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A BIWEEKLY REVIEW OF CLINICAL RADIOLOGIC PRACTICE

Imaging of Focal Sclerotic Bone Lesions

Omer Awan, MD, Jim Wu, MD, and Ronald Eisenberg, MD

This module meets the American Board of Radiology's (ABR's) criteria for self-assessment toward the purpose of fulfilling requirements in the ABR Maintenance of Certification (MOC) program.

Please note that in addition to the SA-CME credits, subscribers completing the activity will receive the usual ACCME credits.

After participating in this activity, the diagnostic radiologist should be better able to identify and interpret the imaging findings of focal sclerotic bone lesions on radiographs and cross-sectional imaging.

CME Category: General Radiology
Subcategory: Musculoskeletal
Modality: Radiography

Key words: Sclerotic Bone Lesion, Focal Bone Lesion

Focal sclerotic bone lesions are encountered commonly in clinical practice. The differential diagnosis remains broad and includes traumatic, vascular, infectious, neoplastic, metabolic, and developmental causes. This article seeks to discuss the various imaging findings in the most commonly encountered focal sclerotic bone lesions, with emphasis on differentiating features through imaging and clinical correlation.

Introduction

Sclerotic bone lesions are regions of increased density within the bone, and focal sclerotic bone lesions are single discrete lesions within the skeleton that demonstrate increased density. There is a broad spectrum of causes of focal sclerotic

Dr. Awan is Assistant Professor, Geisel School of Medicine, Dartmouth College, One Medical Center Drive, Lebanon, NH 03756, E-mail: omer.a.awan@hitchcock.org; Dr. Wu is Assistant Professor, and Dr. Eisenberg is Professor, Department of Radiology, Section of Musculoskeletal Imaging, Beth Israel Deaconess Medical Center/Harvard Medical School, 330 Brookline Ave, Boston, Massachusetts.

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bone lesions (Table 1). The appearance of the sclerotic bone, the location of sclerosis, and the patient's age can be helpful in narrowing the differential diagnosis.

Trauma

Stress Fracture. A stress fracture can be either a fatigue fracture or insufficiency fracture. A fatigue fracture results from abnormal stress on otherwise normal bone, whereas an insufficiency fracture results from normal stress on abnormal bone. Both lesions typically present with pain that is reproducible with activity at the fracture site. Fatigue fractures are especially common in young runners because of chronic, repetitive trauma, whereas insufficiency fractures typically are seen in pathologic bone, most commonly in osteoporotic women older than 60 years.¹ Fatigue and insufficiency fractures occur most commonly in the pelvis, long bones, calcaneus, navicular, metatarsals, and sesamoids. In the acute phase, both fatigue and insufficiency fractures may demonstrate only faint periosteal reaction or cortical resorption on both radiography and CT. In the subacute or chronic phase, they typically produce linear sclerosis that tends to be perpendicular to the bone trabeculae (Figure 1). On MR imaging, a low-signal fracture line with surrounding bone marrow and soft-tissue edema may be seen. Because fatigue fractures tend to heal spontaneously, biopsy should be avoided and treatment aimed at preventing weight bearing. Conversely, untreated insufficiency fractures may lead to a complete fracture and substantial morbidity. Therefore,

treatment of insufficiency fractures includes reducing weight bearing, analgesics, and possibly internal fixation to prevent a complete fracture.¹

Because fatigue stress fractures tend to heal spontaneously, biopsy should be avoided and treatment aimed at preventing weight bearing.

Vascular

Bone Infarct. Among the most important causes of bone infarction are trauma, vasculitis, collagen vascular disease, sickle cell disease, Gaucher disease, alcohol abuse, chronic corticosteroid therapy, and embolism. Clinically, most patients are asymptomatic with only dull pain. The term “bone infarct” is used conventionally for processes involving the metaphysis and/or diaphysis of the intramedullary portion of the bone, whereas “avascular necrosis” typically refers to a similar process in the subchondral bone.² Radiographs of a bone infarct demonstrate an area of amorphous or serpentine sclerosis, which is usually dystrophic. On MRI (Figure 2), fluid-sensitive sequences may show the double-line sign—an inner margin of high signal



Figure 1. Traumatic cause of focal sclerotic bone lesion. Stress fracture. Lateral radiograph of the hindfoot in a 53-year-old male runner reveals linear sclerosis (arrow) oriented perpendicular to bony trabeculae in the calcaneus.

that represents granulation tissue and the inflammatory response to healing with an outer margin of low serpiginous signal separating the normal and necrotic bone. The presence of the characteristic serpentine pattern of dystrophic



Figure 2. Vascular cause of focal sclerotic bone lesion. Bone infarct. Sagittal proton-density MRI examination of the right knee in a 98-year-old man shows serpiginous low-signal geographic abnormality (arrows) in distal femur and proximal tibia. The internal signal of bone marrow remains fatty and bright.

Table 1. Differential Diagnosis of Focal Sclerotic Bone Lesions

Trauma

Stress fracture/insufficiency fracture

Vascular

Bone infarct

Infection

Chronic osteomyelitis

Neoplasm

Benign

Enchondroma

Osteoma

Osteoid osteoma/osteoblastoma

Healed nonossifying fibroma

Malignant

Osteosarcoma

Ewing sarcoma

Metabolic

Paget disease

Developmental

Bone island (enostosis)

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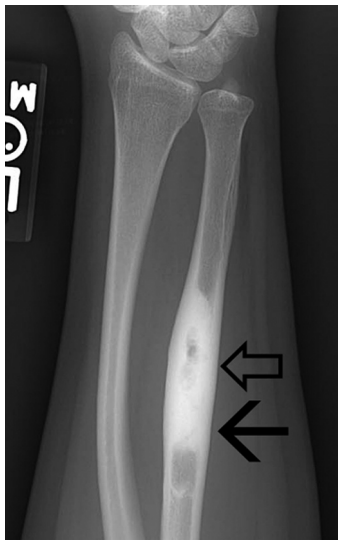


Figure 3. Infectious cause of focal sclerotic bone lesion. Chronic osteomyelitis. Frontal radiograph of the left forearm in a 35-year-old woman demonstrates sclerosis (*closed arrow*) within the ulnar diaphysis. The intramedullary lobular lucency (*open arrow*) represents an intraosseous abscess.

sclerosis on radiographs is pathognomonic for bone infarction. As most bone infarcts are incidental findings on conventional imaging, there is usually no treatment for uncomplicated metadiaphyseal bone infarcts.

Radiographs of a bone infarct demonstrate a metadiaphyseal area of amorphous or serpentine sclerosis, which is usually dystrophic.

Infection

Chronic Osteomyelitis. Chronic osteomyelitis is most commonly focal, although it may be multifocal. This entity most commonly develops in IV drug users, as a complication of diabetes, or in patients after trauma. Representing a persistent infection that evolves over months or years despite treatment, chronic osteomyelitis most commonly affects the long bones, especially the femur and tibia.³ Clinically, patients may present with fever, deep bone pain, and possibly a draining sinus. Radiographs demonstrate a reactive type of sclerotic bone with a thickened irregular cortex along the endosteal and periosteal surfaces (Figure 3). There may be associated soft-tissue swelling and periosteal reaction, which may be thin, disorganized, lamellated, or spiculated. On CT, there may be a bony sequestrum that represents the necrotic portion of bone. MR imaging is much more sensitive than CT for demonstrating active inflammation as bone marrow and soft-tissue edema that has decreased signal intensity on T1-weighted images, increased signal intensity on T2-weighted images, and diffuse contrast enhancement. A sinus tract in osteomyelitis appears as a thin region of soft-tissue enhancement that extends from the site of bone inflammation to the skin. Neoplastic processes may have a similar radiographic appearance, but they should not have the inflammatory changes or sinus tracts seen on MRI or clinical evidence of infection. Chronic osteomyelitis typically is treated with parenteral antibiotics and surgical debridement.³

Chronic osteomyelitis most commonly involves the femur or tibia in IV drug users, diabetic patients, or patients after trauma.

Neoplasm

Enchondroma. An enchondroma is a benign tumor of hyaline cartilage that originates in medullary bone. Although most enchondromas occur in the hands and are characteristically lytic, the chondroid matrix of an enchondroma in the metadiaphyseal region of a long bone typically contains flocculent, punctate regions of sclerosis in a “rings and arcs” pattern. Patients with enchondromas are typically in their third through fifth decades of life, although this lesion can be detected at any age.⁴ Although these patients are usually asymptomatic, they may present with pain if there is a pathologic fracture. Enchondromas are usually centrally located within the metadiaphyseal region and characteristically contain chondroid matrix (Figure 4A). On radiographs, enchondromas may be difficult to distinguish from bone infarcts because both occur in the same central location in long bones. However, a bone infarct generally has more prominent sclerotic margins with thick and dense dystrophic serpiginous sclerosis. On MR imaging, enchondromas exhibit low to intermediate signal intensity on T1-weighted images, with increased signal on fluid-sensitive T2-weighted sequences that is typical of benign cartilaginous lesions and not a feature of bone infarcts. There is usually peripheral and septal enhancement within an enchondroma.

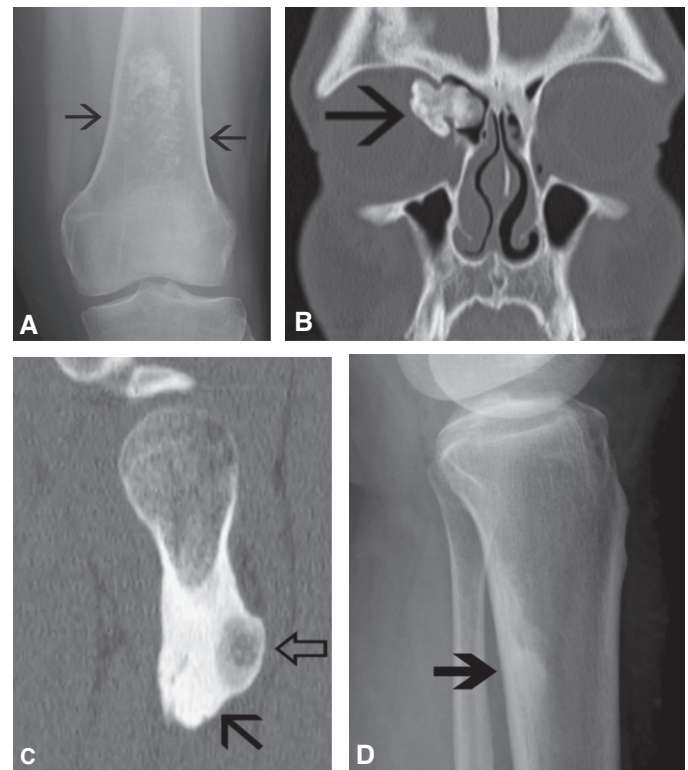


Figure 4. Benign neoplastic causes of focal sclerotic bone lesions. *A:* Enchondroma. This frontal radiograph of the knee in a 40-year-old woman shows increased opacity of the intramedullary portion of the distal femur in a “rings and arcs” pattern (*arrows*). *B:* Osteoma. This coronal CT image in a 29-year-old woman shows a homogeneous lesion isodense to bone (*arrow*) arising from the right frontal sinus. *C:* Osteoid osteoma. This sagittal CT image of the proximal femur in a 22-year-old woman reveals dense reactive sclerosis (*closed arrow*) surrounding central lucency (*open arrow*) within the cortex, representing a central nidus. *D:* Healing nonossifying fibroma. This lateral radiograph of the lower leg in a 24-year-old man demonstrates an increased cortical, eccentrically based opacity (*arrow*) within the metaphysis of the proximal tibia.

The chondroid matrix of an enchondroma in the metaphyseal region of a long bone typically contains flocculent punctate regions of sclerosis in a “rings and arcs” pattern.

The other main differential diagnosis for enchondroma is a low-grade chondrosarcoma. Although an enchondroma is typically centrally located within the bone, it can scallop the underlying cortex. However, if the degree of scalloping is greater than two thirds of the cortical width of the cortex, a low-grade chondrosarcoma should be considered as a diagnostic possibility.⁴ In the absence of pathologic fracture, new or increasing pain should suggest an underlying malignancy.

Incidentally noted small enchondromas often require no further workup or treatment.

Osteoma. An osteoma is a benign bone-forming tumor that most commonly occurs in a characteristic location in the paranasal sinuses or the calvarium. Osteomas are usually incidental, asymptomatic masses that are found most commonly in patients between 50 and 70 years of age and are twice as common in men. As a bone-forming lesion, the sclerosis seen on radiography has a densely homogeneous appearance that results from the osteoid matrix produced by the tumor in the form of well-differentiated lamellar bone (Figure 4B). CT demonstrates the dense, cloud-like osteoid bone matrix better than any other modality. On MRI, the dense lamellar portions of the lesion have low signal on all pulse sequences with no contrast enhancement. The less dense cancellous portions have low signal on T1-weighted images, heterogeneous signal on fluid-signal-intensity sequences, and may show mild contrast enhancement. Osteomas usually need no treatment.

Osteoid Osteoma. An osteoid osteoma is a benign bone-forming tumor that is classically characterized by nocturnal pain that awakens the patient and is relieved by aspirin. It typically presents in young patients between ages 10 and 25 years and is 3 times more common in men. Osteoid osteomas in long bones occur in a diaphyseal and cortical location. In the spine, they involve the posterior elements. On radiographs and CT, an osteoid osteoma appears as an oval lytic lesion within dense cortical bone (Figure 4C). The appearance of a characteristic central circle of sclerosis within an oval lucent nidus is virtually pathognomonic for an osteoid osteoma. On MRI, the nidus is typically round and slightly hyperintense to skeletal muscle on T1-weighted images, hyperintense on T2-weighted images (although it may be less hyperintense if there is calcification in the nidus), and enhances avidly. The reactive cortical thickening has low-signal intensity on all pulse sequences.

When there is extensive reactive sclerosis, it may be difficult to radiographically distinguish an osteoid osteoma from a stress fracture or chronic osteomyelitis. In such cases, CT or MRI can demonstrate the presence of the diagnostic central nidus in an osteoid osteoma. Furthermore, the reactive sclerosis in a stress fracture is frequently linear and crosses the bone. Chronic osteomyelitis may produce a serpiginous sinus track on CT or MRI.

Osteoid osteomas usually are treated by CT-guided radio-frequency ablation, which has a 90% initial success rate.⁵ Cure requires necrosis of the central nidus.

Healing Nonossifying Fibroma. A nonossifying fibroma is a benign fibrous lesion that initially has the characteristic radiographic appearance of a lytic lesion with a thin sclerotic margin. On radiography and CT during the healing phase, the lesion becomes entirely sclerotic (Figure 4D) before eventually disappearing as the lesion involutes into a normal trabecular pattern. Therefore, a healing nonossifying fibroma is seen most commonly during the first 2 decades of life, an important clinical distinction from other sclerotic lesions. Most healing nonossifying fibromas are asymptomatic, and pathologic fracture is rare. A healing nonossifying fibroma is characteristically a cortically based metaphyseal lesion in a long bone around the knee or in the distal tibia. As these lesions naturally heal and involute, no treatment is required.

Osteosarcoma. Osteosarcoma is a malignant osteoid-producing tumor that originates in the intramedullary space and is the most common malignant bone neoplasm in children and adolescents. Most commonly occurring in the second decade of life, conventional osteosarcomas usually develop in long bones, with more than 50% occurring about the knee. The tumor has a second peak in elderly individuals, most of whom have a predisposing factor such as prior radiation therapy or underlying Paget disease of bone.⁶ Patients with osteosarcoma present with a tender mass, deep unremitting pain, and functional limitation; up to 10% have a pathologic fracture. On radiography, an osteosarcoma characteristically has an eccentric, metaphyseal location. The immature and aggressive tumor typically produces a subtle and amorphous sclerotic osteoid matrix. As a malignant tumor, there is usually aggressive periosteal reaction in a sunburst pattern or Codman triangle, permeative bone destruction with a wide zone of transition, and an associated soft-tissue mass (Figure 5A).

CT is rarely necessary to make the diagnosis of conventional osteosarcoma, although this modality is required for staging to detect lung metastases, which may ossify. CT also better delineates the osteoid matrix and any associated soft-tissue mass. On MRI, the osteoid matrix has low signal on all pulse sequences. The nonosteoid portions of the tumor are isointense to skeletal muscle on T1-weighted images and have heterogeneous increased signal on T2-weighted images. There is typically peritumoral edema in both bone and soft tissues (Figure 5B). After contrast administration, there is generally intense heterogeneous enhancement, with areas of nonenhancement representing regions of necrosis. Radionuclide bone scanning may be useful to demonstrate skip lesions and osseous metastases at other locations.^{6,7}

There are also surface variants of conventional osteosarcomas, such as the parosteal osteosarcoma and the periosteal osteosarcoma. A parosteal osteosarcoma typically arises from the surface of the metaphysis of a long bone (Figures 5C and 5D), whereas a periosteal osteosarcoma arises from the surface of most commonly the diaphysis of a long bone (Figure 5E).

Osteosarcomas can be fatal if left untreated.⁶ Before wide resection and possible limb salvage therapy, patients typically

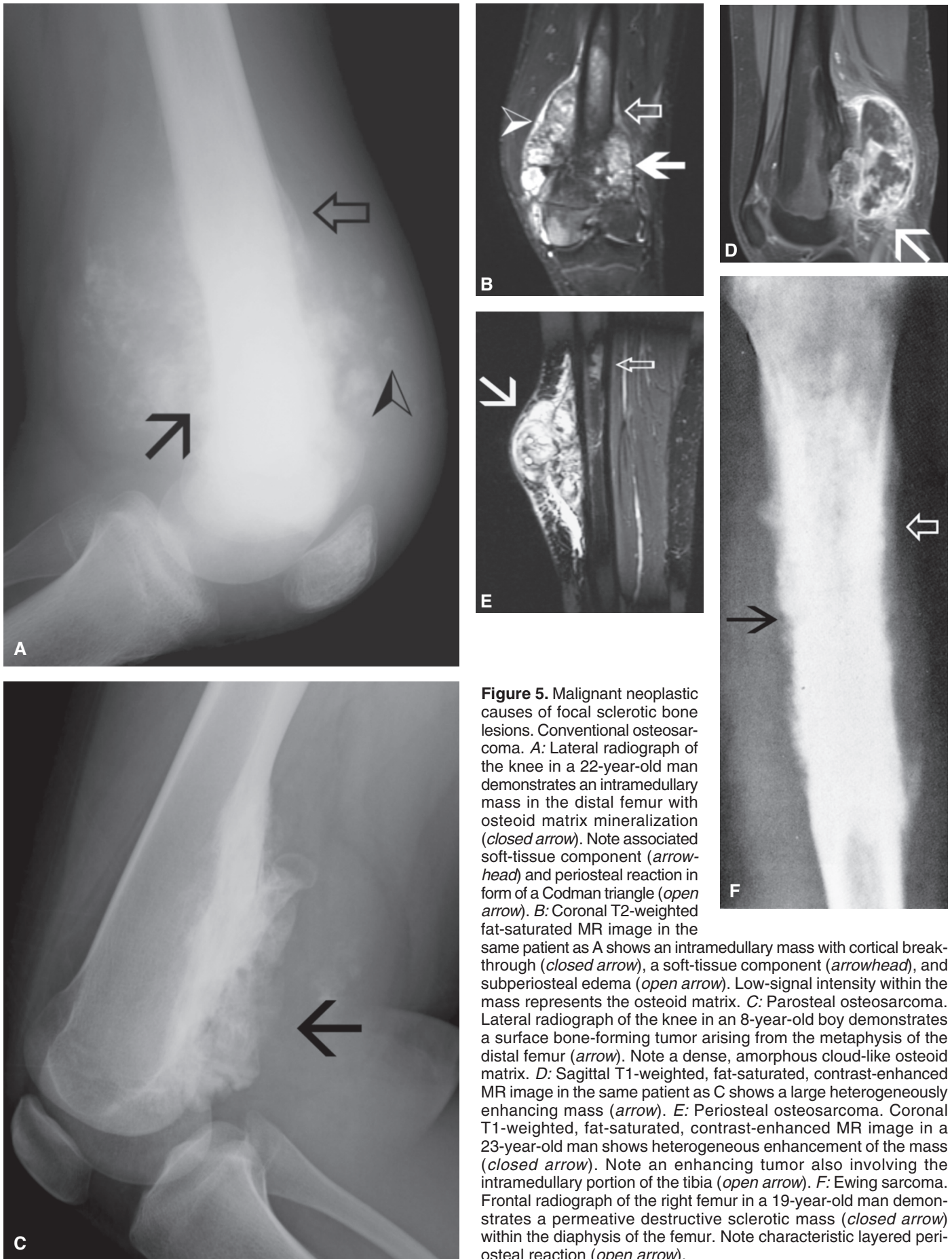


Figure 5. Malignant neoplastic causes of focal sclerotic bone lesions. Conventional osteosarcoma. **A:** Lateral radiograph of the knee in a 22-year-old man demonstrates an intramedullary mass in the distal femur with osteoid matrix mineralization (*closed arrow*). Note associated soft-tissue component (*arrowhead*) and periosteal reaction in form of a Codman triangle (*open arrow*). **B:** Coronal T2-weighted MR image in the same patient as A shows an intramedullary mass with cortical breakthrough (*closed arrow*), a soft-tissue component (*arrowhead*), and subperiosteal edema (*open arrow*). Low-signal intensity within the mass represents the osteoid matrix. **C:** Parosteal osteosarcoma. Lateral radiograph of the knee in an 8-year-old boy demonstrates a surface bone-forming tumor arising from the metaphysis of the distal femur (*arrow*). Note a dense, amorphous cloud-like osteoid matrix. **D:** Sagittal T1-weighted, fat-saturated, contrast-enhanced MR image in the same patient as C shows a large heterogeneously enhancing mass (*arrow*). **E:** Periosteal osteosarcoma. Coronal T1-weighted, fat-saturated, contrast-enhanced MR image in a 23-year-old man shows heterogeneous enhancement of the mass (*closed arrow*). Note an enhancing tumor also involving the intramedullary portion of the tibia (*open arrow*). **F:** Ewing sarcoma. Frontal radiograph of the right femur in a 19-year-old man demonstrates a permeative destructive sclerotic mass (*closed arrow*) within the diaphysis of the femur. Note characteristic layered periosteal reaction (*open arrow*).

receive preoperative chemotherapy and radiation therapy. Chemotherapy is administered routinely after surgery, with postoperative radiation performed only if tumor margins are unclear. Pulmonary metastases may be resected, if limited in number.

Ewing Sarcoma. Ewing sarcoma is the second most common bone sarcoma in the pediatric population (after osteosarcoma).⁸ The tumor most commonly occurs in children between ages 5 and 15 years, who typically present with pain, fever, anemia, and leukocytosis. It usually arises in the metadiaphysis of a long bone, and less frequently involves flat bones such as the pelvis and scapula. On radiographs, Ewing sarcoma demonstrates aggressive permeative osseous destruction with a wide zone of transition. Aggressive laminated or sunburst periosteal reaction often occurs (Figure 5F). Although the tumor is predominantly lytic, the mass may elicit profound reactive bone formation that stimulates tumor osteoid, although this is confined to the bone and does not affect the soft tissues.⁸ The lack of bone formation within soft-tissue extension differentiates Ewing sarcoma from the more common conventional osteosarcoma. A large soft-tissue mass often develops adjacent to a Ewing sarcoma.

The lack of bone formation within soft-tissue extension differentiates Ewing sarcoma from the more common conventional osteosarcoma.

Treatment for Ewing sarcoma consists of initial chemotherapy and radiation therapy followed by wide surgical excision.

Metabolic

Paget Disease. Paget disease is a metabolic condition involving increased and disordered bone turnover and remodeling. Patients most commonly are older than 40 years. They may be asymptomatic or experience deep, constant bone pain, deformity from extremity bowing, hearing loss, or increased skull size.

Paget disease most commonly affects the spine, skull, pelvis, and proximal long bones. It is most commonly focal, although multifocal involvement may occur. Characteristic radiographic findings include cortical thickening, coarsened trabeculae, and enlargement of the underlying bone. Paget disease often starts as a lytic process that progresses into a mixed lytic and sclerotic appearance; it rarely is purely sclerotic (except as an ivory vertebra). When the disease involves a long bone, a useful radiographic clue is that the lesion typically starts at the end of the bone and progresses toward the diaphysis. In the skull, a characteristic finding during the lytic phase is “osteoporosis circumscripta,” in which the lucency primarily affects the frontal or occipital bones. In the mixed lytic/sclerotic phase, there is widening of the diploic space and a “cotton wool” skull consisting of calvarial thickening with focal regions of sclerosis. Within the pelvis (Figure 6A), there is early thickening and sclerosis of the iliopectineal and ischiopubic lines. In the spine, an ivory vertebra may be seen in the late sclerotic phase (Figures 6B and 6C).

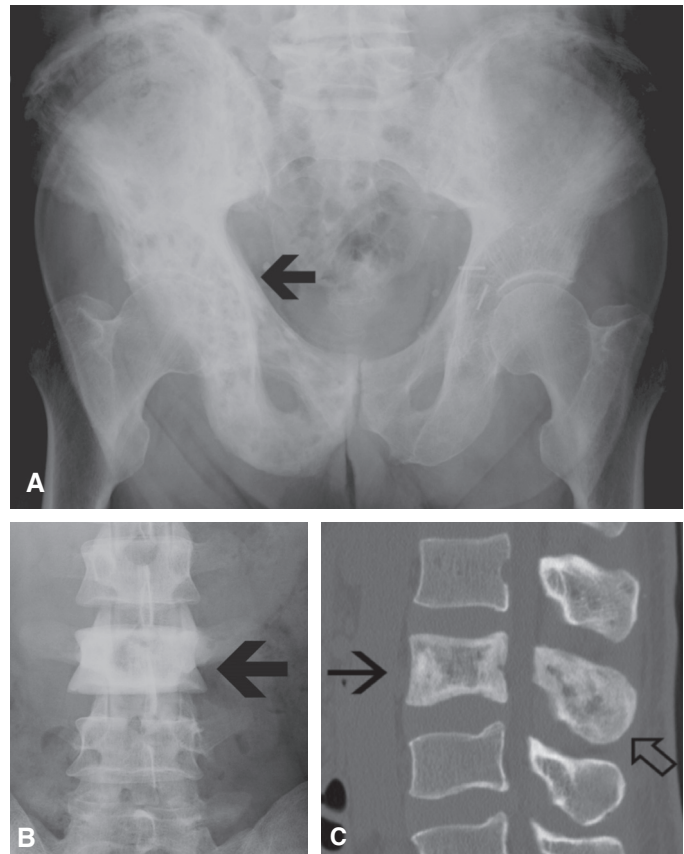


Figure 6. Metabolic cause of focal sclerotic bone lesion. Paget disease. *A:* Frontal radiograph of the pelvis in a 53-year-old man shows cortical thickening and coarsening of trabeculae in the right hemipelvis. Note characteristic thickening of the iliopectineal line (*arrow*). *B:* Frontal radiograph of lumbar spine in a 62-year-old man reveals dense sclerosis (“ivory” vertebra) of the entire L3 vertebral body (*arrow*). *C:* Sagittal CT image confirms dense sclerosis (*closed arrow*) with slight enlargement of the posterior process of the L3 vertebra (*open arrow*), a characteristic finding of Paget disease.

Paget disease often starts as a lytic process that progresses into a mixed lytic and sclerotic appearance; it rarely is purely sclerotic except as an ivory vertebra.

Asymptomatic patients with Paget disease require no treatment. If symptomatic, patients are treated with bisphosphonate therapy to reduce bone turnover.

Developmental

Bone Island (Enostosis). Enostoses, or bone islands, refer to small foci of compact bone within cancellous bone that represent congenital or developmental lesions resulting from failure of osteoclastic activity during bone remodeling. Usually asymptomatic, they usually are 1 cm or less, but may be quite large and progressively increase in size. Enostoses most frequently occur in the pelvis, long bones, spine, and ribs.

Radiographically, a bone island appears as a dense focus of bone that may have radiating spicules at the margins that blend with the surrounding trabeculae (Figure 7). In long bones, they are located within the medullary cavity in the diaphysis or metaphysis; when elliptical, they tend to parallel the long axis

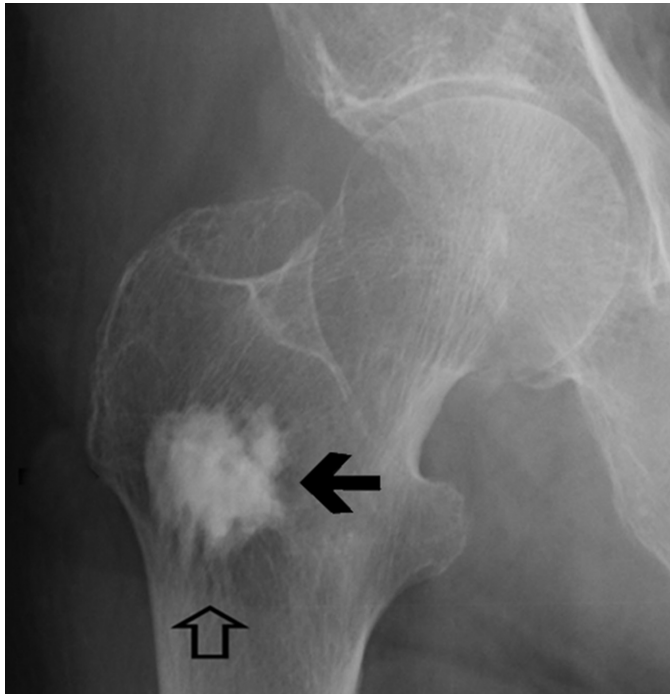


Figure 7. Developmental cause of focal sclerotic bone lesion. Bone island. Coned radiograph of the right hip in a 95-year-old woman demonstrates a homogeneously dense lesion (*closed arrow*) with characteristics of cortical bone in the medullary space. Note the typical appearance of this spiculated lesion fading in its periphery and merging with the normal surrounding trabeculae (*open arrow*).

of the involved bone. CT may show more clearly the peripheral aspect of the lesion fading into normal trabeculae.

Bone islands require no treatment because they are benign, asymptomatic lesions that are detected as incidental findings.

Summary

Focal sclerotic bone lesions are encountered commonly in musculoskeletal imaging. This CME activity emphasizes that meticulous attention to the clinical history, location, distribution, and character of the sclerosis, and associated findings on radiographs and cross-sectional imaging, may permit the radiologist to arrive at the precise diagnosis or a limited differential diagnosis.

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1. The *most* common location of a parosteal osteosarcoma is
- rib
 - scapular wing
 - iliac crest
 - long bone metaphysis
 - cervical spinous process

See Reference No. 7 for further study

2. Which one of the following bones is affected *most* commonly by chronic osteomyelitis?
- Humerus
 - Femur
 - Radius
 - Pelvis
 - Calcaneus

See Reference No. 3 for further study

3. A 6-year-old boy presented with pain in the right thigh and fever. He appeared anemic. Radiographs of the right femur revealed an extensive metadiaphyseal femoral mass with permeative osseous destruction, aggressive laminated periosteal reaction, and an associated soft-tissue mass without an osteoid matrix. The *most* likely diagnosis is
- bone infarct
 - conventional osteosarcoma
 - enchondroma
 - healed nonossifying fibroma
 - Ewing sarcoma

See Reference No. 8 for further study

4. Figure 8 is a reformatted sagittal CT image of the left knee of a 35-year-old woman. On the basis of this CT image, the *most* likely diagnosis of the focal sclerotic distal femoral lesion is
- bone infarct
 - healing nonossifying fibroma
 - enchondroma
 - bone island
 - stress fracture

See Reference No. 4 for further study



Figure 8.

5. A 21-year-old man with sickle cell disease presents to the emergency department after minor left knee injury. Radiographs of the left knee reveal an area of serpentine dystrophic sclerosis in the metadiaphyseal portion of the distal left femur. The *most* likely diagnosis is
- bone infarct
 - osteosarcoma
 - stress fracture
 - healing nonossifying fibroma
 - enchondroma

See Reference No. 2 for further study

6. The radiographs of an 18-year-old boy with severe pain in the thigh reveal a focal diaphyseal sclerotic femoral lesion suggesting an osteoid osteoma. The accepted treatment for this bone lesion is
- IV corticosteroids
 - surgical excision
 - observation
 - CT-guided radiofrequency ablation
 - radiation

See Reference No. 5 for further study

7. Which one of the following statements regarding osteomas is *false*?
- They commonly occur in the paranasal sinuses.
 - They are more common in men.
 - They are usually incidental, asymptomatic masses.
 - They usually require no treatment.
 - They commonly exhibit chondroid matrix mineralization in the form of rings and arcs.

See Reference No. 6 for further study

8. All of the following are radiographic features of conventional osteosarcomas, *except*
- intramedullary mass in a long bone
 - aggressive periosteal reaction of a Codman triangle
 - narrow zone of transition
 - sclerotic osteoid matrix
 - associated soft-tissue mass

See Reference No. 7 for further study

9. All of the following are causes of bone infarcts, *except*
- trauma
 - sickle cell disease
 - corticosteroid therapy
 - hyperparathyroidism
 - Gaucher disease

See Reference No. 2 for further study

10. All of the following are common locations for stress fractures, *except*
- metatarsals
 - calcaneus
 - sesamoids
 - tibia
 - mandible

See Reference No. 1 for further study