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Seminars in
ROENTGENOLOGY

Percutaneous Treatment of Musculoskeletal Disease in Children

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Introduction

There are a myriad of benign and malignant conditions that can cause pain, deformity or pathological fracture in the pediatric musculoskeletal system. While numerous treatment strategies are available, there is growing utilization of percutaneous image-guided techniques in the treatment of both painful benign tumors (eg, osteoid osteoma) and malignant tumors (eg, osteosarcoma), as well as post-traumatic, infectious, and inflammatory conditions. The development of thermal ablation techniques (eg, radiofrequency, microwave, laser, and cryoablation) in combination with percutaneous biopsy offers simultaneous diagnosis and treatment with a low risk of complication and morbidity. In addition, the use of percutaneous irrigation in the treatment of septic arthritis and steroid injection in treatment of bone cysts and inflammatory arthritis has shown benefit in children. Each technique has its advantages, disadvantages and a safety profile that should be familiar to the practicing radiologist. This article will review the most common pediatric musculoskeletal conditions treated percutaneously by pediatric interventional and musculoskeletal radiologists.

Benign Bone Tumors

Osteoid Osteoma

The percutaneous treatment of musculoskeletal neoplasms began with osteoid osteoma (OO) management. The history of OO treatment is helpful for understanding the evolution of percutaneous treatment in the musculoskeletal system. Rosenthal first introduced successful treatment of OO with radiofrequency ablation (RFA) in 1992.[1] In 1998, Rosenthal et al demonstrated equivalence of RFA with surgery for management of OO with fewer complications, lower cost, and morbidity.[2] RFA subsequently became the standard of care for treatment of OO. Since then, there have been numerous publications demonstrating success in treating benign bone and soft tissue tumors using an array of percutaneous ablation techniques.

OO is a benign bone-forming tumor, histologically composed of disorganized trabeculae and prominent osteoblasts. It accounts for approximately 13% of benign bone tumors, and typically affects adolescents, teens, and young adults with a 2:1 male to female preponderance. The tumor causes significant local and occasionally diffuse pain due to a combination of local proliferation of nerve fibers and prostaglandin release. The pain is classically sharp, pinpoint, worse at nights, and relieved by salicylates.[3,4] Although there are reports of lesions becoming asymptomatic in 2-8 years if treated conservatively,[5] most patients are not able to tolerate the pain or side effects of nonsteroidal ant-inflammatory drugs for that long.[2]

OO has 3 histologic subtypes (cortical, medullary, and subperiosteal) with resulting variable imaging appearance. The classic and most common appearance is local reactive osteosclerosis, cortical thickening, and periosteal reaction. A lucent nidus, with or without central calcification, is often present (Fig. 1). On magnetic resonance imaging (MRI), there can be varying amounts of peritumoral edema, which is more commonly seen in young children.[6] Accurate localization of the nidus is crucial for successful treatment of symptoms, and is most easily achieved with computed tomography (CT), although larger lesions are often apparent on radiography or fluoroscopy.[3]

While CT-guided RFA is considered the standard of care, more recently, other ablation techniques including cryoablation, laser photocoagulation, and microwave ablation have been shown to be as effective as RFA with favorable safety profiles.[7-9] Regardless of ablation technique, percutaneous access to the tumor is obtained with imaging guidance and a combination of manual bone biopsy device (Bonopty-Apriomed, Uppsala, Sweden), hand drill, or powered drill (OnControl - Teleflex, Morrisville, NC). General anesthesia is typically required because of the extreme pain incurred by the patient upon OO penetration.

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 https://doi.org/10.1053/j.ro.2019.06.006

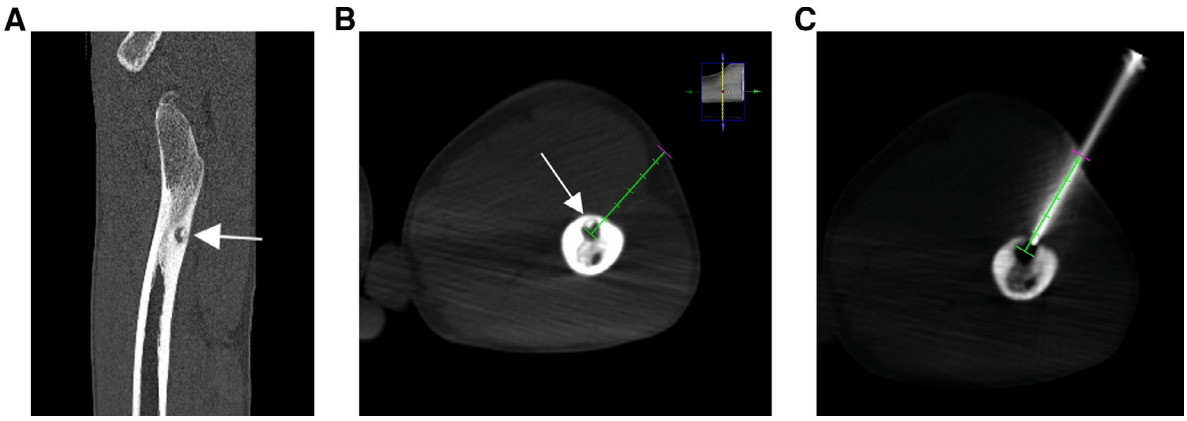

Figure 1 An 8-year-old boy with focal pain in his proximal thigh secondary to an osteoid osteoma of the proximal femur. Sagittal CT image (A) demonstrates classic imaging appearance including a focal lucent nidus (white arrow) with central sclerotic dot and surrounding reactive sclerosis. Intraprocedural axial CT image (B) prior to cryoablation demonstrates the nidus (white arrow). Intraprocedural axial CT image (C) after placement of introducer cannula through the cortex. His symptoms resolved within 24 hours of the procedure.

For RFA ablation, grounding pads are placed on the patient's thighs prior to draping the area. Once accessed, the RFA probe is placed into the biopsy cavity, with the ablation zone of the probe traversing the target area. RFA ablation is typically performed for 4-6 minutes at 90°C with an impedance of 200-600 Ω.[10] Although highly effective in smaller lesions, the high impedance of bone requires placement of multiple probes to assure complete treatment of larger OO and osteoblastoma. Microwave ablation (MWA) offers diffuse tissue heating of the ablation zone, as the heating occurs through excitation of water molecules within the ablation zone, rather than from a point source.[11] MWA is performed for a minimum of 30 seconds at 30 watts for 3 to 4 cycles.[12] MWA is effective, but, until recently, was reserved for specific cases refractory to RFA, or in institutions where RFA is not readily available. Reported complications have been higher with MWA due to elevated ablation temperatures. However, recent case series have shown that the technique has complication rates similar to other ablation technology.[12] Cryoablation is typically performed for 2 10 minute freeze cycles at −40°C, each followed by 5 minutes of active thaw time.[13] Cryoablation has been shown to be less injurious to periarticular tendinous and ligamentous structures, and therefore may be the treatment of choice for at risk joints.[14] Laser ablation has similar efficacy to RFA, and has the added benefit of being MRI compatible. Laser ablation occurs through thermal heating from the laser fiber tip. Therefore, in contrast to other techniques where the emission segment is positioned across the target, laser needle/fiber tip position should be placed at the center of the lesion of the target zone.[4] MR guided focused ultrasound (MRgFUS) has shown significant promise as a truly minimally invasive procedure, but requires availability of expertise and equipment that many institutions lack. MRgFUS is also limited by depth of penetration of sound beams and requires lesions to be somewhat superficial in the bone.

Technically, procedure planning should focus on obliterating the nidus while preserving or avoiding adjacent neurovascular structures and skin injury. Failed treatment is rare (generally reported at <5%), but usually related to inability to adequately treat the nidus. OO's occur throughout the skeleton and can be technically difficult to access and treat (Fig. 2). Treatment of spinal OOs should prompt utilization of neuromonitoring, thermal monitoring, and utilization of

Figure 2 A 17-year-old boy with focal pain on his wrist secondary to an osteoid osteoma of the distal pole of the scaphoid. A coronal T1-weighted MR image shows a well-circumscribed, heterogenous, predominantly T1 hypointense lesion (arrow) of the distal pole of the scaphoid with adjacent marrow edema. Intraprocedural axial cone-beam CT image demonstrates the lesion (arrow) on the dorsal aspect of the scaphoid. Additional intraprocedural axial cone-beam CT image shows the cryoprobe (arrow) within the lesion prior to freezing.

adjunctive strategies to avoid nerve injury related to direct thermal injury or heating of cerebral spinal fluid, when nerves or the spinal cord are at risk.[12] Care should be taken to keep the skin out of the treatment field, as skin ulceration and necrosis can occur with all modalities.[13] If cryoablation is the ablative technology utilized, placing a sterile glove filled with warm saline over the skin adjacent to the treatment zone can mitigate skin freezing (Table 1).

Postprocedure care focuses on recovery from sedation/anesthesia and pain control in the short term, and prevention of pathologic fracture in the long term. Occasionally patients have immediate pain relief, but most patients require postprocedural pain control for the first day or 2, rarely up to a week. Many patients notice cessation of tumor related pain within 24 hours.[15] For larger ablation zones in weight-bearing bones with risk of fracture, or in those where ambulation is limited because of pain, it is best to arrange for preprocedure crutch training. Ambulation assistance in younger patients can be difficult, as they often lack the coordination required to use crutches. If necessary we have used walkers to assist patient postprocedure. There is limited consensus regarding activity restrictions post-treatment. Most patients can return to daily activities immediately and sports activity within a week. If the procedure is performed in a weight-bearing bone, stressful weight-bearing or long-distance running should be avoided for 3 months.[10,15] Although there are no specific criteria that increase fracture risk, in practice the authors use greater precaution in patients who will not self-limit activity, have larger lesions, lesions without sclerosis, femoral neck lesions (intra-articular) and those with recurrent symptoms. Clinical follow-up can be obtained 1 month after the procedure to ensure resolution of symptoms. Imaging follow-up is usually not necessary unless symptoms reoccur.

Chondroblastoma

Chondroblastoma is a benign bone tumor that usually occurs in the epiphyses of long bones in teenagers and young adults. They account for less than 3% of benign bone tumors and are twice as common in males. Patients typically present with pain and limited movement in the adjacent joint. Chondroblastoma do not spontaneously resolve, have reported recurrence rates of 8%-20%, and have a rare reported risk of malignant transformation, therefore intervention is necessary.[16,17] Imaging features are characteristic and consist of a lucent lesion in the epiphysis or apophysis (epiphyseal equivalent) of long bones. MR demonstrates a well-circumscribed lesion with low to intermediate T1 and T2 signal internally. There is usually surrounding marrow edema and joint effusion as well, which accounts for the pain caused by these lesions.[18,19]

Although surgical curettage and packing is the current standard of care, numerous case series have been reported demonstrating efficacy and safety of radiofrequency ablation.[16,17,19,20] The largest study to date with long-term follow-up of patients treated with RFA demonstrated a recurrence rate of 12%.[21] Surgical curettage and cryosurgery has also been reported in the orthopedic literature demonstrating a lower recurrence rate.[22] Because chondroblastoma are typically epiphyseal in location, careful attention should be paid to both the joint cartilage and growth plate when planning the ablation zone (Fig. 3). Biopsy can be performed at the time of ablation in a single procedure if the diagnosis is in doubt.[16]

Unicameral Bone Cyst

Unicameral or solitary bone cysts are benign fluid-filled cystic lesions, usually seen in children in the second decade of life (80%), and often diagnosed either incidentally or following a pathological fracture.[23] These lesions make up approximately 3% of benign bone lesions, and usually involve long bones with about 70% occurring in the proximal humerus. Radiography and CT demonstrate a lucent metaphyseal well-circumscribed, expansile, oblong lesion aligned with the longitudinal axis. MR may reveal homogeneous or heterogeneous fluid signal, occasionally with a fluid-fluid level.

Table 1 Osteoid Osteoma Ablation Modalities

Technique	Cycle Parameters	Notes
Radiofrequency Ablation (Motamedi et al 2009)	Duration/Cycle: 3-6 minutes Intensity: 90°C Cycles: 1-2	Cool skin with moist cool sterile water. Retract or remove any conducting canula from the tip of the RFA probe (min 1 cm gap).
Cryotherapy (O'Dell et al 2018)	Duration/Cycle: 10 freeze / 5 thaw Intensity: -40°C Cycles: 2	Use sterile glove filled with warm saline to mitigate skin freezing.
Laser Ablation (Gangi et al 2007)	Duration/Cycle: 6-10 minutes Intensity: 2-5 W/active cm (max 1200 J) Total Energy = (Nidus Size (mm) × 100) + 200 Cycles:1	Tip centered in center of target lesion. Perform pre-char of probe if "dry." Area of treatment dependent on cumulative energy delivered. max ~16 mm
Microwave Ablation (Rizler et al)	Duration: 30s Active/30s Cooling (minimum) Intensity: Min 30 Watts/90°C Cycles 3-4	Insensitive to high impedance. Energy must be modulated to prevent nontarget thermal damage.

Exact parameters vary based on equipment specifications and local preferences. The above information is general reference and should be validated with your medical equipment manufacturer.

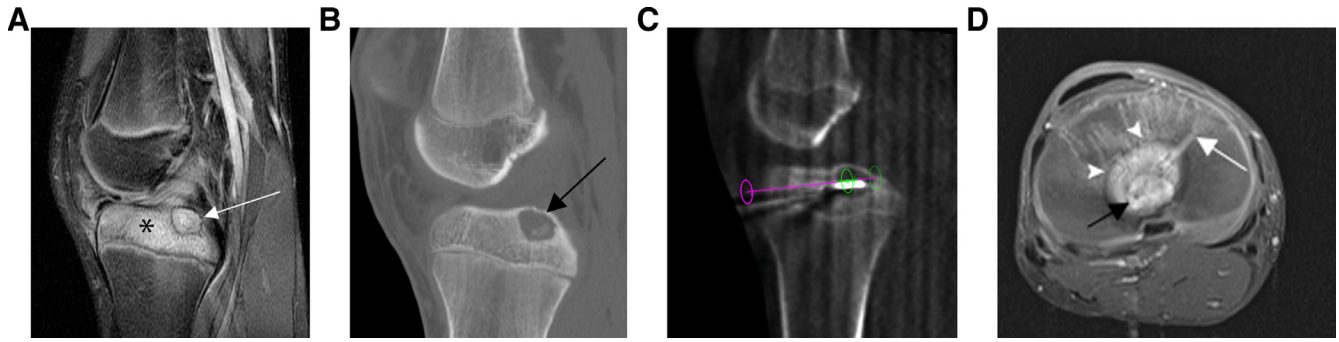

Figure 3 A 15-year-old boy with a painful osteochondroma of the tibial epiphysis. (A) Sagittal T2-weighted MR image of the knee demonstrates the well-circumscribed T2-hyperintense lesion (arrow) with surrounding bone marrow edema (asterisk). Sagittal CT image (B) shows a lucent lesion with internal chondroid matrix (arrow). An intraprocedural sagittal cone-beam CT image (C) utilizing software guidance demonstrates a cryoprobe within the lesion. A 1-month follow-up axial T2-weighted MRI image (D) shows the treated lesion (black arrow) with surrounding cryoablation zone (white arrowheads) and ablation tract (white arrow).

Intravenous contrast on CT or MR may result in peripheral enhancement of the cyst or thin septation(s), with occasional areas of nodular enhancement, especially in the setting of recent or remote fracture.[23] The presence of a solid enhancing component should prompt reconsideration of the diagnosis.

Lesions are not painful, except in the context of associated pathologic fracture. Although there are many different methods for treating a unicameral bone cyst, the goal of therapy is to re-establish the thick cortical buttress of the bone and restore the internal trabecular architecture of the marrow. This is accomplished by disrupting the membrane of the cyst, aspirating the cystic contents, and replacing them with a substance that can assist with new bone formation. The endothelium of the cyst can be disrupted with open surgical curettage, cryosurgery,[24] percutaneous curettage, injection of sclerosants into the cyst cavity, or percutaneous cryoablation.[25,26] The cavity can then be filled with methylprednisolone, autologous bone marrow, demineralized bone matrix, and/or cement.[23] Clinical success is typically measured by the amount of sclerosis or increased thickness of the cortex (Fig. 4). Success rates for each technique vary significantly in the literature.

Aneurysmal Bone Cyst

Aneurysmal bone cysts (ABC) are benign lesions most commonly seen in the metaphysis of children and young adults. They account for 1% of benign bone lesions and can be found anywhere in the skeleton. The etiology is unknown, but the leading theory is that blood-filled voids occur due to venous obstruction in the bone. Historical studies have reported that up to one-third of ABCs are secondary to another primary lesion, which further supports this theory. Histologically, these lesions lack an endothelial wall, but are instead lined by fibroblasts, giant-cells, and trabecular bone.[27]

Initial evaluation with X-ray demonstrates a well-circumscribed, expansile lucent lesion with thick septations and trabeculations (ie, "soap bubble" appearance) within the

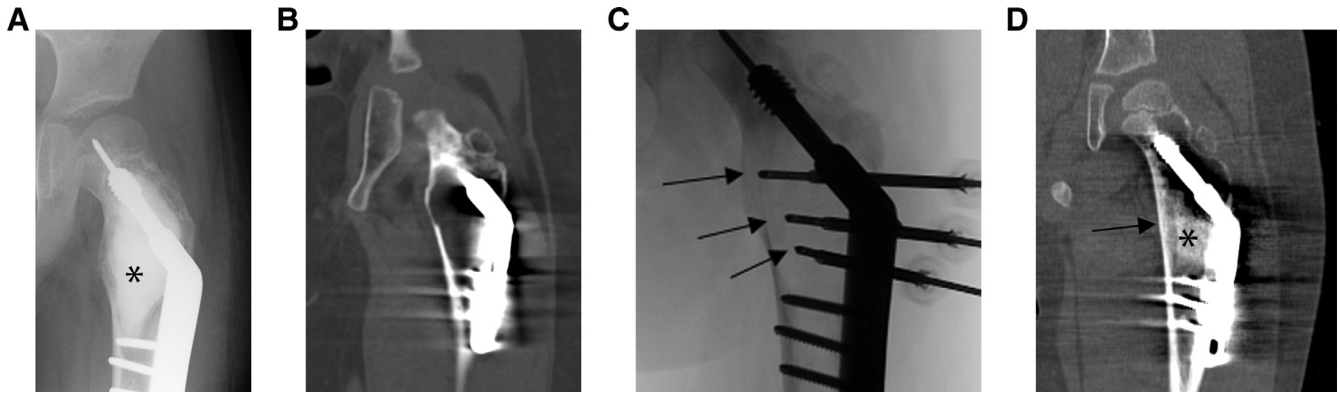

Figure 4 An 8-year-old boy initially presenting to ED with pathologic fracture of the left femoral neck, treated initially with open curettage, reduction and fixation with cementoplasty of the cystic component. An AP radiograph (A) demonstrates the left hip hardware and sequelae of cementoplasty (asterisk). Coronal CT image (B) several years after initial treatment because of a second pathologic fracture and cyst recurrence. Intraprocedural fluoroscopic image (C) showing 3 cryoprobes (black arrows) placed within the cyst. A postprocedural coronal CT image (D) demonstrates new sclerosis of the cyst (asterisk) and thickening of the cortex (black arrow). AP, anteroposterior; ED, emergency department.

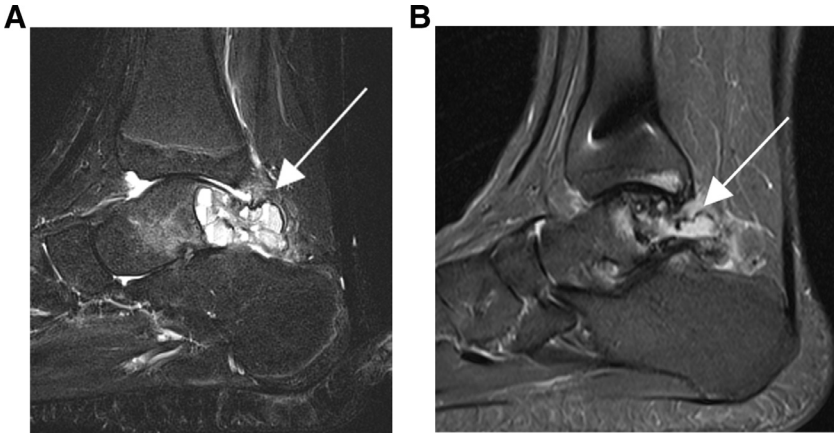

Figure 5 A 13-year-old girl with an aneurysmal bone cyst of the posterior talus placing the patient at risk for pathologic fracture. The lesion was incidentally noted during workup for a fracture of the distal tibia. Initial sagittal T2-weighted MR image (A) demonstrates a predominantly T2-hyperintense, lobular, multiseptated cystic lesion (white arrow) of the posterior talus with fluid levels. There is some edema in the surrounding soft tissues and a small ankle effusion. Sagittal proton density MR image (B) following multiple treatments with doxycycline sclerotherapy and cryoablation shows contraction of the lesion with areas of dense sclerosis and mild persistent fluid-filled cystic component (white arrow). Note the susceptibility artifact from hardware in the distal tibia.

lesion (Fig. 5). If pathological fracture is suspected, CT is helpful to define the osseous borders of the lesion and to evaluate for cortical disruption. MRI typically demonstrates fluid-fluid levels, perilesional extension and edema. Incisional biopsy is the current standard to exclude the alternative diagnosis of telangiectatic osteosarcoma,[27] although core biopsy is sufficient in most cases, given the rare incidence of malignancy.

ABCs were historically treated with en bloc surgical resection and grafting, which can be associated with high morbidity depending on lesion size and location. More recently, surgical curettage with or without grafting has become the standard of care. Recurrence rates are high, ranging from 10% to 60% in some studies.[27,28] Given the high morbidity of en bloc resection, and high recurrence rates of curettage, minimally invasive approaches to treatment are becoming increasingly utilized, in particular within the axial skeleton (Fig. 6). Numerous studies demonstrate efficacy rates approaching those of curettage, with relatively low complication rates, procedure time and cost.[28] In terms of procedural planning, it can be helpful to think of ABCs as a combination of an arteriovenous malformation and a solitary bone cyst. There can be significant arterial inflow and venous drainage from the lesion that can result in nontarget embolization and potential catastrophic complications. Care should be taken when injecting sclerosants not to pressurize the cyst or cause intra-arterial reflux.[29] When surgery is determined to be the treatment of choice, patients may still benefit from preoperative arterial embolization, which can mitigate catastrophic bleeding.

Malignant Bone Tumors

Successful palliative treatment of painful malignant bone lesions has also been described using percutaneous ablation techniques.[30,31] Osteosarcoma and Ewing sarcoma, respectively, are the 2 most common malignant bone tissues in children. Rhabdomyosarcoma is the most common malignant soft tissue tumor in the musculoskeletal system of children (Fig. 7). These tumors are treated with primary or neoadjuvant chemotherapy for large tumors, and en bloc surgical resection for smaller tumors. While percutaneous image-guided techniques are not curative, they can be helpful to provide a diagnosis via percutaneous core needle biopsy or to provide palliative therapy in cases of painful metastases.[32] Malignant bone lesions cause pain diffusely through release of chemical mediators or locally by direct invasion, stretching of periosteum, or microfractures.[33] Each of the ablative techniques has been described for local therapy of malignant lesions. Cryoablation is particularly effective due to its inherent local anesthetic properties, as well as its ability to provide direct visualization of an ablation zone that can be adapted to the size and shape of the lesion using multiple probes (Figs. 8 and 9). Several studies have shown cryoablation to be effective in decreasing pain caused by metastatic lesions and subjectively increasing quality of life. Studies have also demonstrated superiority of cryoablation over other thermal ablation techniques.[30] As a technical note, osteosarcoma metastases tend to be densely sclerotic in children and may require mechanical drilling to cross the lesion for cryoprobe placement.

Benign Soft Tissue Tumors

Fibrous Desmoids

Fibrous desmoid tumors are relatively uncommon benign soft tissue tumors in children, accounting for 3% of soft tissue tumors. These tumors arise from mesenchymal stem cells and occur along musculoaponeurotic structures. Desmoid

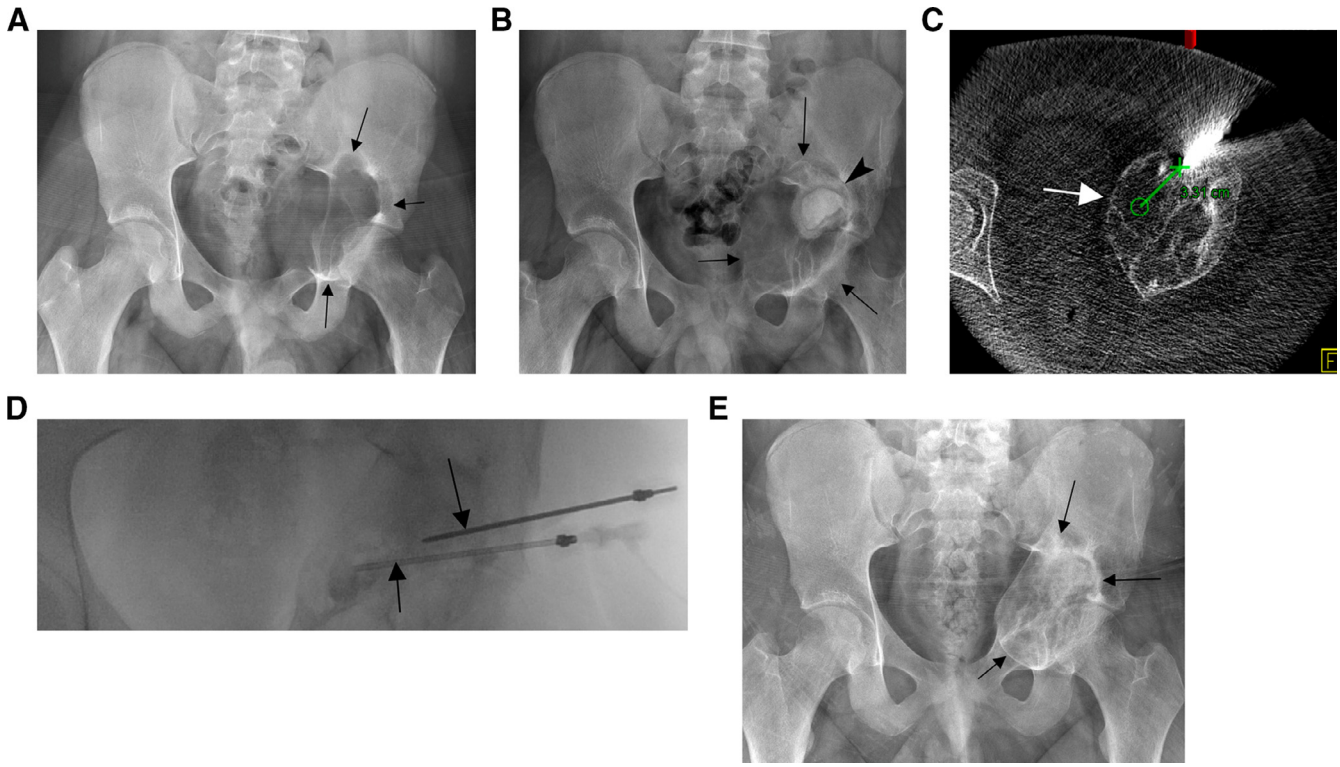

Figure 6 Adolescent male with expanding lucent lesion (black arrows) of the left acetabulum on initial radiograph (A), confirmed as aneurysmal bone cyst on open biopsy and curettage. A large residual component (black arrows) on 4-month postoperative radiograph (B), with graft material noted at the superior lateral aspect (black arrowhead). Following percutaneous biopsy (not shown), sclerotherapy at 2 sites with a total of 18 mL/180 mg of Doxycycline foam was performed. Cone Beam CT with guidance software (C) was used to target and treat all components of the ABC (white arrow). Note the introducer needles on fluoroscopy (D). Follow-up pelvic radiograph at 2 months post-treatment (E) shows interval sclerosis (black arrows) consistent with interval healing of the ABC. Patient was able to return to full weight bearing status following ABC healing. (Images used with permission of Dr. Abhay 'Finn' Srinivasan).

tumors are usually sporadic, but 5%-15% are associated with familial adenomatous polyposis syndrome (ie, Gardner syndrome). Clinically, desmoids are typically asymptomatic unless exerting mass effect on sensitive structures such as nerves, muscle, or fascia.[34]

Also known as "aggressive fibromatosis," these tumors can create a therapeutic dilemma due to their ability to infiltrate tissues and recur after excision. Additionally, 5%-10% of lesions will regress without treatment. Treatment, therefore, tends to be conservative unless the tumor is symptomatic or exerting mass effect on crucial structures. Surgical excision and radiation therapy are reserved for specific cases.[35] Percutaneous ablation has emerged as an adjunctive, minimally invasive therapy for local tumor control as it is generally well-tolerated and can be performed as often as necessary (Fig. 10).

Plantar Fibroma

Palmar-plantar fibromatoses are uncommon benign soft tissue tumors affecting the aponeuroses of the hands and feet of adults and children. It presents as a single or multiple palpable nodules that can cause focal pain and eventually lead to contractures. Children are more likely to present with foot lesions, most commonly along the medial plantar arch, as these are more likely to be symptomatic in an active child. In one study, the prevalence increases significantly after the age of 5, and was twice as common in females. In that study, other associated clinical findings included knuckle pads, keloids, epilepsy, and fifth finger clinodactyly.[36]

Ultrasound is the best way to image these lesions, which appear as focal, oval, heterogenous/disorganized lesions of the plantar fascia. Lobulations and central scarring can be seen in larger lesions with occasional areas of internal color flow. MRI appearance is quite variable and in general MR is less sensitive for identifying smaller lesions.[37] Given the high recurrence rate of the tumor, minimally invasive techniques are preferred for initial management and include ultrasound-guided steroid injection and more recently cryoablation.[36] With cryoablation, careful procedural planning is necessary to prevent skin ulceration. Techniques include ensuring an adequate length of the soft tissue tract prior to accessing the lesion and placing a warming device over the skin at the cryoablation zone.[38] Surgical consultation should be obtained prior to intervention in cases where contracture is present.

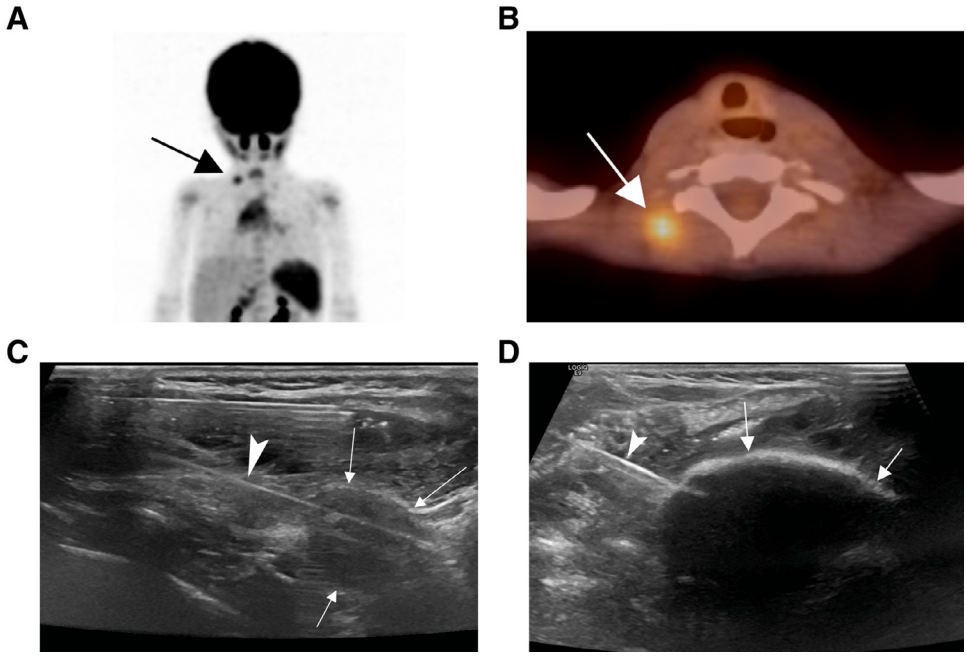

Figure 7 3-year-old male with history of stage III embryonal rhabdomyosarcoma of the thorax (at 1 year of age). PET/CT coronal MIP (A) and axial fusion (B) images demonstrates tumor recurrence with a single hypermetabolic nodule (arrow) in the right posterior neck soft tissues, overlying the trapezius muscle. Local control of the nodule with cryoablation under ultrasound guidance. Image C shows nodule (arrows) localization with placement of the cryoprobe (arrowhead). Image D shows post ablation with a well-formed ice-ball (arrows) completely encapsulating the nodule. MIP, maximum intensity projection; PET/CT, positron emission tomography/computed tomography. (Images used with permission of Dr. Abhay 'Finn' Srinivasan).

Pigmented Villonodular Synovitis

Pigmented villonodular synovitis (PVNS), also known as tenosynovial giant cell tumor, is a rare proliferative disorder of the synovium, bursae, and tendon sheaths. The disease is usually seen in teens and young adults, and is typically monoarticular involving a large joint (the knee being the most common location). There is no gender predisposition. PVNS is best imaged with MRI, which typically shows mass-like synovial proliferation with low signal intensity and "blooming" artifact on gradient echo sequences. CT may demonstrate osseous erosions, effusion, and slightly hyperdense mass-like synovial proliferation.[39,40] Histologically, PVNS may look like sarcoma, so imaging correlation is crucial for the pathologist.

Treatment depends on the joint location and extent of disease. There are 3 forms of PVNS: localized, diffuse, and extra-articular. The goal of therapy is to remove all abnormal synovial tissue to preserve the joint and relieve pain. Therefore, surgery is the mainstay of therapy and can be accomplished through arthroscopic or open techniques.[39] Occasionally, there are areas of PVNS that are unsafe to access surgically, or there is focal recurrence following

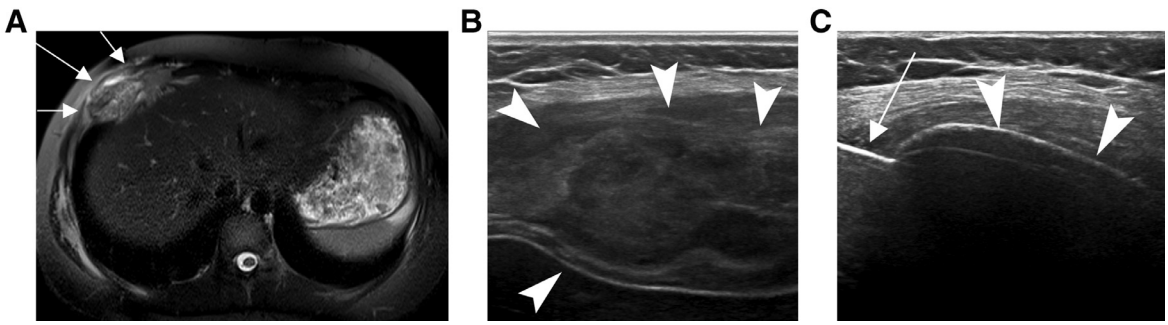

Figure 8 A 14-year-old girl with a history of metastatic osteosarcoma presents with focally painful lesions of her right ribs. Axial T2-weighted MR image (A) demonstrates an edematous, expansile, destructive lesion (white arrows) of the right 10th rib anteriorly. Gray-scale ultrasound image (B) demonstrating the same lesion (white arrowheads), which appears lobular and heterogenous. Intraprocedural gray-scale ultrasound image (C) demonstrating placement of the cryoprobe (white arrow) within the lesion after formation of the iceball (white arrowheads).

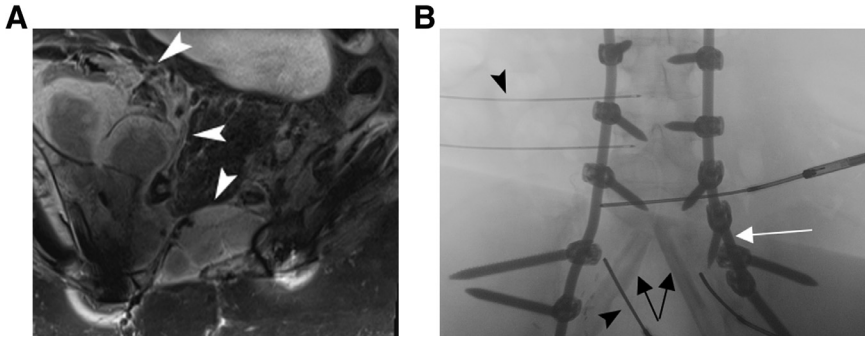

Figure 9 A 14-year-old girl with Ewing sarcoma with painful osseous metastases of the pelvis and lumbosacral spine presented seeking palliative treatment for pain related to compression of lumbosacral nerves. Axial T2-weighted image of the pelvis (A) shows an aggressive soft tissue mass involving the right iliac bone and sacrum (arrowheads). An intraprocedural AP fluoroscopic image shows 5 cryoprobes (arrowheads) within the soft tissue mass adjacent to lumbosacral nerves. Also noted are hardware from prior spinal fusion (white arrow) and fibular bone grafts (black arrows) placed during sacral resection.

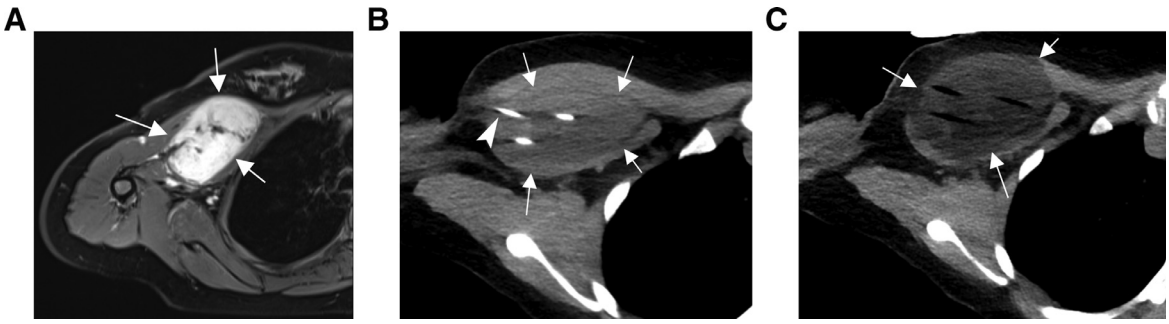

Figure 10 Adolescent female with history of right axillary desmoid under active treatment with chemotherapy, prior surgical debulking and cryoablation. T1 VIBE postcontrast with subtraction image (A) demonstrates a large well-circumscribed avidly enhancing soft tissue mass (arrows), diagnosed as a desmoid tumor. A total of 4 cryoablation probes were placed under ultrasound guidance to contour the treatment zone and preserve the neurovascular bundle. Axial CT (B) image demonstrates cryoprobes (arrowhead) within the mass (arrows). Postcryoablation axial CT image (C) demonstrate a well-formed ice-ball (arrows) extending over 80% of the lesion with preservation of the brachial plexus and axillary vasculature (at superior margin of lesion). (Images used with the permission of Dr. Michael Acord.)

synovectomy. In such cases, percutaneous ablation can be a helpful adjunct, although literature is limited. In one small cohort, RFA was shown to be safe and effective for local control of PVNS.[40] Both RFA and cryoablation have shown injury to cartilage within the ablation zone in animal models. However, cryoablation appears to result in less injury to tendinous structures.[35]

Steroid Injections of Joints and Tendon Sheaths

Injecting steroids into joints and around tendon sheaths is a common practice in many rheumatology and pediatric interventional radiology departments. Juvenile idiopathic arthritis is the most common chronic pediatric arthritis, and is primarily treated with systemic therapy. Intra-articular and tendon sheath steroid injections can be a helpful adjunctive therapy for pain relief. Localized joint inflammation may also be seen in chronic sports injuries or following orthopedic surgery. Sacroiliac joint injections may also provide pain relief in children with sacroiliitis.[41] Steroid injections can be safely performed in most joints with ultrasound guidance.[42] On ultrasound, inflamed joints may appear normal, or have increased fluid and thickened hyperemic synovium. Inflamed tendon sheaths may be thickened with increased Doppler color flow and fluid within the tendon sheath.[43] Fluoroscopic, CT or Cone Beam CT guidance is selectively utilized in children, but may be helpful in the setting of obesity or a postoperative joint. Anesthesia requirements vary based on the age of the child, and range from local anesthesia only to general anesthesia.[44] Steroid doses are based on the patient's age and weight, and the size of the joint being injected (Table 2).

Steroids are divided into particulate and nonparticulate. In practice, particulate steroids tend to be less soluble, and therefore are favored for local anti-inflammatory action, lower systemic absorption, and longer therapeutic effect. Of note, there is a reported risk of vascular injury or

Table 2 Sample Intra-articular Steroid Injections

Joint Size	Triamcinolone acetonide 10 mg/mL or 40 mg/Ml
Very small (IP, MCP)	2.5 mg
Small (wrist, subtalar)	5 mg, max dose 10 mg
Medium (elbow, tibial-talar)	5-10 mg
Large (hip, knee, and shoulder)	5-15 mg, max dose 40 mg

Dose taken from package insert. Limit total injected dose to <80 mg. Dose can be administered either in the 10 mg/mL or the 40 mg/mL concentration, dependent on the anticipated joint capacity.

embolic infarct when using particulate steroids near the spinal cord. Historically both triamcinolone hexacetonide (Aristospan, Novartis Princeton, NJ) and triamcinolone acetonide (Kenalog-10/40, Bristol-Meyer-Squibb, NY, NY) have been used to give good effect for treatment of disease. However, initial manufacturing delays were followed by discontinuation of the triamcinolone hexacetonide by the manufacturer in 2016.

Local anesthetics including bupivacaine, ropivacaine, lidocaine, and mepivicaine give short-term pain relief to the joint and can be combined with the steroid if desired. However, because of the risk of chondrolysis with high doses and concentrations of local anesthetic, intra-articular use should be performed with caution.[45] A 2016 meta-analysis comparing in vitro and in vivo animal studies confirmed higher rates of chondrocyte injury with all lidocaine preparations (0.5%-2%) and higher concentration of the other local anesthetics.[46] In practice the authors use ropivicaine in place of lidocaine in cases where local anesthetic may intentionally or unintentionally enter the articular joint space. Complications with joint injections are infrequent, but the most common complaints are subcutaneous atrophy, erythema, pruritis, and skin hypopigmentation.[42] Care should be taken to avoid pressurizing small joints, in particular, where the joint space is close to the skin surface. The utilization of image guidance for large joints varies from institution to institution. Narrow

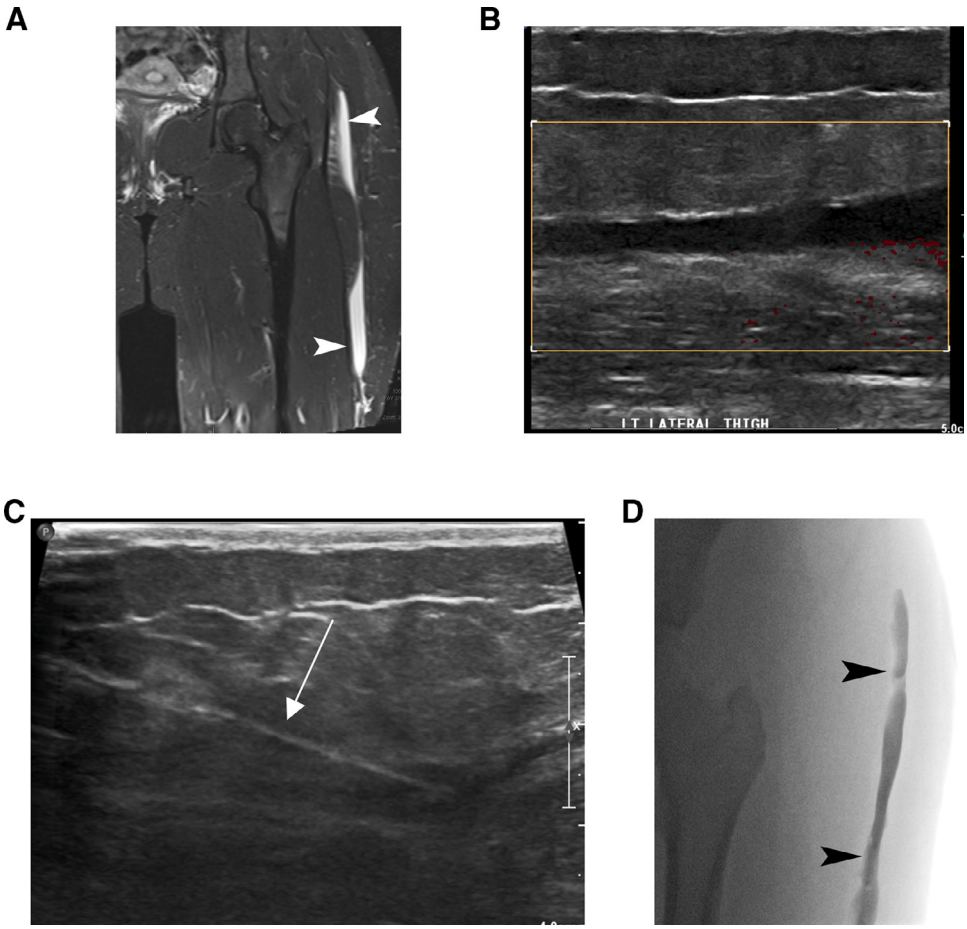

Figure 11 Adolescent female with history of traumatic injury to the left elbow, pelvis and leg (train vs pedestrian). Three months following injury and recovery, the patient presents for evaluation of fluctuance along the lateral aspect of the left thigh. Coronal T2W MR image (A) demonstrates an elipsoid T2 hyperintense fluid collection at the myofascial junction between the vastus lateralis and subcutaenous fat compatible with Morel-Lavallee Lesion. Under ultrasound guidance (B & C), the anechoic, avascular collection (asterisks) was accessed with a needle and drain was placed (arrow). Contrast was injected and a single fluoroscopic image (D) was obtained to document placement and extent of collection. The patient was then treated with a cycle of 3 doxycycline treatments (100 mg/treatment). In this patient, fluid recurred 3 months post-treatment. The lesion eventually required capsulectomy for definitive treatment.

(sacroiliac, subtalar), or sensitive joints (temporal mandibular joint) are more frequently performed with alternative imaging guidance (cone beam CT, CT or Fluoroscopy).

Morel-Lavallee Lesion

Morel-Lavallee lesion is the eponym given to closed degloving injuries that result from abrupt traumatic separation of subcutaneous fat from the underlying fascia.[40] Lesions most commonly develop in the peritrochanteric region and proximal thigh. Disruption of the tissue interface, coupled with the rich vascular (blood and lymph) supply in this area result in accumulation of fluid within the potential space, and in some instances, development of a secondary inflammatory capsule. Initial treatment of these lesions is typically conservative therapy including application of a compression dressing and serial aspirations. Refractory lesions frequently are empirically treated with sclerosant therapy utilizing ethanol or doxycycline either with a single treatment or cyclic treatment via a drain. Reported success rates vary with this technique and the length of observation following treatment (Fig. 11).[41] Proposed algorithms typically advocate for attempts at percutaneous drainage with sclerotherapy prior to open debridement.[42] Attempts at sclerotherapy do not interfere with the definitive surgical treatment with open drainage and capsulectomy.

Conclusion

The pediatric interventional radiologist provides a critical role in both diagnosis and treatment of patients with benign and malignant musculoskeletal lesions. Percutaneous methods offer minimally invasive and effective techniques in treatment of musculoskeletal lesions with low complication rates and efficacious outcomes. Integration of these services in conjunction with more traditional surgical intervention offers treatment options for patients with both primary and refractory disease.

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