mass lesions and are well circumscribed from the surrounding bone,^{51,52} whereas osteoid osteomas have a sclerotic appearance and appear hyperdense and expansile on computed tomography (CT), without evidence of bony destruction (Fig. 3). Osteoblastomas commonly have a “ground-glass” appearance on CT and usually present in the cancellous bone of the lamina or pedicles of the cervical and lumbar spine (Fig. 4).⁴⁵ Osteoid osteomas grossly appear firm and sclerotic and can have a granulomatous component.^{51,52}

Osteoblastoma and osteoid osteoma also share many clinical presentation findings, but osteoblastomas are more likely to present with neurological deficits because of their larger size⁸⁰ and because they are not typically responsive

TABLE 2. Characteristics of pediatric spinal column tumors

Tumor Type	Presenting Signs & Symptoms	Imaging Characteristics	Tumor Behavior	Location in Spinal Column	Location in Vertebrae	Treatment
Osteoid osteoma	Nocturnal pain, responsive to NSAIDs	CT: sclerotic, hyperdense, & expansile; MRI: T2 hyperintensity of bone & surrounding muscle, <1 cm	Benign	Cervical & lumbar spine	Posterior elements: lamina, pedicles, & facet joints	Surgery, observation, radiofrequency ablation
Osteoblastoma	Pain, unresponsive to NSAIDs	Ground-glass appearance on CT w/ low-density center; >2 cm	Benign, locally invasive	Cervical & lumbar spine	Posterior elements: cancellous bone of lamina & pedicles	Surgery
Osteochondroma	Pain, neurological deficits secondary to canal invasion	CT: sessile or pedunculated mass w/ ring/arc calcifications; MRI: cartilaginous cap appears dark on T1 & bright on T2	Benign; undergo malignant transformation to osteosarcoma in 10%	Cervical, thoracic, & lumbar spine	Posterior elements: lamina, spinous processes, transverse processes	Surgery
Osteosarcoma	Pain, soft tissue swelling over the lesion, 40% have neurological symptoms ⁴⁷	Radiographs: radiolucent, radiodense, or mixed radiolucent-radiodense lesion; MRI: bone component low signal on T1 & T2 & soft tissue mass high signal on T1 & T2	Malignant w/ local & systemic invasion	Thoracic & lumbar spine	Vertebral body	Local-control surgery, chemotherapy, radiation therapy
Aneurysmal bone cyst	Localized pain that worsens w/ activity; possible neurological dysfunction or spinal instability due to pathological fractures	Radiographs: expansile, radiolucent lesion; MRI: multiloculated, septated, expansile lesion w/ fluid-fluid levels that create low intensity on T1 & high intensity on T2; CT: fluid-fluid levels surrounded by "eggshell" rim of cortical bone	Benign, locally invasive	Lumbar spine, but can occur in thoracic & cervical spine	Posterior elements; may extend into pedicle & vertebral body & span multiple vertebral levels	Surgery, consider preop embolization, cases of denosumab treatment reported
Eosinophilic granuloma	Neck pain, nerve root irritation, early myelopathy, spinal deformity	Radiographs: vertebra plana; CT: lytic destruction, vertebral plana	Benign, destructive	Cervical & thoracic spine	Vertebral body	Observation, biopsy, excision (if causing neurological dysfunction)
Giant-cell tumor	Pain, localized swelling, tenderness	Radiographs: area of focal destruction as a "radiolucent zone"; MRI: contrast-enhancing expansile lesion	Benign, locally invasive	Sacral & cervical	Posteriorly along sacrum; occur when outside sacrum, occur in vertebral body	Surgery: wide resection when possible due to high recurrence (80%); ⁴⁸ denosumab
Ewing sarcoma	Pain & neurological deficit w/ tender, soft tissue mass; constitutional symptoms: fever, weight loss	Radiography: lytic lesion lacking characteristic "onion skin" found in long bone Ewing sarcoma; CT/MRI: demonstrate surrounding soft tissue mass, but no specific radiological criteria exist	Malignant	Sacrum, then lumbar spine	Posterior elements, sacral ala	Surgical biopsy; for high-grade lesion: chemotherapy & radiation, salvage surgery for residual tumor; for low-grade lesion: en bloc resection followed by adjuvant chemotherapy

TABLE 3. Primary osseous spinal column tumor locations within the vertebra

Location in Vertebra	Malignant	Benign
Anterior elements	Osteosarcoma	Eosinophilic granuloma Giant cell tumor Hemangioma Osteoblastoma
Posterior elements	Ewing sarcoma	Aneurysmal bone cyst Osteoblastoma Osteoid osteoma Osteochondroma

to nonsteroidal antiinflammatory drugs (NSAIDs). Osteoid osteoma most commonly presents with localized pain over the lesion, but radicular pain can be present in the setting of nerve root compression or irritation.⁵¹ The characteristic pain is severe but intermittent and will worsen with activity and is motion related; the hallmark finding is nocturnal pain that is relieved with the use of aspirin.⁵¹ Moreover, NSAIDs can be used to control symptoms of osteoid osteomas that are difficult to access surgically.²⁷

Magnetic resonance imaging (MRI) of an osteoid osteoma often demonstrates T2 signal hyperintensity of the bone as well as the surrounding muscle. In either osteoid osteoma or osteoblastoma, the onset of clinical symptoms can precede the formation and identification of findings on plain radiography or CT. In this scenario, if there is high clinical suspicion, MRI and nuclear medicine radioisotope studies may be more sensitive in detecting smaller lesions;⁴⁵ specifically, single-photon emission computed tomography (SPECT) can be helpful in diagnosing osteoid osteomas. An additional finding with both lesions is a

high incidence of spinal deformity; Saifuddin et al.⁸⁶ reported that 293 (63%) of 465 children with either osteoid osteoma or osteoblastoma had scoliosis.

Management of these lesions can vary based on location, severity of symptoms, and associated neurological symptoms. For children with suspected osteoid osteoma and minimal symptoms that are easily controlled, observation may be appropriate as some of these lesions can spontaneously involute.⁴⁵ Patients experiencing persistent pain or neurological symptoms may be candidates for excision, with gross-total resection as the primary goal. In cases in which gross-total resection is achieved, pain resolution and tumor control are excellent. In addition, there can be significant improvement in spinal deformity after resection; Ozaki et al.⁷⁷ reported improvement in 16 (94%) of 17 patients after the removal of either osteoid osteoma or osteoblastoma.

There is a 10% risk of local recurrence after resection of either lesion.^{36,39,80} Excision of osteoblastomas should include extended intralesional curettage with resection of the entire nidus as the goal.²⁷ Fusion adjuncts and stabilization may be indicated for lesions in which resection will result in spinal instability.²⁷

Because of the small size of these lesions, preoperative and intraoperative localization can be a challenge. Similarly, in the case of osteoid osteomas, the sclerotic appearance of the lesion in comparison with adjacent bone can make localization difficult. Although techniques such as CT-guided dye injection or intraoperative radioisotope scanning have been described,^{14,59} they are not necessary with careful preoperative planning. For recurrent osteoid osteoma or osteoblastoma, the treatment options are resection or radiation therapy. For osteoid osteomas, the risk of radiation-induced malignancy is less than 1%,⁶⁷ but reop-

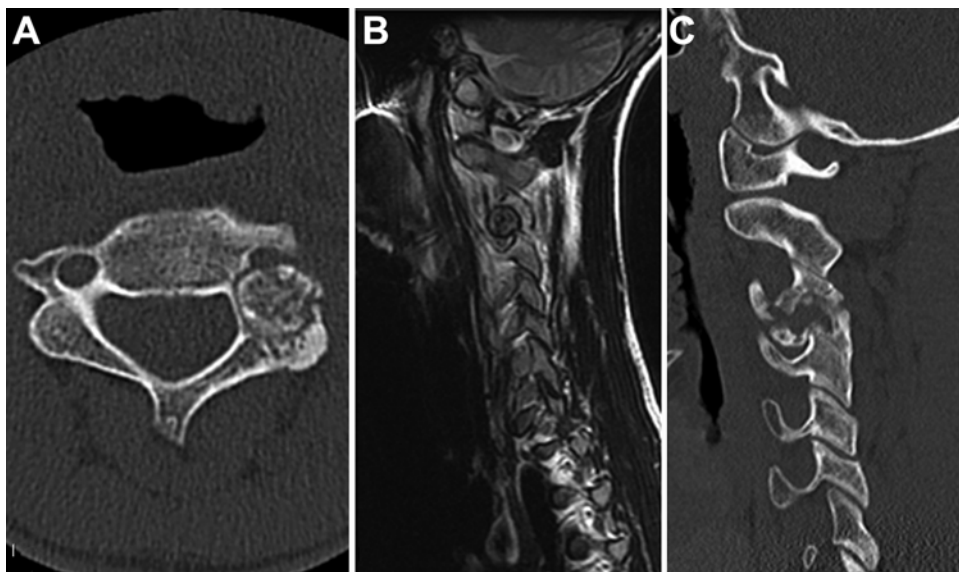


FIG. 3. A 16-year-old boy presented with severe neck pain and neck spasms. His neck pain was initially worse at night and responsive to nonsteroidal antiinflammatory drugs (NSAIDs). **A:** Axial CT showed a 1-cm sclerotic mass centered in the left pars and pedicle of C-3 associated with narrowing of the C-3 vertebral artery canal. **B:** On sagittal T2-weighted MRI, the lesion was hypointense. **C:** Sagittal CT showed resection of the lesion, which was identified as an osteoid osteoma, via a left C-3 hemilaminectomy. Repeat imaging 10 months after surgery demonstrated no evidence of spinal instability or malalignment, and the patient has been clinically stable for 3 years.

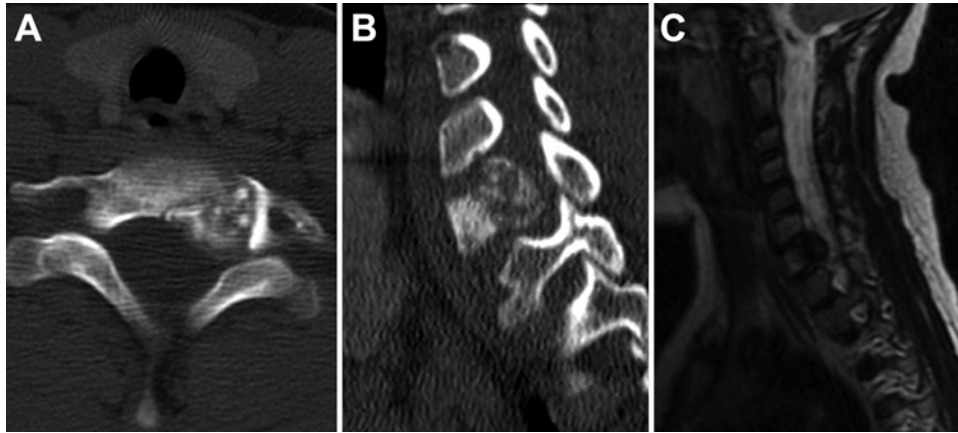


FIG. 4. A 7-year-old girl presented with progressive neck pain that was unresponsive to NSAIDs. Axial (A) and sagittal (B) CT demonstrated a destructive bone lesion measuring 2.2 cm in the left C-7 pedicle and vertebral body. Pathological analysis of the biopsy specimen indicated a diagnosis of osteoblastoma. Repeat MRI (C) 4 years later showed no recurrence, and the patient continues to do well 10 years after surgery.

eration is recommended for recurrent or residual lesions if the location is amenable.^{4,36,39,51,73} Additional treatment options can include radiofrequency ablation with or without CT guidance, which has shown good results in deactivating osteoid osteoma.^{43,69} Vanderschueren et al.⁹⁸ reported on 24 patients who underwent radiofrequency ablation for osteoid osteomas, 19 of whom were successfully treated. The authors concluded that radiofrequency ablation can be used in osteoid osteoma without nerve root compression and can also improve scoliosis associated with spinal osteoid osteoma (4 [57%] of 7 patients).

Osteochondroma

Osteochondromas, also known as osteocartilaginous exostosis, represent 30%–40% of benign osseous tumors and 4% of solitary spinal column tumors,⁴⁵ making them the most common bone tumor in children and adolescents. Patients with osteochondromas present between 10 and 20 years of age. The tumor can occur in the setting of hereditary osteochondromatosis, which is an autosomal dominant syndrome, or as a solitary sporadic lesion, which is the more common presentation. Males are more likely than females to have osteochondromas (2.5:1).^{3,108} Approximately 1%–7% of all osteochondromas occur in the spine. They most commonly affect the cervical spine (Fig. 2), which is involved in > 50% of reported cases, and are often located along the lamina arches, transverse processes, and spinous processes (Figs. 1 and 5).^{3,90,108} Osteochondromas can involve multiple spinal levels and extend from the lamina into the spinal canal and neural foramen, leading to neurological dysfunction and spinal deformity in addition to back pain.^{3,108}

Because osteochondromas are primarily cartilaginous, plain radiographs can be inadequate in assessing them; CT or MRI may be necessary for the diagnosis. Computed tomography can demonstrate a sessile or pedunculated mass with ring and/or arc calcifications; MRI demonstrates the lesion with a distinct cartilaginous cap that can appear dark on T1- and bright on T2-weighted imaging. The natural history of osteochondroma is slow growth of the le-

sion until skeletal maturity; however, lesions can regress during childhood and puberty.²⁷ Surgical treatment is the standard, and complete resection is often curative, with significantly reduced pain and alleviation of neurological dysfunction. The risk of recurrence is low, and no adjuvant therapy is needed.²⁷ In the setting of regrowth, reoperation is recommended. In 10% of cases, malignant transformation can occur, resulting in osteosarcoma.⁴⁵

Osteosarcoma

Osteosarcoma is the most common primary malignant bone tumor, and about 5% of all osteogenic sarcomas are lesions of the spinal column. They are most commonly located in the thoracic and lumbar spine (Fig. 2).⁵⁰ Lesions can present anywhere along the vertebrae, but the most common location is the vertebral body with extension into the spinal canal and pedicles (Fig. 1). Most children diagnosed with osteosarcoma are between 10 and 20 years of

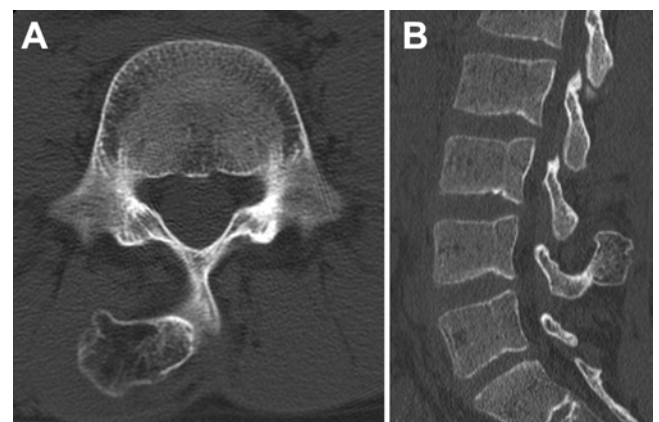


FIG. 5. A 15-year-old boy presented with a lump on his lower back that slowly increased in size over time. Axial (A) and sagittal (B) CT demonstrated a lesion consistent with an osteochondroma emanating from the spinous process of L-4 on the right. The lesion was subsequently resected. The patient had no clinical or radiographic recurrence on follow-up.

age.¹¹ Children can present with pain, soft tissue swelling over the lesion, or neurological dysfunction; in fact, up to 40% have neurological abnormalities on presentation.⁵⁰

Imaging findings in osteosarcoma can vary. Plain radiographs can demonstrate a radiolucent, radiodense, or mixed radiolucent-radiodense destructive lesion.²⁷ Magnetic resonance imaging can be helpful in narrowing the diagnosis: the bony component of the tumor is hypointense on T1- and T2-weighted imaging, whereas the adjacent soft tissue mass is hyperintense on both T1- and T2-weighted imaging (Fig. 6).²⁷ A soft tissue mass invading the spinal canal can be present in more than 80% of patients with osteosarcoma,¹¹ so neurosurgeons should maintain a high index of suspicion when coming across such findings.

The surgical treatment for osteosarcoma of the spine is based on location and the ability to safely achieve wide margins.²⁷ After tissue diagnosis is obtained, through either en bloc resection or biopsy, neoadjuvant chemotherapy is administered to treat the primary tumor and metastatic lesions.²⁷ Because of the anatomical constraints of the spine and tumor blood supply, surgical planning is of the utmost importance. Use of the Weinstein-Boriani-Biagini (WBB) and Enneking spinal tumor staging systems can assist in surgical planning.^{20,28} The WBB staging system divides the spine segments with the tumor into 12 radiating zones and also takes into account the transverse plane and 5 layers (A to E, from the paravertebral extraosseous region to the area of dural involvement) of the spine segment.^{20,29} Enneking et al.²⁸ also proposed staging based on tumor compartments and anatomical barriers, a system that was later adopted to the spine by Tomita et al.,⁹⁶ who concluded that one vertebra could be considered as a single oncological compartment and its surrounding tissues (ligaments, periosteum, and cartilage) as barriers.^{29,96} These tools are the hallmarks of oncological spine surgery and should be considered when planning surgery on a primary or metastatic osseous tumor in the pediatric spine.

Although the combination of chemotherapy and local-control surgery has improved survival rates for children with osteosarcoma,^{7,76} the 5-year mortality rate remains high for patients with osteosarcoma of the spine, with a median overall survival of 29.5 months.⁸⁸ Ozaki et al.⁷⁶ demonstrated a median survival of 23 months, with 3 of 22 patients surviving without disease for > 6 years after treatment; these authors found that patients with primary metastases, large tumors, and sacral tumors had lower overall survival.

Aneurysmal Bone Cyst

Aneurysmal bone cysts represent 1.4% of all primary bony tumors,²⁵ and the spinal column is affected anywhere from 3% to 20% of the time.^{25,100} Patients with aneurysmal bone cysts usually present within the first 2 decades of life (Table 1)^{27,100} and have symptoms of localized pain that worsens with activity. Neurological symptoms can occur as the lesion compresses the neural structures; pathological fractures can also occur, leading to spinal instability as normal vertebral elements are infiltrated and replaced.⁴⁵ These lesions have a predilection for the posterior elements of the vertebrae (70%) and most commonly occur in the lumbar spine (Table 3),^{35,47,65,78} although they can also occur

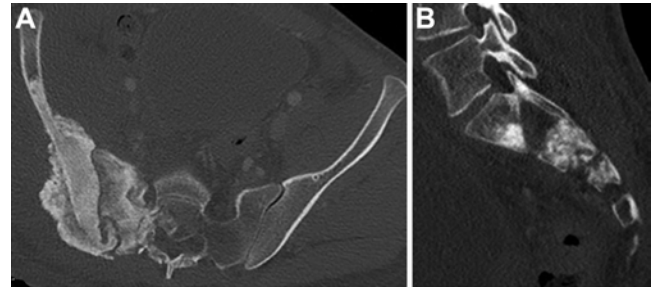


FIG. 6. A 15-year-old boy presented with worsening pelvic pain. **A:** Axial CT showed a lesion consistent with osteosarcoma involving the right sacrum and iliac with osteoid matrix and lobular contours with areas of calcification in the sacrum. **B:** Sagittal reformat demonstrating lateral extension of the tumor abutting the right S-1 and S-2 nerve roots. The patient had metastatic disease with pulmonary, thoracic paraspinous, and acetabular lesions. He continues to have disease progression despite treatment with chemotherapy and palliative radiation.

in the thoracic and cervical spine (Figs. 7 and 8). They can extend into the pedicle and vertebral body and span multiple vertebral levels.²² On occasion, aneurysmal bone cysts can be associated with additional bone lesions, including Langerhans cell histiocytosis, chondroblastoma, giant cell tumor, and osteosarcoma.²⁷ In such cases, the patients will require long-term follow-up even after treatment.

Plain radiographs often show an expansile, radiolucent lesion. Magnetic resonance imaging demonstrates a multiloculated, septated expansile lesion with obvious fluid-fluid levels that generate hypointense signal on T1-weighted images and hyperintense signal on T2-weighted images (Fig. 7).²⁷ The fluid-fluid levels in the central region of the trabeculae are surrounded by an “eggshell” rim of cortical bone.⁴⁵ Computed tomography can also be useful in determining the extent of bone involvement.

Surgical intervention includes obtaining a tissue diagnosis, although this is often not necessary because of the lesion’s unique appearance on preoperative imaging, followed by complete resection, and stabilization, if necessary based on tumor location. Aneurysmal bone cysts are considered benign but locally aggressive lesions.⁴⁷ Histologically, the lesions have a hemorrhagic component with findings of hemosiderin-laden macrophages, multinucleated giant cells, fibrous tissue, and expansion of the cortical margins.⁴⁵

Historically, surgical treatment involved only intralesional curettage, but this was followed by recurrence rates up to 60%.^{19,22,47,78} Additional intraoperative steps—cauterization of the osseous cyst wall, extended curettage with a high-speed diamond bur, and dilute (5%) phenolization with avoidance of the dura or major blood vessels—have drastically reduced the recurrence rate of intralesional curettage alone.³⁵ Although en bloc resection is the goal, it is often not feasible; thus, thorough intralesional curettage should be performed. For larger aneurysmal bone cysts with involvement of multiple vertebral levels and significant ventral extension, preoperative embolization should be considered; although rare, intraoperative death from hemorrhage has been reported.⁷⁸ The use of serial embolization alone has been reported for spinal aneurysmal bone cysts;¹⁹ however, its use should be reserved for

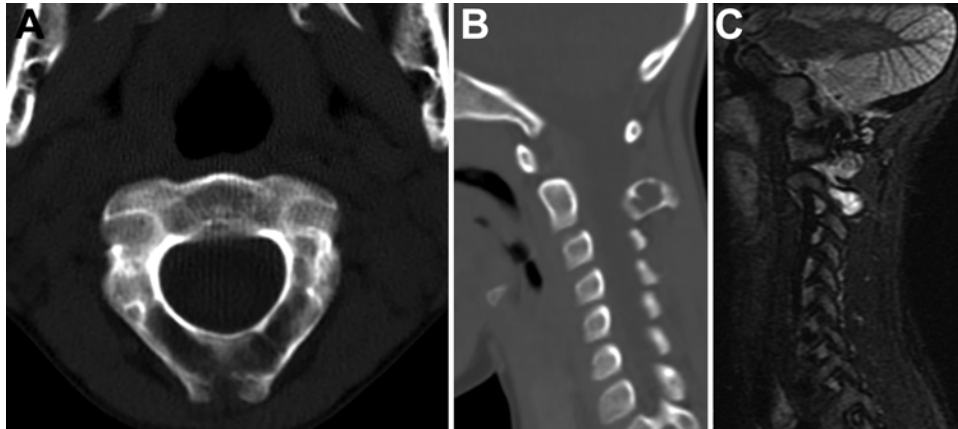


FIG. 7. A 7-year-old boy who presented with neck pain that worsened with activity was found to have an aneurysmal bone cyst at C-2 on imaging. **A:** Axial CT showed an expansile lytic lesion of C-2 involving both laminae and the left pedicle. **B:** Sagittal CT demonstrated normal height of the vertebral bodies and no associated soft tissue mass. **C:** Sagittal T2-weighted MR image demonstrated an expansile lesion in the posterior bony elements of C-2 with layering fluid-fluid level. The patient underwent C-2 laminectomy for removal of the lesion. One year postresection, he has had no radiographic recurrence.

lesions located in areas that are difficult to access surgically. After removal of the lesion, instrumentation and fusion may be necessary to maintain spinal alignment and stability (Fig. 8).

Residual aneurysmal bone cysts have a high propensity for progressive enlargement with the potential for symptom recurrence.⁴⁵ The presence of residual or recurrent aneurysmal bone cyst after an initial surgical attempt is not uncommon, with rates as high as 14%.^{75,78,109} Recurrence can be delayed, but the most common scenario is recurrence within 6 months.⁷⁸ Even in the setting of recurrent or residual aneurysmal bone cyst, the preferred treatment modality is surgery. The use of denosumab, a human monoclonal antibody that inhibits osteoclast function by inhibiting the cytokine receptor activator of the nuclear factor- κ B ligand (RANKL) and is approved for the treatment of giant cell tumors of the bone (see below), has also been reported in 2 children with recurrent aneurysmal bone cysts after surgery⁶¹ and 1 adult with a large sacral aneurysmal bone cyst.⁹² All 3 patients had pain relief with no side effects and showed no progression of the lesion on

follow-up. As this represents a potential novel treatment option, further study is warranted.

Eosinophilic Granuloma

Eosinophilic granuloma is an umbrella term that encompasses a heterogeneous group of conditions characterized by the presence of a benign destructive osteolytic lesion with proliferation of a dendritic cell type called Langerhans cells, which are antigen-presenting cells. Syndromes that encompass eosinophilic granuloma include Langerhans cell histiocytosis (histiocytosis X), Hand-Schüller-Christian disease, and Letterer-Siwe disease. Solitary eosinophilic granuloma can involve any bones but most commonly occurs in the skull (calvaria and temporal bones), ribs, mandible, pelvis, and spine.⁴⁰ Involvement of the vertebral column occurs in 10%–15% of children with eosinophilic granuloma,⁶⁴ and the thoracic and cervical segments are the most common locations.^{30,34,82,107} Eosinophilic granuloma can occur at any age, but most often occurs in children younger than 15 years of age (Table 1), with males being more affected than females.²¹ Spinal eo-

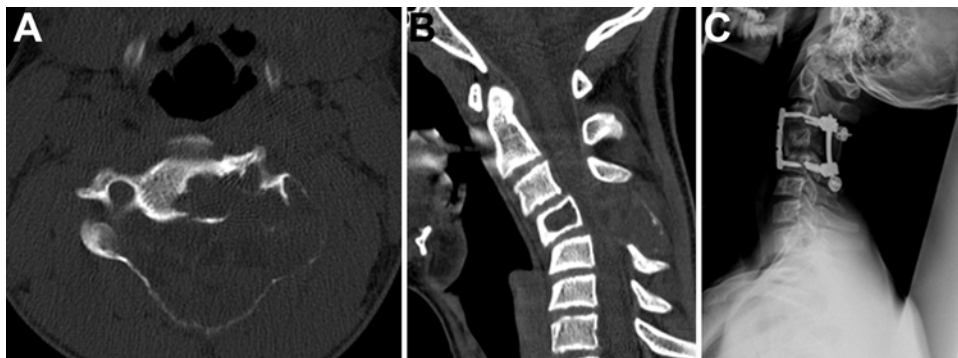


FIG. 8. A 13-year-old boy who presented with neck and shoulder pain and a large aneurysmal bone cyst at C-4. **A:** Axial CT demonstrating an expansile lytic lesion of C-4 including body and neural arch elements. **B:** Sagittal CT showed 27° focal kyphosis at the C4–5 level. **C:** Lateral postoperative radiograph following C-4 laminectomy for excision of the aneurysmal bone cyst, followed by posterior instrumentation from C-3 to C-5, then an anterior C-4 corpectomy with C3–5 fusion. Cervical spine radiographs at 3 years revealed a stable appearance of the cervical spine. The patient has had no recurrence and has required no further treatment.

sinophilic granuloma can present as pain and a restricted range of motion;⁵⁷ however, neurological deficits occur rarely.^{13,40} Patients who present with neurological symptoms can have weakness or pain secondary to nerve root compression from vertebral body collapse or, in severe cases, can have early progressive myelopathy with gait dysfunction.

Radiographic findings in eosinophilic granuloma range from lytic lesions to vertebral collapse (partial to complete collapse) with normal adjacent disc spaces and lack of soft tissue mass or extraaxial spread.³⁴ The vertebral collapse is secondary to the osteolytic lesion of the underlying bone and can progress to vertebra plana (Fig. 9).⁶⁰ Computed tomography and plain radiography can demonstrate bony destruction. Magnetic resonance imaging can be performed to further characterize these lesions and evaluate for soft tissue involvement. Flexion-extension radiographs of the spine can provide insight into the presence of a kyphotic spinal deformity secondary to the lesion. Additionally, a skeletal survey can be used to search for other lesions associated with multifocal disease.³²

Management of spine lesions is individualized and tailored to clinical and radiographic presentation. Bertram et al.¹³ reported that most cases of spine involvement included in a meta-analysis were managed with observation. Surgical intervention with excision, segmental fusion, or internal fixation is reserved for patients with neurological deficit, spinal instability, and noncompliance with external bracing. Open or CT-guided biopsy is performed when definitive diagnosis is sought. Chemotherapy is only recommended for disseminated forms of eosinophilic granuloma.⁴⁶ Radiotherapy is no longer recommended because of the long-term risks of the development of malignant tumors in the radiation field, although radiotherapy is considered by some physicians in the treatment of solitary bony lesions in children.³¹

Giant Cell Tumor

Giant cell tumors represent 5% of all primary bone tumors.⁹⁷ Although they do not typically present until the 3rd or 4th decade of life,²⁷ they can very rarely occur in children. There is an overall predilection for females.⁴⁵ Pain, localized swelling, and tenderness are the most common presenting symptoms, although spinal cord compression from tumor extension can occur as well.²⁷ Giant cell tumors most commonly present in the sacrum but can also occur in the cervical spine (Fig. 2).⁴⁵ If located in the sacrum, they can enlarge and involve the sacroiliac joints causing secondary referred pain. Those outside of the sacrum often involve the vertebral body,⁴⁵ but vertebral lesions are rare, especially in children.⁸⁹

Giant cell tumors are benign but locally aggressive lesions. Radiographs demonstrate an area of expansile focal destruction that projects as a “radiolucent zone” without a cortical margin. Computed tomography and MRI can be helpful adjuncts in diagnosis and for preoperative staging.²⁰ Giant cell tumors are contrast-enhancing expansile lesions on MRI (Fig. 10). Once the diagnosis of giant cell tumor is suspected, chest imaging should be performed to rule out pulmonary lesions, which can be present in up to 9% of patients with a giant cell tumor.^{12,54,84}

The treatment of children with giant cell tumors should

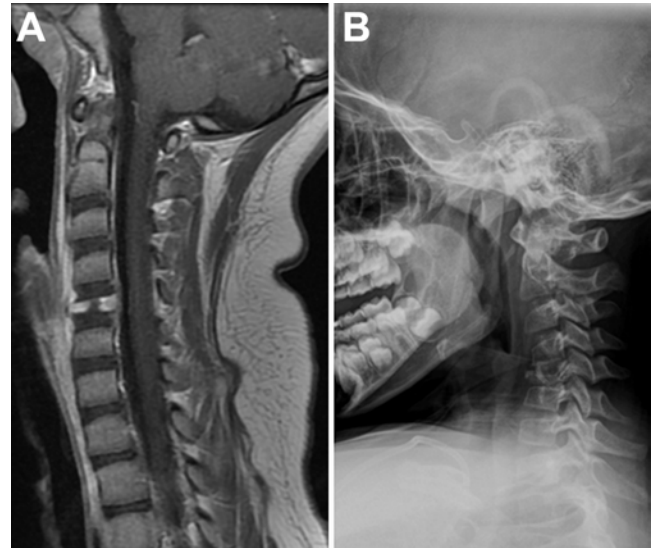


FIG. 9. A 7-year-old girl presented with neck pain and was found to have an eosinophilic granuloma of the C-5 vertebral body. **A:** Sagittal T1-weighted MR image with gadolinium demonstrated a C-5 pathological fracture with near-complete loss of vertebral height (vertebra plana). **B:** The patient developed worsening kyphosis (shown), and early myelopathy was treated with a C-5 anterior corpectomy and interbody fusion from C-4 to C-6. Cervical spine radiographs at 2 months after surgery demonstrated stable alignment with osseous fusion from C-4 to C-6.

be primarily surgical. There is a high risk of recurrence (80%), so wide resection of the lesion should be undertaken when possible.¹⁰² When the giant cell tumor is located within or adjacent to the vertebral body, resection can be difficult; thus, the extended curettage technique can be employed, as described above.^{17,27,44} Embolization has also been used as the sole primary treatment in some cases;⁶⁶ more recently, the successful use of bisphosphonates has been reported.^{37,110} Radiation therapy can be used, but given the overall benign histological profile of giant cell tumors, it should be reserved for patients with inoperable lesions.⁷⁴ The use of denosumab, a monoclonal antibody, has been described for the treatment of giant cell tumors of the bone.¹⁰⁶ Denosumab targets RANKL, which is expressed by giant cells and is the cause of the aggressive osteolytic nature of the tumor. In an open-label phase 2 study of patients with unresectable giant cell tumors who received denosumab, 30 (86%) of 35 demonstrated tumor response to the drug via histology or radiology.⁹⁵ The antibody was approved by the US Food and Drug Administration for the treatment of unresectable giant cell tumors of bone in adults and skeletally mature adolescents, or when resection is unsafe or will cause significant morbidity;² thus, it can be an option for difficult-to-access lesions in the vertebral column.

As with the other primary osseous lesions of the spine, instrumentation should be used in the setting of mechanical instability; caution should be exercised in choosing the hardware to minimize artifacts on postoperative imaging studies. Close follow-up is important to monitor for signs of recurrent tumor, especially in patients with locally aggressive disease and residual tumor burden after surgery.

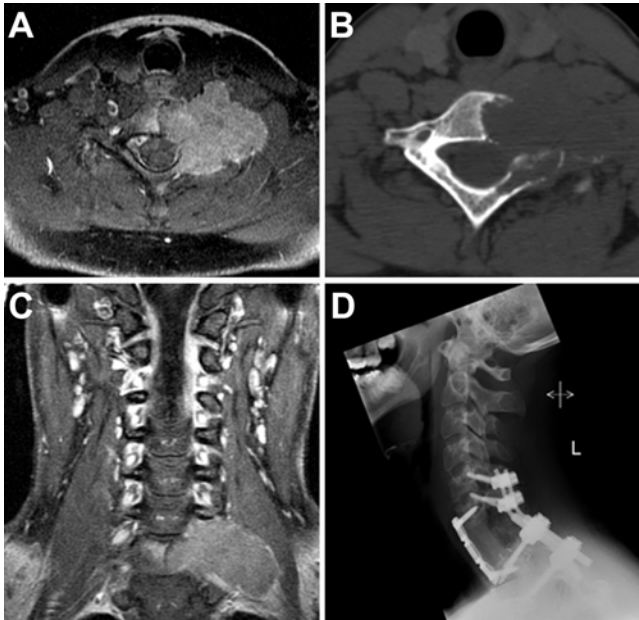


FIG. 10. A 16-year-old boy presented with left arm numbness. Axial (A) and coronal (B) T1-weighted MR images with gadolinium demonstrated a mass centered around the left side of C-7 involving the vertebral body and invasion into the surrounding structures including trunks of the lower brachial plexus. Axial CT (C) showed an erosive soft tissue mass with destruction of the left C-7 vertebral body, pedicle, and lamina. The lesion (D), diagnosed as giant cell tumor, was removed in a 2-stage procedure consisting of posterior resection with C6–T1 laminectomies and posterior spinal fusion from C-5 to T-2 with resection of tumor invading into the brachial plexus, followed by an anterior C-7 corpectomy and anterior cervical fusion from C-6 to T-1. Computed tomography of the cervical spine and soft tissue 7 years after surgery showed no recurrence; no further treatment was necessary.

Ewing Sarcoma

Nearly 75% of cases of Ewing sarcoma occur in children between the ages of 5 and 15 years.⁶³ Ewing sarcoma is the most common primary malignant bone tumor seen in the pediatric spine. It is thought that between 3.5% and 10% of all cases of Ewing sarcoma originate in the spine.^{99,104} Spinal lesions can be primary or metastatic. The sacrum is the most common location for these lesions to occur, followed by the lumbar and thoracic spine, and rarely the cervical spine.⁹⁹

Venkateswaran et al.⁹⁹ presented evidence that the most commonly reported presenting symptoms were pain (9%) and neurological deficit (9%). In some children, there can be an associated tender soft tissue mass. Like children with other malignancies, children with spinal Ewing sarcoma can have constitutional symptoms including weight loss and fever; serum inflammatory markers are also elevated in most children.²⁷

Although Ewing sarcoma typically has a characteristic moth-eaten appearance with a large soft tissue mass in long bones and aggressive periosteal new bone formation with an “onion skin” appearance, its appearance in the spine is not as distinguishing.²⁷ Radiographs or CT imaging may show vertebra plana with an associated soft tissue mass. Magnetic resonance imaging can detect bone lesions but is mostly used in identifying and evaluating the

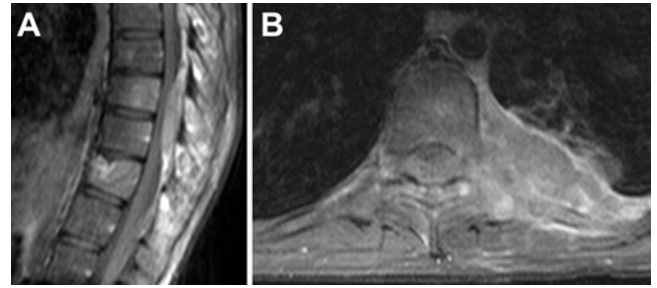


FIG. 11. A 17-year-old girl presented with progressive back pain and difficulty walking. A: Sagittal T1-weighted MR image with gadolinium showed a T9–10 epidural mass causing cord compression. B: Axial T1-weighted MR image with gadolinium demonstrated bony destruction of the pedicle of T-9 on the left side and associated large left-sided paraspinal mass. The patient underwent emergent T7–10 laminectomies for resection of the extradural tumor identified on histopathology as Ewing sarcoma. She is currently undergoing chemotherapy and radiation treatment.

extent of soft tissue involvement and epidural compression (Fig. 11).²⁷ Grossly, tumors often appear firm, gray, and friable with distinct areas of hemorrhage and necrosis.⁴⁵

The treatment for Ewing sarcoma has evolved significantly. Current treatment recommendations include biopsy with initial chemotherapy and radiation therapy for high-grade malignancies. Salvage surgery for residual tumor can be considered based on location and prognosis. Spinal resection and reconstruction (spondylectomy) can be considered following chemotherapy to reduce the risk of local recurrence, with improved long-term survival compared with that following intralesional excision or radiation therapy;²⁶ cases involving the sacrum may involve pelvic fixation and reconstruction. In the case of lower-grade tumors, surgery followed by adjuvant chemotherapy and radiation is the current treatment standard.^{42,111}

For surgical planning, location is key and plays an important role in survival. For instance, lesions that present in the sacrum are often large prior to diagnosis, making en bloc resection technically challenging.⁹ Lesions of the mobile spine, however, often present earlier and are more amenable to resection. For Ewing sarcoma, subtotal or partial resection should be avoided; en bloc resection with negative tumor margins should be the surgical goal.^{9,15}

Unfortunately, metastatic disease can be present in 25% of patients at presentation. The most common locations for metastatic spread include the lungs, other osseous sites, the lymphatic system, the brain, and the abdominal viscera.^{7,99} Although it is an aggressive lesion, Ewing sarcoma has responded more favorably than other sarcomas to radiation, and many patients can respond well to external beam radiation.⁵⁸ Survival for patients with Ewing sarcoma of the vertebral column is better than that for patients with osteosarcoma; children with an isolated vertebral column lesion have a median survival of 90 months, and those with evidence of metastatic disease have a median survival of 20 months. The 5-year overall survival rate is 41%.⁷²

Favorable factors for survival in Ewing sarcoma include age < 10 years, tumor volume < 100 ml, positive response to chemotherapy, and en bloc resection.¹⁵ Negative factors include metastatic disease, tumor larger than 8 cm, elevated white blood cell count or erythrocyte sedimentation

rate, and poor response to chemotherapy (< 90% reduction of tumor volume).¹⁰⁵

Additional Tumors

Although the focus of this review is primary osseous tumors of the pediatric spinal column, several other pathologies can present with symptoms and neurological deficits similar to those of the aforementioned lesions.

Neuroblastoma

Neuroblastoma stands as the most common extracranial solid tumor in children, and the most common neoplasm in infants.⁴⁵ It also represents the most common malignant tumor of the spine and spinal cord treated by neurosurgeons. Lesions arise from the sympathetic nervous system, adrenal glands, and ganglia of the thoracic, cervical, and pelvic regions and grow to a large size before there is spinal involvement. These lesions typically encroach on neural foramina and result in a dumbbell configuration.⁴⁵ Metastatic spread of neuroblastoma with epidural compression of the vertebral column can occur; thus, in a patient with a significant history and evidence of soft tissue compression of the epidural space, neuroblastoma should be considered. The lesion is sensitive to chemotherapy and radiation, but surgical decompression can be considered in the setting of acute neurological decline. Parikh et al.⁷⁹ reported on 22 patients, 19 of whom attained a favorable outcome and long-term survival. Sandberg et al.⁸⁷ concluded that high-risk neuroblastoma patients with high-grade spinal cord compression may respond to chemotherapy, but a percentage will require surgical decompression for progressive neurological deficits. For patients at low risk, the 5-year survival rate is greater than 95%; for those in the intermediate-risk group, the rate is between 90% and 95%; and for those in the high-risk group, the rate is between 40% and 50%.⁵ The decision to pursue surgery, however, should be balanced with the timing and degree of symptoms, the risk for postoperative deformity, and the chemo- and radiosensitivity of the tumor.⁵³

Rhabdomyosarcoma

Rhabdomyosarcomas account for 8% of pediatric solid tumors.⁴⁵ When there is spinal involvement, this lesion occurs in a manner similar to neuroblastoma, that is, a dumbbell-shaped tumor with a large paraspinal soft tissue mass that can present with epidural compression.⁴⁵ Rhabdomyosarcoma is sensitive to chemotherapy and radiation, so surgery should be reserved for patients with neurological deficits.²⁴

Chordoma

Chordomas are locally aggressive lesions that arise because of malignant transformation of notochordal elements, the embryological source of the nucleus pulposus. They are rare in children but can arise primarily in the skull base at the sphenoid-occipital junction, occasionally in the mobile portion of the spine, and infrequently in the sacrococcygeal region (Fig. 2).⁹¹ Because of the cell of origin, there is inherent involvement of the vertebral body and associated osteolysis and a large associated soft tissue

mass.⁴⁵ Surgery for chordomas includes en bloc resection with tumor-free margins; proton beam radiotherapy is used for residual or recurrent tumor.¹⁶ For chordomas located at the skull base, radical excision is the treatment of choice. Occipitocervical fusion may be necessary, depending on tumor location and infiltration at the time of diagnosis,¹⁰ if there is a risk of mechanical instability. Chordomas involving the sacrococcygeal region may also require stabilization if radical resection is pursued, but it may be difficult and could necessitate pelvic fixation and reconstruction. The use of imatinib in locally advanced chordoma has been described, with a > 70% arrest of tumor growth, a median duration of response of 10 months, and > 20% of patients with the absence of progression at 18 months.⁴⁹ Sunitinib and imatinib have also been used,⁶² and there are additional molecular therapies on the horizon. The 5-year survival rate is approximately 50%.^{83,93}

Conclusions

Although primary osseous spinal column tumors are rare in children and young adults, a high index of suspicion should be maintained when evaluating children with back pain either with or without neurological dysfunction. Primary osseous lesions of the pediatric spine can be benign or malignant and commonly present diagnostic and therapeutic challenges. A thorough understanding of the clinical and radiographic findings in each of these pathological conditions can help facilitate diagnosis and appropriate treatment. Surgical decision making can be guided by a complete understanding of the pathology. When properly performed, surgery can often lead to a complete resolution of pain and neurological symptoms.

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Disclosures

Dr. Schmidt is a consultant for Ulrich Medical USA.

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Conception and design: Brockmeyer, Ravindra. Acquisition of data: Ravindra, Eli. Analysis and interpretation of data: all authors. Drafting the article: Ravindra, Eli. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Brockmeyer. Study supervision: Brockmeyer.

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