

**American College of Radiology  
ACR Appropriateness Criteria®  
Suspected Primary Bone Tumors**

**Variant 1:                   Adult or child. Suspected primary bone tumor. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
Radiography area of interest	Usually Appropriate	Varies
US area of interest	Usually Not Appropriate	○
MRI area of interest without and with IV contrast	Usually Not Appropriate	○
MRI area of interest without IV contrast	Usually Not Appropriate	○
Bone scan whole body	Usually Not Appropriate	⊕⊕⊕
Bone scan whole body with SPECT or SPECT/CT area of interest	Usually Not Appropriate	⊕⊕⊕
FDG-PET/CT whole body	Usually Not Appropriate	⊕⊕⊕⊕
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies
CT area of interest without IV contrast	Usually Not Appropriate	Varies

**Variant 2:                   Adult or child. Suspected primary bone tumor. No lesions on radiographs. Next imaging study.**

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without and with IV contrast	Usually Appropriate	○
MRI area of interest without IV contrast	Usually Appropriate	○
Bone scan whole body	May Be Appropriate	⊕⊕⊕
Bone scan whole body with SPECT or SPECT/CT area of interest	May Be Appropriate	⊕⊕⊕
CT area of interest with IV contrast	May Be Appropriate (Disagreement)	Varies
CT area of interest without IV contrast	May Be Appropriate (Disagreement)	Varies
US area of interest	Usually Not Appropriate	○
FDG-PET/CT whole body	Usually Not Appropriate	⊕⊕⊕⊕
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies

**Variant 3:**                    **Adult or child. Suspected primary bone tumor. Lesion on radiographs. Benign appearance. Not osteoid osteoma. Next imaging study.**

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without and with IV contrast	May Be Appropriate	○
MRI area of interest without IV contrast	May Be Appropriate	○
CT area of interest without IV contrast	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	○
Image-guided biopsy area of interest	Usually Not Appropriate	Varies
Bone scan whole body	Usually Not Appropriate	☼☼☼
Bone scan whole body with SPECT or SPECT/CT area of interest	Usually Not Appropriate	☼☼☼
FDG-PET/CT whole body	Usually Not Appropriate	☼☼☼☼
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies

**Variant 4:**                    **Adult or child. Suspected primary bone tumor. Osteoid osteoma suspected on radiographs or osteoid osteoma suspected based on clinical presentation with no lesions on radiographs. Next imaging study.**

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without and with IV contrast	Usually Appropriate	○
CT area of interest without IV contrast	Usually Appropriate	Varies
MRI area of interest without IV contrast	May Be Appropriate	○
CT area of interest with IV contrast	May Be Appropriate	Varies
CT area of interest without and with IV contrast	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	○
Image-guided biopsy area of interest	Usually Not Appropriate	Varies
Bone scan whole body	Usually Not Appropriate	☼☼☼
Bone scan whole body with SPECT or SPECT/CT area of interest	Usually Not Appropriate	☼☼☼
FDG-PET/CT whole body	Usually Not Appropriate	☼☼☼☼

**Variant 5:****Adult or child. Suspected primary bone tumor. Lesion on radiographs. Indeterminate or aggressive appearance for malignancy. Next imaging study.**

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without and with IV contrast	Usually Appropriate	○
MRI area of interest without IV contrast	Usually Appropriate	○
FDG-PET/CT whole body	Usually Appropriate	⊕⊕⊕⊕
Bone scan whole body with SPECT or SPECT/CT area of interest	May Be Appropriate	⊕⊕⊕
CT area of interest with IV contrast	May Be Appropriate	Varies
CT area of interest without and with IV contrast	May Be Appropriate	Varies
CT area of interest without IV contrast	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	○
Image-guided biopsy area of interest	Usually Not Appropriate	Varies
Bone scan whole body	Usually Not Appropriate	⊕⊕⊕

## SUSPECTED PRIMARY BONE TUMORS

Expert Panel on Musculoskeletal Imaging: Shivani Ahlawat, MD<sup>a</sup>; Leon Lenchik, MD<sup>b</sup>; Jonathan C. Baker, MD<sup>c</sup>; Hailey Allen, MD<sup>d</sup>; James Banks, MD<sup>e</sup>; Vaia Florou, MD, MS<sup>f</sup>; Hillary W. Garner, MD<sup>g</sup>; Matthew R. Hammer, MD<sup>h</sup>; Susan M. Hiniker, MD<sup>i</sup>; Sarah I. Kamel, MD<sup>j</sup>; Yi Lu, MD, PhD<sup>k</sup>; Kimberly S. Peairs, MD<sup>l</sup>; Jinel A. Scott, M<sup>m</sup>; Daniel E. Wessell, MD, PhD<sup>n</sup>.

### Summary of Literature Review

#### **Introduction/Background**

The term “bone tumor” may be applied to a broad range of entities including primary and metastatic neoplasms as well as a variety of tumor-like lesions related to developmental, metabolic, hematopoietic, lymphatic, or reactive abnormalities that affect bone. This document addresses tumors and tumor-like conditions that occur primarily in bones in adults and children and specifically excludes metastatic involvement of bones from both musculoskeletal and nonmusculoskeletal primary malignancies, such as lymphoma or plasma cell myeloma that may present as a solitary osseous lesion. Primary bone tumors are conventionally classified by the World Health Organization as benign, intermediate (locally aggressive or rarely metastasizing), or malignant [1]. Benign tumors include a wide variety of developmental abnormalities and true neoplasms. Because many benign bone tumors are asymptomatic, the true incidence of these tumors is unknown. Similarly, the incidence of intermediate primary bone tumors including giant cell tumor, osteoblastoma, and desmoplastic fibroma is also not known. Primary malignant bone tumors may also arise from malignant mesenchymal cells (sarcomas). Primary malignant bone tumors are quite rare, with an estimated incidence of 1 case per 100,000 persons per year [2].

Diagnosis of benign and malignant primary bone tumors requires a multidisciplinary approach and relies on a coordinated evaluation of both clinical and radiological information. Many primary bone tumors can be effectively stratified based on age, lesion size, location, and number.

This document applies to the evaluation of osseous lesions throughout the entire body (including skull, upper extremity, ribs, spine, pelvis, and lower extremity). Generally, primary bone tumors most often develop in the long bones [1], therefore, the general imaging recommendations for imaging are aligned to a long bone origin. However, when lesions occur in locations with complex osseous anatomy, such as the skull, spine, pelvis, or small bones of the hand or foot, CT may be a more suitable initial imaging modality. As noted within the document, the following recommendations must be adapted by the user, based on lesion size, location, and suspected biological aggressiveness. Because primary bone sarcomas are rare, there is sparse level 1 evidence in the literature specifically addressing their imaging evaluation.

#### **Special Imaging Considerations**

Clinically suspected benign or malignant primary bone tumors located in anatomically complex sites or the axial skeleton may require advanced imaging using CT for detection and characterization. Dual-energy CT (DECT) is an established technique with emerging musculoskeletal applications, including the detection of tophaceous gout/urate crystal deposition and bone marrow edema. DECT, performed by obtaining 2 spatially matched CT data sets using 2 distinct tube energies (eg, 70 and 150 kVP), enables material decomposition based on the atomic number and has shown promising results for generating virtual noncontrast images by removing iodine from contrast-enhanced images within and beyond the musculoskeletal system [3-9]. In the setting of primary bone tumors, a virtual noncontrast CT in conjunction with contrast-enhanced DECT can help distinguish areas of contrast enhancement from areas of osseous matrix production while simultaneously providing anatomic imaging evaluation.

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<sup>a</sup>Johns Hopkins University School of Medicine, Baltimore, Maryland. <sup>b</sup>Panel Chair, Wake Forest University School of Medicine, Winston Salem, North Carolina. <sup>c</sup>Panel Vice-Chair, Mallinckrodt Institute of Radiology Washington University School of Medicine, Saint Louis, Missouri. <sup>d</sup>University of Utah Health, Salt Lake City, Utah. <sup>e</sup>Nova Southeastern University, Fort Lauderdale, Florida. <sup>f</sup>Huntsman Cancer Institute, University of Utah, Salt Lake City, Utah; American Society of Clinical Oncology. <sup>g</sup>Mayo Clinic Florida, Jacksonville, Florida. <sup>h</sup>UT Southwestern Medical Center, Dallas, Texas. <sup>i</sup>Stanford University School of Medicine, Stanford, California; Commission on Radiation Oncology. <sup>j</sup>Thomas Jefferson University Hospital, Philadelphia, Pennsylvania. <sup>k</sup>Brigham & Women's Hospital & Harvard Medical School, Boston, Massachusetts; American Association of Neurological Surgeons/Congress of Neurological Surgeons. <sup>l</sup>Johns Hopkins University School of Medicine, Baltimore, Maryland, Primary care physician. <sup>m</sup>SUNY Downstate Health Sciences University and NYC Health and Hospitals, Brooklyn, New York. <sup>n</sup>Specialty Chair, Mayo Clinic, Jacksonville, Florida.

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## **Initial Imaging Definition**

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (i.e., only one procedure will be ordered to provide the clinical information to effectively manage the patient's care)

OR

- There are complementary procedures (i.e., more than one procedure is ordered as a set or simultaneously where each procedure provides unique clinical information to effectively manage the patient's care).

## **Discussion of Procedures by Variant**

### **Variant 1: Adult or child. Suspected primary bone tumor. Initial imaging.**

The goal of initial imaging of an adult or child with a suspected primary bone tumor is to detect the suspected bone tumor and characterize its biologic behavior. In addition, the optimal strategy can provide insight into tumor histology (presence or absence of tumor matrix) and stratify the risk for pathological fracture. Once a primary bone tumor is detected, accurate characterization optimizes patient management: For example, in the setting of asymptomatic nonaggressive lesions, initial imaging often allows definitive diagnosis and negates the need for further evaluation. Conversely, when initial imaging identifies an aggressive-appearing lesion or a lesion at risk for pathological fracture, orthopedic oncology referral and advanced imaging is typically warranted.

The body regions covered in this clinical scenario include the skull, cervical, thoracic, and lumbosacral spine, ribs, pelvis, hip, femur, knee, lower leg (tib/fib), ankle, foot, shoulder, humerus, elbow, forearm, wrist, and hand.

### **Bone Scan Whole Body**

Bone scan is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of Tc-99m bone scan in the initial imaging of primary bone tumors.

### **Bone Scan Whole Body With SPECT or SPECT/CT Area of Interest**

Bone scan with single-photon emission CT (SPECT) or SPECT/CT localized to the area of interest is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of Tc-99m bone scan in the initial imaging of primary bone tumors.

### **CT Area of Interest With IV Contrast**

CT with intravenous (IV) contrast is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of CT in the initial imaging of primary bone tumors.

### **CT Area of Interest Without and With IV Contrast**

CT without and with IV contrast is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of CT in the initial imaging of primary bone tumors.

### **CT Area of Interest Without IV Contrast**

CT without IV contrast is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of CT in the initial imaging of primary bone tumors.

### **FDG-PET/CT Whole Body**

PET using the tracer fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)/CT is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of FDG-PET/CT in the initial imaging of primary bone tumors.

### **MRI Area of Interest Without and With IV Contrast**

MRI without and with IV contrast is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of MRI in the initial imaging of primary bone tumors.

### **MRI Area of Interest Without IV Contrast**

MRI without IV contrast is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of MRI in the initial imaging of primary bone tumors.

## **Radiography Area of Interest**

Radiographs remain the most useful imaging modality for screening and initial characterization of primary bone tumors. Radiographs effectively provide information in regard to tumor location, size, and shape, as well as evidence of tumor biological activity [10]. Tumor margin and periosteal reaction provide a reliable index of biological potential of the tumor, whereas matrix, if identified, is a key to the underlying histology [10-13]. Although the usefulness of radiographs in stratifying bone lesions by biological activity is well established, there is sparse literature documenting concrete values on accuracy. A prospective study evaluating 200 consecutive bone tumors of the hand showed that subjective grading of tumors based on radiographic features provided a correct categorization of tumor grade (benign versus malignant) in 82.5% of cases [14]. In a retrospective study applying a modified Lodwick-Madewell grading system to categorize 183 bone tumors, Caracciolo et al [15] found that a low radiographic grade assignment correlates with benignity and that increasing grade correlates with an increasing risk of malignancy. It should be noted that accurate radiographic characterization of some primary bone tumors (such as low-grade cartilage lesions) is inherently difficult because of overlapping radiographic features of some benign and malignant chondroid lesions. Crim et al [16] performed a retrospective review of 53 cases of low-grade cartilage lesions (enchondroma and grade 1 chondrosarcoma) and found that radiographs suggested the correct diagnosis of enchondroma in 67.2% of cases and the correct diagnosis of chondrosarcoma in only 20.8% of cases. In a retrospective analysis of 35 enchondromas and 43 central grade 1 chondrosarcomas, Geirnaerd et al [17] found that morphologic features seen on radiographs in combination with clinical symptoms did not improve the ability to differentiate between enchondromas and central grade 1 chondrosarcomas.

## **US Area of Interest**

Ultrasound (US) is not routinely used in the initial evaluation of primary bone tumors. There is no relevant literature regarding the use of US in the initial imaging of primary bone tumors.

### **Variant 2: Adult or child. Suspected primary bone tumor. No lesions on radiographs. Next imaging study.**

In cases in which radiographs are negative or radiographic findings do not adequately explain the symptoms, further imaging should be considered based on history and level of clinical concern. The goal of this next imaging study is to detect and characterize a radiographically occult primary tumor in an adult or child to ensure appropriate patient care management.

The body regions covered in this clinical scenario include the skull, cervical, thoracic, and lumbosacral spine, ribs, pelvis, hip, femur, knee, lower leg (tib/fib), ankle, foot, shoulder, humerus, elbow, forearm, wrist, and hand.

## **Bone Scan Whole Body**

Despite its historical usefulness in detecting radiographically occult bone abnormalities, studies that are more recent have shown that MRI is superior in this role. A retrospective analysis comparing the sensitivity of MRI and scintigraphy in the detection of malignant bone tumors in 106 patients showed that MRI revealed a focal abnormality compatible with tumor that was occult on scintigraphy in 28% of cases [18]. Although not typically the next imaging study, bone scan remains a viable imaging option in certain situations such as in cases that require evaluation of the full extent and distribution of disease because it can provide a comprehensive evaluation of the entire skeleton.

## **Bone Scan Whole Body With SPECT or SPECT/CT Area of Interest**

There is no literature supporting the use of bone scan whole body with SPECT or SPECT/CT covering the area of interest for the detection of radiographically occult primary bone tumors. Although not typically the next imaging study, bone scan whole body with SPECT or SPECT/CT may be a reasonable imaging option in certain situations such as in cases that require evaluation of the full extent and distribution of disease because it can provide a comprehensive evaluation of the entire skeleton.

## **CT Area of Interest With IV Contrast**

There is no relevant literature specifically regarding the use of CT with IV contrast in the evaluation of suspected primary bone tumor with negative or equivocal radiographs or radiographs that do not explain symptoms. CT may be useful for the characterization of a primary bone tumor in anatomically complex area and the axial skeleton as well as the differentiation of areas of contrast enhancement from areas of osseous matrix production. In addition, contrast can be helpful if a soft tissue component is suspected. However, if contrast is given, a single-phase contrast-enhanced CT may be more beneficial in conjunction with postprocessed virtual noncontrast reconstruction derived from modern DECT scanners rather than a traditional CT with IV contrast for the differentiation of osseous matrix production from enhancement [4,7,8].

### **CT Area of Interest Without and With IV Contrast**

There is no relevant literature specifically regarding the use of CT without and with IV contrast in the evaluation of suspected primary bone tumor with negative or equivocal radiographs or radiographs that do not explain symptoms. Contrast may be helpful if a soft tissue component is suspected. However, if contrast is given, a single-phase contrast-enhanced CT may be more beneficial in conjunction with postprocessed virtual noncontrast reconstruction derived from modern DECT scanners rather than a traditional dual-phase CT without and with IV contrast.

### **CT Area of Interest Without IV Contrast**

In cases in which radiographs are negative or fail to adequately explain symptoms, CT can be a helpful tool in facilitating detection of bony abnormalities, such as nondisplaced fractures, subtle periosteal reaction, or occult bone tumors. CT can be especially helpful in evaluating regions of complex or overlapping osseous anatomy, in which radiographic evaluation can be limited. In a retrospective study of 47 patients with negative radiographic findings and positive bone scintigraphy findings specifically involving the ribs, CT was effective in detecting rib fractures and avoiding further unnecessary examinations [19]. Some cases may benefit from both MRI and CT because these modalities provide complementary information regarding soft tissue (often better evaluated on MRI) and matrix mineralization (often better evaluated on CT). In addition to detection of a primary bone tumor, CT enables measurements of Hounsfield units, however, there is no consensus on using quantitative CT derived metrics for the characterization of primary bone tumors [20-22].

If CT is performed for a radiographically occult skeletal lesion, CT without IV contrast is more useful for the evaluation of matrix mineralization than CT with IV contrast or CT without and with IV contrast.

### **FDG-PET/CT Whole Body**

FDG-PET/CT is not routinely used for the evaluation of primary bone tumors in patients with positive localized or regional symptoms and negative radiographs or findings that do not explain symptoms. Although FDG-PET/CT can detect metabolically active tumors, there is no relevant literature regarding the use of FDG-PET/CT in patients with positive localized or regional symptoms and negative radiographs or findings that do not explain symptoms.

### **MRI Area of Interest Without and With IV Contrast**

Although administration of gadolinium-based contrast may be especially useful in biopsy planning and assessment of anatomic extent as well as response to therapy, it is not necessary for the detection of a radiographically occult primary bone tumor.

### **MRI Area of Interest Without IV Contrast**

Although there is no relevant literature specifically regarding the general use of MRI in this setting, the excellent soft tissue characterization afforded by MRI facilitates detection of radiographically occult pathology within both the bone and the surrounding tissues. In addition to its ability to detect occult bone tumors, MRI can identify other radiographically occult abnormalities, such as osseous contusion, developing stress fracture, infection, or regional soft tissue injury, which may account for the patient's symptoms. There is evidence that MRI is superior to bone scan [18] as detailed in the bone scan section below. For these reasons, MRI is considered the study of choice in patients with suspected bone tumor when radiographs do not explain the patient's symptoms.

### **US Area of Interest**

Although US may be helpful in detecting regional soft tissue abnormalities that could explain symptoms, US is quite limited in its ability to evaluate bone. There is no relevant literature regarding the use of US for the evaluation of primary bone tumors in patients with positive localized or regional symptoms and negative radiographs or findings that do not explain symptoms.

### **Variant 3: Adult or child. Suspected primary bone tumor. Lesion on radiographs. Benign appearance. Not osteoid osteoma. Next imaging study.**

An asymptomatic benign-appearing lesion on radiographs is usually an incidental finding. If the lesion is symptomatic, at risk for pathological fracture (large aneurysmal bone cyst), or of indeterminate malignant potential (large enchondroma), please consult Variant 5.

The body regions covered in this clinical scenario include the skull, cervical, thoracic, and lumbosacral spine, ribs, pelvis, hip, femur, knee, lower leg (tib/fib), ankle, foot, shoulder, humerus, elbow, forearm, wrist, and hand.

### **Bone Scan Whole Body**

Bone scan is not routinely used in the evaluation of lesions that are definitely benign on radiographs. There is no relevant literature regarding the use of Tc-99m bone scan in the evaluation of definitely benign primary bone tumors.

### **Bone Scan Whole Body With SPECT or SPECT/CT Area of Interest**

There is no relevant literature regarding the use of bone scan with SPECT or SPECT/CT covering the area of interest in the evaluation of definitely benign primary bone tumors.

### **CT Area of Interest With IV Contrast**

CT with IV contrast is not routinely used in the evaluation of lesions that are definitely benign on radiographs. There is no relevant literature regarding the use of CT with IV contrast in the evaluation of definitely benign primary bone tumors.

### **CT Area of Interest Without and With IV Contrast**

CT without and with IV contrast is not routinely used in the evaluation of lesions that are definitely benign on radiographs.

### **CT Area of Interest Without IV Contrast**

CT is not routinely used in the evaluation of lesions that are definitely benign on radiographs. There is no relevant literature regarding the use of CT in the evaluation of definitely benign primary bone tumors. However, if such lesions are symptomatic, CT imaging without IV contrast may be useful to identify complications, determine risk for pathological fracture, or for surgical planning.

### **FDG-PET/CT Whole Body**

FDG-PET/CT is not routinely used in the evaluation of lesions that are definitely benign on radiographs. There is no relevant literature regarding the use of FDG-PET/CT in the evaluation of definitely benign primary bone tumors.

### **Image-Guided Biopsy Area of Interest**

Image-guided biopsy is not routinely performed in the evaluation of lesions that are definitely benign on radiographs.

### **MRI Area of Interest Without and With IV Contrast**

MRI without and with IV contrast is not routinely used in the evaluation of lesions that are definitely benign on radiographs. In the case of symptomatic lesion, MRI without and with IV contrast may be useful to identify unusual complications, such as stress fracture, secondary aneurysmal bone cyst formation, or malignant transformation [23]. Rarely, radiographically nonaggressive and asymptomatic primary bone tumor (like a large aneurysmal bone cyst at risk for pathological fracture) may require further imaging for definitive characterization before intervention. In such clinical scenarios, MRI with and without IV contrast can be useful in definitive characterization and distinguishing a primary from secondary aneurysmal bone cyst [24,25].

### **MRI Area of Interest Without IV Contrast**

MRI without IV contrast is not routinely used in the evaluation of lesions that are definitely benign on radiographs. In the case of symptomatic lesion or large asymptomatic lesion that require further characterization before definitive management, MRI without IV contrast may be useful to identify unusual complications, such as stress fracture, secondary aneurysmal bone cyst formation, or malignant transformation; however, MRI with and without IV contrast may be preferred [23].

### **US Area of Interest**

US is not routinely used in the evaluation of lesions that are definitely benign on radiographs. There is no relevant literature regarding the use of US in the evaluation of definitely benign primary bone tumors.

### **Variant 4: Adult or child. Suspected primary bone tumor. Osteoid osteoma suspected on radiographs or osteoid osteoma suspected based on clinical presentation with no lesions on radiographs. Next imaging study.**

A clinically or radiographically suspected osteoid osteoma in an adult or child often requires advanced imaging for definitive characterization and subsequent management. Although there are rare case reports of asymptomatic or painless osteoid osteoma, the lack of symptoms is unusual, and these lesions typically manifest clinically, requiring further imaging and treatment [26].

The body regions covered in this clinical scenario include the skull, cervical, thoracic, and lumbosacral spine, ribs, pelvis, hip, femur, knee, lower leg (tib/fib), ankle, foot, shoulder, humerus, elbow, forearm, wrist, and hand.



### **Bone Scan Whole Body**

Although bone scan is sensitive for the detection of osteoid osteoma, it lacks specificity [27] and therefore not routinely performed as the next imaging study for radiographically or clinically suspected osteoid osteoma.

### **Bone Scan Whole Body With SPECT or SPECT/CT Area of Interest**

Bone scan is sensitive for the detection of osteoid osteoma but lacks specificity. SPECT or SPECT/CT may help improve specificity [27], however, it is typically not performed as the imaging study for radiographically or clinically suspected osteoid osteoma.

### **CT Area of Interest With IV Contrast**

There is no relevant literature specifically regarding the use of CT with IV contrast in the evaluation of clinically or radiologically suspected osteoid osteoma. CT with IV may be useful for the characterization of an osteoid osteoma in anatomically complex area and the axial skeleton.

### **CT Area of Interest Without and With IV Contrast**

There is no relevant literature specifically regarding the use of CT without and with IV contrast in the evaluation of clinically or radiologically suspected osteoid osteoma. However, if contrast is given, a single-phase CT with IV contrast may be more beneficial in conjunction with postprocessed virtual noncontrast reconstruction from modern DECT scanners rather than a traditional dual-phase CT without and with IV contrast for the characterization of a suspected osteoid osteoma in anatomically complex area and the axial skeleton as well as the differentiation of areas of contrast enhancement from areas of osseous matrix production.

CT perfusion is a dynamic without and with IV contrast CT examination, which facilitates further characterization in the setting of suspected osteoid osteoma. A comparative study looking at CT perfusion parameters of 15 patients with a final diagnosis of osteoid osteoma, 15 patients with lesions that mimic osteoid osteomas, and 26 patients with other bone lytic lesions showed that enhancement curve morphology of the osteoid osteomas was significantly different from its mimickers. All osteoid osteomas had early enhancement with a delay between nidus and arterial peak below 30 seconds. Eighty percent of the mimickers demonstrated a slow and progressive pattern of enhancement. The perfusion parameters of the other lytic bone lesions were similar to those of the osteoid osteomas in 46.1% of the patients, indicating that early enhancement is suggestive but not pathognomonic of osteoid osteomas [28].

### **CT Area of Interest Without IV Contrast**

CT without IV contrast is considered the optimal imaging modality in patients with suspected osteoid osteoma. CT is preferred over MRI when osteoid osteoma is strongly suspected because it is extremely sensitive for detection and precise delineation of the nidus [29], which is important both for diagnosis and treatment. In a study including 19 patients with histologically proven osteoid osteoma who underwent CT and MRI before excision of the lesion, Assoun et al [30] found that CT was more accurate than MRI in detection of the osteoid osteoma nidus in 63% of cases.

When CT is performed for radiographically or clinically suspected osteoid osteoma, CT without IV contrast is preferred for imaging. If IV contrast material is administered, a single-phase contrast-enhanced DECT may be considered more appropriate than a CT with and without IV contrast.

### **FDG-PET/CT Whole Body**

FDG-PET/CT is not routinely used in the evaluation of suspected osteoid osteoma. There is no relevant literature regarding the use of FDG-PET/CT in the evaluation of suspected osteoid osteoma.

### **Image-Guided Biopsy Area of Interest**

Although image-guided biopsy offers high diagnostic yield (approximately 85%) and accuracy (approximately 92%) for the definitive diagnosis of a primary bone tumor, it is not routinely performed as the next imaging study in the evaluation of a suspected osteoid osteoma [31]. For patients undergoing definitive management of osteoid osteoma, an image-guided biopsy can be obtained if the advanced imaging modalities like CT or MRI are not determinate, although frequently not performed at all [32].

### **MRI Area of Interest Without and With IV Contrast**

Liu et al [33] performed a retrospective study including 11 patients with pathologically proven osteoid osteomas who underwent nonenhanced MRI, dynamic gadolinium-enhanced MRI, and CT. They showed that, compared with CT, dynamic gadolinium-enhanced MRI demonstrated the osteoid osteoma equally well in 8 of 11 patients and with better conspicuity in 3 of 11 patients, although this difference was not statistically significant ( $P = .69$ ). Furthermore,

the dynamic gadolinium-enhanced MRIs demonstrated the osteoid osteomas significantly better than the nonenhanced T1-weighted ( $P < .001$ ) and T2-weighted ( $P < .001$ ) MRIs. In the majority of cases, peak enhancement of the osteoid osteoma occurred in the arterial phase with early partial washout. However, MRI without IV contrast or MRI without and with IV contrast may be useful in some cases to identify alternative diagnoses such as osteomyelitis.

#### **MRI Area of Interest Without IV Contrast**

MRI without IV contrast is generally considered inferior to CT in the evaluation of suspected osteoid osteoma because it may fail to demonstrate the typical nidus and can present a confounding imaging appearance. Davies et al [34] performed a retrospective review of the MRI findings of 43 patients with osteoid osteoma and then compared the results with those of other imaging modalities. The authors found that the potential for a missed diagnosis of osteoid osteoma on MRI was 35%. They cautioned that osteoid osteoma may be difficult to identify on MRI and the imaging features may be easily misinterpreted. In a study including 19 patients with histologically proven osteoid osteoma who underwent CT and MRI before excision of the lesion, Assoun et al [30] found that MRI was better than CT in showing intramedullary and soft tissue changes in all cases. However, the authors cautioned that such findings on MRI may produce a misleading aggressive appearance. Liu et al [33] performed a retrospective study including 11 patients with pathologically proven osteoid osteomas who underwent nonenhanced MRI, dynamic gadolinium-enhanced MRI, and CT. They showed that, compared with CT, dynamic gadolinium-enhanced MRI demonstrated the osteoid osteoma equally well in 8 of 11 patients and with better conspicuity in 3 of 11 patients, although this difference was not statistically significant ( $P = .69$ ). Furthermore, the dynamic gadolinium-enhanced MRIs demonstrated the osteoid osteomas significantly better than the nonenhanced T1-weighted ( $P < .001$ ) and T2-weighted ( $P < .001$ ) MRIs. In the majority of cases, peak enhancement of the osteoid osteoma occurred in the arterial phase with early partial washout. However, MRI without IV contrast or MRI without and with IV contrast may be useful in some cases to identify alternative diagnoses such as osteomyelitis.

#### **US Area of Interest**

US is not routinely used in the evaluation of suspected osteoid osteoma. There is no relevant literature regarding the use of US in the evaluation of suspected osteoid osteoma.

#### **Variant 5: Adult or child. Suspected primary bone tumor. Lesion on radiographs. Indeterminate or aggressive appearance for malignancy. Next imaging study.**

Lesions seen on radiographs that are indeterminate or aggressive often require additional characterization using imaging studies. This variant encompasses bone tumors that are suspicious for malignancy, at risk for pathological fracture (eg, a large aneurysmal bone cyst), and of indeterminate malignant potential (such as a large chondroid lesion). In rare occurrences, a radiographically nonaggressive and asymptomatic primary bone tumor (like a large aneurysmal bone cyst) may require further imaging for definitive characterization and intervention. Similarly, a large enchondroma may warrant clinical or imaging surveillance, often requiring orthopedic oncology consultation [35,36]. The next best imaging examination is not always clearly defined because the choice will be influenced by the radiographic appearance of the lesion, location, number of lesions, plan for biopsy and/or treatment, as well as underlying patient-specific clinical parameters. The goal of imaging an indeterminate or aggressive primary bone tumor is to improve lesion characterization and guide management.

The body regions covered in this clinical scenario include the skull, cervical, thoracic, and lumbosacral spine, ribs, pelvis, hip, femur, knee, lower leg (tib/fib), ankle, foot, shoulder, humerus, elbow, forearm, wrist, and hand.

#### **Bone Scan Whole Body**

Despite its historical usefulness in further characterizing lesions detected on radiographs, there are no controlled studies in the literature over the last 10 years specifically evaluating the efficacy of bone scan in this role, therefore, bone scan is not routinely performed as the next imaging study for indeterminate or aggressive skeletal lesion.

#### **Bone Scan Whole Body With SPECT or SPECT/CT Area of Interest**

Despite its historical usefulness in further characterizing lesions detected on radiographs, there are no controlled studies in the literature over the last 10 years specifically evaluating the efficacy of bone scan in this role. However, recent advances in technology, such as the addition of SPECT/CT to bone scan, may provide a useful tool in the evaluation of primary bone tumors. A retrospective review of 99 patients with 108 vertebral lesions showed that SPECT/CT was superior to planar scintigraphy and SPECT alone, but not CT alone, in the characterization of indeterminate vertebral lesions found on bone scintigraphy [37].

### **CT Area of Interest With IV Contrast**

There is no relevant literature regarding the specific use of CT with IV contrast in the evaluation of suspected primary bone tumor with radiographs that are indeterminate for malignancy. However, if contrast is given, a single-phase contrast-enhanced DECT may be more beneficial in conjunction with postprocessed virtual noncontrast reconstructions rather than a traditional dual-phase CT without and with IV contrast for the differentiation of areas of contrast enhancement from areas of osseous matrix production.

### **CT Area of Interest Without and With IV Contrast**

There is no relevant literature regarding the specific use of dual-phase CT without and with IV contrast in the evaluation of suspected primary bone tumor with radiographs that are indeterminate for malignancy. However, if contrast is given, a single-phase contrast-enhanced CT may be more beneficial in conjunction with postprocessed virtual noncontrast reconstruction derived from modern DECT scanners, rather than a traditional CT single-phase postprocessed noncontrast CT for the differentiation of areas of contrast enhancement from areas of osseous matrix production.

### **CT Area of Interest Without IV Contrast**

CT continues to play a role in the evaluation of indeterminate bone lesions discovered on radiographs, particularly in lesions with mineralized matrix or in suspected cases of osteoid osteoma (see Variant 4). Both MRI and CT have been used to evaluate the degree of cortical involvement in chondroid lesions [38]. In addition to detection of a primary bone tumor, CT enables measurements of Hounsfield units, however, there is no consensus on use of quantitative CT derived metrics for the characterization of primary bone tumors [20-22]. In comparison with radiographs and MRI, CT has been shown to better delineate the presence of cortical destruction and the character of matrix mineralization patterns in patients with clear cell chondrosarcoma [39]. In a retrospective review of 40 pathologically confirmed telangiectatic osteosarcomas, Murphey et al [40] noted that CT was the optimal imaging modality for demonstration of subtle matrix mineralization seen in 85% of cases in the intraosseous or soft tissue components of the lesion.

Not all studies conclude that one modality, CT or MRI, is better than the other. A multi-institutional collaborative study assessing the relative accuracy of CT and MRI in the local staging of primary malignant musculoskeletal neoplasms showed no statistically significant difference between CT and MRI in determining tumor involvement of muscle, bone, joints, or neurovascular structures. Furthermore, the combined interpretation of CT and MRI did not significantly improve accuracy [41]. Advanced CT techniques, such as DECT, have shown promise in differentiating malignant from nonmalignant tumors, although further research in this area is needed [42].

MRI is generally considered the preferred imaging modality for staging of bone tumors. Some cases may benefit from both MRI and CT because these modalities provide complementary information regarding soft tissue (often better evaluated on MRI) and matrix mineralization (often better evaluated on CT).

In summary, when CT is performed for an indeterminate or suspected aggressive skeletal lesion, CT without IV contrast is preferred for the evaluation of matrix mineralization. If IV contrast material is administered, a single-phase contrast-enhanced DECT may be considered more useful than a CT with and without IV contrast.

### **FDG-PET/CT Whole Body**

FDG-PET has proven useful for further characterizing indeterminate bone tumors identified on radiographs. PET information can be co-registered with CT or MRI, taking advantage of the inherent benefits of these modalities. A number of studies have shown FDG-PET and FDG-PET/CT to be a valuable adjunct to conventional imaging in the diagnosis, staging, restaging, and surveillance of primary bone tumors [43-49]. Shin et al [50] evaluated the efficacy of FDG-PET/CT in differentiating benign from malignant pathologic fractures in a series of 34 patients. With a standardized uptake value max cut-off set at 4.7, they found the sensitivity, specificity, and diagnostic accuracy of FDG-PET/CT to be 89.5%, 86.7%, and 88.2%, respectively. However, it was noted that there may be significant overlap in the metabolic activity of benign and malignant lesions, such as those containing myxoid or necrotic components with inherent low metabolic activity. In a study of 29 patients assessing the benefit of PET in appropriately characterizing cartilage neoplasms, the overall sensitivity of PET in differentiating benign from malignant lesions was 90.9%, with a specificity of 100% and an accuracy of 96.6% [51]. Bredella et al [44] found that FDG-PET can help differentiate benign from malignant spinal compression fractures with a sensitivity of 86% and a specificity of 83%, however, there was overlap in the range of standardized uptake value in the benign and malignant groups. A meta-analysis evaluating the diagnostic accuracy of FDG-PET for the characterization of bone tumors as benign or malignant reported the sensitivity, specificity, and area under the curve of bone sarcomas to be

87.2% (95% confidence interval [CI], 78.1%-94.8%), 71.4% (95% CI, 58.3%-82.6%), and 86.9%, respectively [52]. Specifically for osteosarcomas, FDG-PET offers high diagnostic accuracy for the characterization of the primary lesion and assessment of systemic stage [53].

### **Image-Guided Biopsy Area of Interest**

Although image-guided biopsy offers high diagnostic yield (approximately 85%) and accuracy (approximately 92%) for the definitive diagnosis of a primary bone tumor, it is not routinely performed as the next imaging study in the evaluation of a radiographically indeterminate or aggressive bone tumor [31]. Cross-sectional imaging as well as a multidisciplinary approach is often required prior to biopsy to determine an optimal biopsy trajectory.

### **MRI Area of Interest Without and With IV Contrast**

Several studies have shown that contrast-enhanced MRI and MR angiography can provide additional information (eg, more accurate characterization, evaluation of viability, and biopsy planning) for the preoperative evaluation of primary bone tumors [54-56]. In a study of 37 patients with cartilaginous tumors, Geirnaerd et al [57] evaluated the usefulness of fast contrast-enhanced MRI in differentiating benign from malignant tumors. They found that differentiation of malignancy from benignity was possible with this technique, with a sensitivity of 61% and specificity of 95%. Although there is variability in the methods of image acquisition and interpretation for the evaluation of cartilaginous tumors, MRI can provide insight into imaging features associated with high-grade chondrosarcomas [58]. The usefulness of MRI with dynamic contrast enhancement in characterizing lesions as benign or malignant has been evaluated in several additional studies with mixed results [59,60].

### **MRI Area of Interest Without IV Contrast**

MRI is a robust tool that can further characterize an indeterminate bone lesion detected on radiographs. Despite its widespread use in this role, there are few controlled studies in the literature over the last 10 years specifically evaluating the role of MRI in further characterizing lesions detected on radiographs. Several studies do exist that serve to highlight the role of MRI in further characterizing the tissue composition (such as fat, hemorrhage, fluid levels) and anatomic extent of a variety of bone tumors [38-40,61,62]. MRI has also been shown to be useful in predicting the grade (benign versus malignant) of known primary bone tumors. A prospective study evaluating 200 consecutive bone tumors of the hand showed that MRI improved grading in comparison with radiography alone by correctly upgrading malignant tumors and downgrading benign tumors in 8% and 12% of cases, respectively [14]. Crim et al [16] performed a retrospective review of 53 cases of low-grade cartilage lesions (enchondroma and grade 1 chondrosarcoma) and found that MRI suggested the correct diagnosis of enchondroma in 57.8% of cases (radiographs correctly diagnosed 67.2% of cases) and the correct diagnosis of chondrosarcoma in 57.8% of cases (radiographs correctly diagnosed 20.8% of cases). Overall, MRI had an increased rate of both true-positive and false-positive diagnosis for chondroid lesions in comparison with radiographs. Similar to radiographic characterization, the characterization of low-grade chondroid lesions on MRI is challenging because of overlapping features of benign and malignant lesions.

MRI is generally considered the preferred imaging modality for staging of bone tumors [29]. Hogeboom et al [63] compared the benefit of MRI to CT in the evaluation of bone tumors in a prospective study of 25 patients. They found that MRI has better soft tissue contrast than CT, making it possible to study the relationship of the bone tumor to the soft tissues, bone marrow, and joints more accurately. They found that CT better defines destruction of cortical bone. Specifically, MRI was superior to CT in detecting cortical bone destruction in only 4.5% of patients studied but better at evaluating marrow involvement in 25%, soft tissue involvement in 31%, joint involvement in 36.4%, and invasion of neurovascular structures in 15.3% of patients. MRI and CT were judged equivalent in these categories the majority of the time (ranging from 63% to 82% of the time for the various categories). CT was superior to MRI for some patients in 2 categories: detecting cortical bone destruction (13.6%) and neurovascular involvement (7.7%). Overall, the authors suggest that MRI is preferable to CT.

A prospective study comparing the staging of primary bone sarcoma with CT, MRI, bone scintigraphy, and angiography in 56 patients showed that MRI was superior in defining tumor length, demonstrating involvement of muscle compartments, and delineating the relationship between tumor and major neurovascular bundles [64]. In the same study, MRI was shown to be comparable to CT in demonstrating cortical bone and joint involvement [64]. In contrast, results of a multi-institutional collaborative study assessing the relative accuracy of CT and MRI in the local staging of primary malignant musculoskeletal neoplasms showed no statistically significant difference between CT and MRI in determining tumor involvement of muscle, bone, joints, or neurovascular structures [41]. Furthermore, the combined interpretation of CT and MRI did not significantly improve accuracy [41]. However, a more recent retrospective study comparing the diagnostic accuracy of radiographs, CT, MRI, bone scintigraphy,

and FDG-PET/CT versus pathology reports in 409 biopsy-proven tumors showed that the sensitivity of MRI and FDG-PET/CT was better than that of CT, bone scintigraphy, and radiographs. In spine lesions, MRI was the most sensitive modality for detection of tumors, followed by FDG-PET/CT and CT [65].

Other MRI sequences, such as diffusion-weighted and chemical shift MRI, have been shown to be useful in differentiating benign from malignant bone tumors [66-68]. MRI with dynamic contrast enhancement [59], as well as diffusion and chemical shift MRI [68], can help differentiate benign from malignant spinal compression fractures. Characterization of bone tumors as benign or malignant with MR spectroscopy has shown promise in small observational studies, although further research is needed [69,70].

### **US Area of Interest**

US is routinely not used in the evaluation of indeterminate or aggressive bone lesions seen on radiographs. There is no relevant literature regarding the use of US in the evaluation of an indeterminate or aggressive lesion detected on radiographs.

### **Summary of Highlights**

This is a summary of the key recommendations from the variant tables. Refer to the complete narrative document for more information.

- **Variante 1:** For an adult or child with suspected primary bone tumor, radiography of the area of interest is recommended as the initial imaging study for both detection and characterization.
- **Variante 2:** For an adult or child with suspected primary bone tumor and no lesion detected by radiography, MRI area of interest without and with IV contrast or MRI area of interest without IV contrast are recommended as the next imaging studies for detection and evaluation of anatomic extent.
- **Variante 3:** For an adult or child with suspected primary bone tumor and a benign lesion (excluding an osteoid osteoma) detected by radiography, MRI of area of interest without and with IV contrast, MRI of area of interest without IV contrast, or CT of area of interest without IV contrast may be useful to identify complications, determine risk for pathological fracture, or for surgical planning.
- **Variante 4:** For an adult or child with radiographically detected or clinically suspected osteoid osteoma, CT of area of interest without IV contrast is considered the optimal next imaging study for confirmation and delineation of the nidus. In addition, MRI of area of interest with and without IV contrast can also be useful in some cases to identify alternative diagnoses such as osteomyelitis.
- **Variante 5:** For an adult or child with an indeterminate or aggressive appearing skeletal lesion on radiographs, MRI focused on the area of interest without and with IV contrast or MRI without IV contrast is the next imaging study to evaluate anatomic extent, assess viability, and plan biopsy. In addition, FDG-PET/CT whole body can be useful in characterizing an indeterminate skeletal lesion as benign or malignant.

### **Supporting Documents**

The evidence table, literature search, and appendix for this topic are available at <https://acsearch.acr.org/list>. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents go to [www.acr.org/ac](http://www.acr.org/ac).

### **Gender Equality and Inclusivity Clause**

The ACR acknowledges the limitations in applying inclusive language when citing research studies that pre-dates the use of the current understanding of language inclusive of diversity in sex, intersex, gender and gender-diverse people. The data variables regarding sex and gender used in the cited literature will not be changed. However, this guideline will use the terminology and definitions as proposed by the National Institutes of Health [71].

## Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

## Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® [Radiation Dose Assessment Introduction](#) document [72].

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
○	0 mSv	0 mSv
⊕	<0.1 mSv	<0.03 mSv
⊕⊕	0.1-1 mSv	0.03-0.3 mSv
⊕⊕⊕	1-10 mSv	0.3-3 mSv
⊕⊕⊕⊕	10-30 mSv	3-10 mSv
⊕⊕⊕⊕⊕	30-100 mSv	10-30 mSv

\*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

## References

1. Fletcher CDM, World Health Organization, International Agency for Research on Cancer. *WHO classification of tumours of soft tissue and bone*. 5th ed. Lyon: IARC Press; 2020.

2. National Cancer Institute. Surveillance, Epidemiology, and End Results (SEER). Cancer Stat Facts: Bone and Joint Cancer. Available at: <https://seer.cancer.gov/statfacts/html/bones.html>. Accessed September 30, 2024.
3. Bucolo GM, Ascenti V, Barbera S, et al. Virtual Non-Contrast Spectral CT in Renal Masses: Is It Time to Discard Conventional Unenhanced Phase? *J Clin Med* 2023;12.
4. Demehri S, Baffour FI, Klein JG, et al. Musculoskeletal CT Imaging: State-of-the-Art Advancements and Future Directions. *Radiology* 2023;308:e230344.
5. Liang H, Du S, Yan G, et al. Dual-energy CT of the pancreas: comparison between virtual non-contrast images and true non-contrast images in the detection of pancreatic lesion. *Abdom Radiol (NY)* 2023;48:2596-603.
6. McCoombe K, Dobeli K, Meikle S, Llewellyn S, Kench P. Sensitivity of virtual non-contrast dual-energy CT urogram for detection of urinary calculi: a systematic review and meta-analysis. *Eur Radiol* 2022;32:8588-96.
7. Stern C, Graf DN, Bouaicha S, Wieser K, Roszkopf AB, Sutter R. Virtual non-contrast images calculated from dual-energy CT shoulder arthrography improve the detection of intraarticular loose bodies. *Skeletal Radiol* 2022;51:1639-47.
8. Stern C, Marcon M, Bouaicha S, Wieser K, Roszkopf AB, Sutter R. Dual energy CT arthrography in shoulder instability: successful iodine removal with virtual non-contrast images and accurate 3D reformats of the glenoid for assessment of bone loss. *Skeletal Radiol* 2022;51:1027-36.
9. Verstraeten S, Ansems J, Ommen WV, Linden DV, Looijmans F, Tesselaar E. Comparison of true non-contrast and virtual non-contrast images in the characterization of renal lesions using detector-based spectral CT. *Br J Radiol* 2023;96:20220157.
10. Lodwick GS. A probabilistic approach to the diagnosis of bone tumors. *Radiol Clin North Am* 1965;3:487-97.
11. Madewell JE, Ragsdale BD, Sweet DE. Radiologic and pathologic analysis of solitary bone lesions. Part I: internal margins. *Radiol Clin North Am* 1981;19:715-48.
12. Ragsdale BD, Madewell JE, Sweet DE. Radiologic and pathologic analysis of solitary bone lesions. Part II: periosteal reactions. *Radiol Clin North Am* 1981;19:749-83.
13. Sweet DE, Madewell JE, Ragsdale BD. Radiologic and pathologic analysis of solitary bone lesions. Part III: matrix patterns. *Radiol Clin North Am* 1981;19:785-814.
14. Oudenhoven LF, Dhondt E, Kahn S, et al. Accuracy of radiography in grading and tissue-specific diagnosis--a study of 200 consecutive bone tumors of the hand. *Skeletal Radiol* 2006;35:78-87.
15. Caracciolo JT, Temple HT, Letson GD, Kransdorf MJ. A Modified Lodwick-Madewell Grading System for the Evaluation of Lytic Bone Lesions. *AJR Am J Roentgenol* 2016;207:150-6.
16. Crim J, Schmidt R, Layfield L, Hanrahan C, Manaster BJ. Can imaging criteria distinguish enchondroma from grade 1 chondrosarcoma? *Eur J Radiol* 2015;84:2222-30.
17. Geirnaerd MJ, Hermans J, Bloem JL, et al. Usefulness of radiography in differentiating enchondroma from central grade 1 chondrosarcoma. *AJR Am J Roentgenol* 1997;169:1097-104.
18. Frank JA, Ling A, Patronas NJ, et al. Detection of malignant bone tumors: MR imaging vs scintigraphy. *AJR Am J Roentgenol* 1990;155:1043-8.
19. Niitsu M, Takeda T. Solitary hot spots in the ribs on bone scan: value of thin-section reformatted computed tomography to exclude radiography-negative fractures. *J Comput Assist Tomogr* 2003;27:469-74.
20. Azar A, Garner HW, Rhodes NG, Yarlagadda B, Wessell DE. CT Attenuation Values Do Not Reliably Distinguish Benign Sclerotic Lesions From Osteoblastic Metastases in Patients Undergoing Bone Biopsy. *AJR Am J Roentgenol* 2021;216:1022-30.
21. Elangovan SM, Sebros R. Accuracy of CT Attenuation Measurement for Differentiating Treated Osteoblastic Metastases From Enostoses. *AJR Am J Roentgenol* 2018;210:615-20.
22. Ulano A, Bredella MA, Burke P, et al. Distinguishing Untreated Osteoblastic Metastases From Enostoses Using CT Attenuation Measurements. *AJR Am J Roentgenol* 2016;207:362-8.
23. Murphey MD, Suhardja A, Senchak L, Walker E, Fanburg-Smith J, Kransdorf MJ. Imaging of unusual complications of non-ossifying fibroma. *Skeletal Radiol* 2016;45:1158.
24. Gruenewald LD, Koch V, Gruber-Rouh T, et al. MR angiography facilitates the differentiation of aneurysmal from unicameral bone cysts. *Br J Radiol* 2023;96:20220849.
25. Josip E, Kremser C, Haider B, Thaler M, Dammerer D, Henninger B. MRI analysis of simple and aneurysmal bone cysts in the proximal humerus: what actually matters in clinical routine. *Skeletal Radiol* 2022;51:819-27.
26. McDermott MB, Kyriakos M, McEnery K. Painless osteoid osteoma of the rib in an adult. A case report and a review of the literature. *Cancer* 1996;77:1442-9.
27. Sharma P, Mukherjee A, Karunanithi S, et al. 99mTc-Methylene diphosphonate SPECT/CT as the one-stop imaging modality for the diagnosis of osteoid osteoma. *Nucl Med Commun* 2014;35:876-83.

28. Gondim Teixeira PA, Lecocq S, Louis M, et al. Wide area detector CT perfusion: can it differentiate osteoid osteomas from other lytic bone lesions? *Diagn Interv Imaging* 2014;95:587-94.
29. Sundaram M, McLeod RA. MR imaging of tumor and tumorlike lesions of bone and soft tissue. *AJR Am J Roentgenol* 1990;155:817-24.
30. Assoun J, Richardi G, Railhac JJ, et al. Osteoid osteoma: MR imaging versus CT. *Radiology* 1994;191:217-23.
31. Crenn V, Vezole L, Bouhamama A, et al. Percutaneous Core Needle Biopsy Can Efficiently and Safely Diagnose Most Primary Bone Tumors. *Diagnostics (Basel)* 2021;11.
32. Efthymiadis A, Tsikopoulos K, Uddin F, et al. Which is the optimal minimally invasive treatment for osteoid osteoma of the hip? A systematic review and proportional meta-analysis. *J Orthop Sci* 2022;27:456-62.
33. Liu PT, Chivers FS, Roberts CC, Schultz CJ, Beauchamp CP. Imaging of osteoid osteoma with dynamic gadolinium-enhanced MR imaging. *Radiology* 2003;227:691-700.
34. Davies M, Cassar-Pullicino VN, Davies AM, McCall IW, Tyrrell PN. The diagnostic accuracy of MR imaging in osteoid osteoma. *Skeletal Radiol* 2002;31:559-69.
35. Ahmed S, Jubouri S, Mulligan M. Incidental long bone cartilage lesions: is any further imaging workup needed? *Skeletal Radiol* 2021;50:1189-96.
36. Akoh CC, Craig E, Troester AM, Miller BJ. Radiographic Enchondroma Surveillance: Assessing Clinical Outcomes and Costs Effectiveness. *Iowa Orthop J* 2019;39:185-93.
37. Sharma P, Dhull VS, Reddy RM, et al. Hybrid SPECT-CT for characterizing isolated vertebral lesions observed by bone scintigraphy: comparison with planar scintigraphy, SPECT, and CT. *Diagn Interv Radiol* 2013;19:33-40.
38. Bui KL, Ilaslan H, Bauer TW, Lietman SA, Joyce MJ, Sundaram M. Cortical scalloping and cortical penetration by small eccentric chondroid lesions in the long tubular bones: not a sign of malignancy? *Skeletal Radiol* 2009;38:791-6.
39. Collins MS, Koyama T, Swee RG, Inwards CY. Clear cell chondrosarcoma: radiographic, computed tomographic, and magnetic resonance findings in 34 patients with pathologic correlation. *Skeletal Radiol* 2003;32:687-94.
40. Murphey MD, wan Jaovisidha S, Temple HT, Gannon FH, Jelinek JS, Malawer MM. Telangiectatic osteosarcoma: radiologic-pathologic comparison. *Radiology* 2003;229:545-53.
41. Panicek DM, Gatsonis C, Rosenthal DI, et al. CT and MR imaging in the local staging of primary malignant musculoskeletal neoplasms: Report of the Radiology Diagnostic Oncology Group. *Radiology* 1997;202:237-46.
42. Yuan Y, Zhang Y, Lang N, Li J, Yuan H. Differentiating malignant vertebral tumours from non-malignancies with CT spectral imaging: a preliminary study. *Eur Radiol* 2015;25:2945-50.
43. Aoki J, Watanabe H, Shinozaki T, et al. FDG PET of primary benign and malignant bone tumors: standardized uptake value in 52 lesions. *Radiology* 2001;219:774-7.
44. Bredella MA, Essary B, Torriani M, Ouellette HA, Palmer WE. Use of FDG-PET in differentiating benign from malignant compression fractures. *Skeletal Radiol* 2008;37:405-13.
45. Dehdashti F, Siegel BA, Griffeth LK, et al. Benign versus malignant intraosseous lesions: discrimination by means of PET with 2-[F-18]fluoro-2-deoxy-D-glucose. *Radiology* 1996;200:243-7.
46. Liu F, Zhang Q, Zhu D, et al. Performance of Positron Emission Tomography and Positron Emission Tomography/Computed Tomography Using Fluorine-18-Fluorodeoxyglucose for the Diagnosis, Staging, and Recurrence Assessment of Bone Sarcoma: A Systematic Review and Meta-Analysis. *Medicine (Baltimore)* 2015;94:e1462.
47. Shin DS, Shon OJ, Han DS, Choi JH, Chun KA, Cho IH. The clinical efficacy of (18)F-FDG-PET/CT in benign and malignant musculoskeletal tumors. *Ann Nucl Med* 2008;22:603-9.
48. Treglia G, Salsano M, Stefanelli A, Mattoli MV, Giordano A, Bonomo L. Diagnostic accuracy of (1)(8)F-FDG-PET and PET/CT in patients with Ewing sarcoma family tumours: a systematic review and a meta-analysis. *Skeletal Radiol* 2012;41:249-56.
49. Wang LJ, Wu HB, Wang M, et al. Utility of F-18 FDG PET/CT on the evaluation of primary bone lymphoma. *Eur J Radiol* 2015;84:2275-9.
50. Shin DS, Shon OJ, Byun SJ, Choi JH, Chun KA, Cho IH. Differentiation between malignant and benign pathologic fractures with F-18-fluoro-2-deoxy-D-glucose positron emission tomography/computed tomography. *Skeletal Radiol* 2008;37:415-21.
51. Feldman F, Van Heertum R, Saxena C, Parisien M. 18FDG-PET applications for cartilage neoplasms. *Skeletal Radiol* 2005;34:367-74.



52. Younis MH, Abu-Hijleh HA, Aldahamsheh OO, Abualruz A, Thalib L. Meta-Analysis of the Diagnostic Accuracy of Primary Bone and Soft Tissue Sarcomas by 18F-FDG-PET. *Med Princ Pract* 2020;29:465-72.
53. Liu F, Zhang Q, Zhou D, Dong J. Effectiveness of (18)F-FDG PET/CT in the diagnosis and staging of osteosarcoma: a meta-analysis of 26 studies. *BMC Cancer* 2019;19:323.
54. Feydy A, Anract P, Tomeno B, Chevrot A, Drape JL. Assessment of vascular invasion by musculoskeletal tumors of the limbs: use of contrast-enhanced MR angiography. *Radiology* 2006;238:611-21.
55. Seeger LL, Widoff BE, Bassett LW, Rosen G, Eckardt JJ. Preoperative evaluation of osteosarcoma: value of gadopentetate dimeglumine-enhanced MR imaging. *AJR Am J Roentgenol* 1991;157:347-51.
56. Swan JS, Grist TM, Sproat IA, Heiner JP, Wiersma SR, Heisey DM. Musculoskeletal neoplasms: preoperative evaluation with MR angiography. *Radiology* 1995;194:519-24.
57. Geirnaerd MJ, Hogendoorn PC, Bloem JL, Taminiau AH, van der Woude HJ. Cartilaginous tumors: fast contrast-enhanced MR imaging. *Radiology* 2000;214:539-46.
58. Deckers C, Steyvers MJ, Hannink G, Schreuder HWB, de Rooy JWJ, Van Der Geest ICM. Can MRI differentiate between atypical cartilaginous tumors and high-grade chondrosarcoma? A systematic review. *Acta Orthop* 2020;91:471-78.
59. Arevalo-Perez J, Peck KK, Lyo JK, Holodny AI, Lis E, Karimi S. Differentiating benign from malignant vertebral fractures using T1 -weighted dynamic contrast-enhanced MRI. *J Magn Reson Imaging* 2015;42:1039-47.
60. Verstraete KL, De Deene Y, Roels H, Dierick A, Uyttendaele D, Kunnen M. Benign and malignant musculoskeletal lesions: dynamic contrast-enhanced MR imaging--parametric "first-pass" images depict tissue vascularization and perfusion. *Radiology* 1994;192:835-43.
61. Campbell RS, Grainger AJ, Mangham DC, Beggs I, Teh J, Davies AM. Intraosseous lipoma: report of 35 new cases and a review of the literature. *Skeletal Radiol* 2003;32:209-22.
62. Si MJ, Wang CS, Ding XY, et al. Differentiation of primary chordoma, giant cell tumor and schwannoma of the sacrum by CT and MRI. *Eur J Radiol* 2013;82:2309-15.
63. Hogeboom WR, Hoekstra HJ, Mooyaart EL, et al. MRI or CT in the preoperative diagnosis of bone tumours. *Eur J Surg Oncol* 1992;18:67-72.
64. Bloem JL, Taminiau AH, Eulderink F, Hermans J, Pauwels EK. Radiologic staging of primary bone sarcoma: MR imaging, scintigraphy, angiography, and CT correlated with pathologic examination. *Radiology* 1988;169:805-10.
65. Lange MB, Nielsen ML, Andersen JD, Lilholt HJ, Vyberg M, Petersen LJ. Diagnostic accuracy of imaging methods for the diagnosis of skeletal malignancies: A retrospective analysis against a pathology-proven reference. *Eur J Radiol* 2016;85:61-67.
66. Douis H, Davies AM, Jeys L, Sian P. Chemical shift MRI can aid in the diagnosis of indeterminate skeletal lesions of the spine. *Eur Radiol* 2016;26:932-40.
67. Liu LP, Cui LB, Zhang XX, et al. Diagnostic Performance of Diffusion-weighted Magnetic Resonance Imaging in Bone Malignancy: Evidence From a Meta-Analysis. *Medicine (Baltimore)* 2015;94:e1998.
68. Thawait SK, Marcus MA, Morrison WB, Klufas RA, Eng J, Carrino JA. Research synthesis: what is the diagnostic performance of magnetic resonance imaging to discriminate benign from malignant vertebral compression fractures? Systematic review and meta-analysis. *Spine (Phila Pa 1976)* 2012;37:E736-44.
69. Fayad LM, Wang X, Salibi N, et al. A feasibility study of quantitative molecular characterization of musculoskeletal lesions by proton MR spectroscopy at 3 T. *AJR Am J Roentgenol* 2010;195:W69-75.
70. Wang CK, Li CW, Hsieh TJ, Chien SH, Liu GC, Tsai KB. Characterization of bone and soft-tissue tumors with in vivo 1H MR spectroscopy: initial results. *Radiology* 2004;232:599-605.
71. National Academies of Sciences, Engineering, and Medicine; Division of Behavioral and Social Sciences and Education; Committee on National Statistics; Committee on Measuring Sex, Gender Identity, and Sexual Orientation. *Measuring Sex, Gender Identity, and Sexual Orientation*. In: Becker T, Chin M, Bates N, eds. *Measuring Sex, Gender Identity, and Sexual Orientation*. Washington (DC): National Academies Press (US) Copyright 2022 by the National Academy of Sciences. All rights reserved.; 2022.
72. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: <https://www.acr.org/-/media/ACR/Files/Appropriateness-Criteria/RadiationDoseAssessmentIntro.pdf>. Accessed September 30, 2024.

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.