Imaging Findings Of Bone Tumors: A Pictorial Review

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Learning objectives

To determine the imaging characteristics (conventional radiography, CT and MRI) of malignant and benign bone tumors.

Provide a simplified diagnostic approach of bone tumors, regarding age group, location and morphology of the lesions.
Background

While radiographs are often sufficient to enable a diagnosis, advanced imaging is sometimes needed.

MR images and CT scans may provide additional information by virtue of their tomographic nature, multiplanar capability, and better soft-tissue contrast than radiographs.

**CT**: is useful for evaluating subtle mineralization in a lytic lesion, for demonstrating radiographically occult bone destruction, or for demonstrating the lucent nidus of an osteoid osteoma amid a large area of reactive sclerosis.

**MRI**: has become the standard for evaluating the local extent of a malignant process for the purposes of staging and assessing tumor response to chemotherapy.

However, it must be stressed that CT and MR images should only be interpreted with concurrent radiographic correlation.

Diagnostic approach of bone tumors

The two most important aspects of evaluating a bone tumor are the location of the tumor and the age of the patient.

Knowledge of this information alone is enough to narrow the differential diagnosis without even looking at any images.

The specific radiographic appearance should then help narrow the list even further and will often lead to the single correct diagnosis.

*The approach to the radiographic diagnosis* of bone tumors consists of analyzing the lesion in an organized method, with attention paid to several specific radiographic features.

While these features were originally described with reference to the appearance of the lesion on conventional radiographs, they can also be applied to computed tomographic (CT) images. However, they cannot be applied to magnetic resonance (MR) images, because the aggressiveness of some benign lesions can be overestimated on MR images as a result of marrow and soft-tissue edema.

The specific radiographic features that should be evaluated are:

- tumor location,
- margins and zone of transition,
- periosteal reaction,
- mineralization,
- size and number of lesions, and
- presence of a soft-tissue component.

1. Patient Age (fig 1)

Most bone tumors have a predilection for a specific age group; therefore, the most important piece of clinical information when assessing a bone tumor is the patient's age.

For example, simple bone cysts and chondroblastomas occur in skeletally immature people, while giant cell tumors occur in skeletally mature people. Ewing sarcoma typically occurs in 10-20-year-old patients, while conventional osteosarcoma has two age peaks, one, arising de novo, in teenagers and the second, arising in pagetic or previously irradiated bone, in adults older than 50 years.

A malignant bone lesion in an adult over 40 years old is much more likely to be metastatic carcinoma, myeloma, or metastatic non-Hodgkin lymphoma rather than a primary bone sarcoma.

2. Location (fig 2)

Most bone tumors, regardless of whether they are benign or malignant, often occur in a characteristic location in the skeleton (ie, axial vs appendicular skeleton or long vs flat bone).

Thus, some tumors (eg, osteosarcoma) have a predilection for sites of rapid bone growth, usually the metaphyseal region, while other tumors (eg, Ewing sarcoma) tend to follow the distribution of red marrow.

Furthermore, a lesion in a long bone may be characterized by its longitudinal location (epiphyseal vs metaphyseal vs diaphyseal) and by its transverse location (medullary vs cortical vs juxtacortical).

3. Margin (fig 3)

Bone lesions may range from a discrete well-defined abnormality to an ill-defined infiltrative process. The margin of the lesion and the zone of transition between lesion and adjacent bone are key factors in determining if a lesion is aggressive.
A lesion with **sharp** margins and a **narrow transition zone** is radiographically considered **nonaggressive**, particularly when the margins have a sclerotic border.

-A focal discrete lesion is called "geographic": type 1: **innocuous** and nonaggressive

categorized as type 1a (well-defined border with sclerotic rim), type 1b (well-defined border but without sclerotic rim), and type 1c (focal lytic lesion with ill-defined border).

- On the other hand, an **infiltrative** lesion has ill-defined margins and a broad zone of transition, and its pattern of bone destruction may be "moth-eaten" (type 2) or "permeated" (type 3), which refer to small, patchy, ill-defined areas of lytic bone destruction. Type 3 lesions are the most aggressive appearing.

The classification of a lesion is not as important as an understanding of the radiographic features that make the abnormality look innocuous or aggressive.

However, while a nonaggressive appearance suggests a benign process and an aggressive appearance suggests a malignant one, this is not always the case: localized Langerhans cell histiocytosis are benign processes that can have an aggressive permeated appearance, and a giant cell tumor may look well defined but be locally aggressive and, on rare occasions, may even metastasize.

### 4. Periosteal Reaction (fig 4)

The presence and appearance of periosteal reaction are also important radiographic features that help characterize a bone lesion.

- **Solid or unilamellated periosteal reaction** is a **nonaggressive** appearance, since it indicates that the underlying lesion is slow growing and is giving the bone a chance to wall the lesion off.

- **A multilamellated or "onionskin" appearance** suggests an intermediate **aggressive** process, such as one that waxes and wanes or one that the bone is continually trying to wall off but cannot.

- **Interruption** (ie, regional disruption) of either the uni- or multilamellated periosteal reaction suggests an **aggressive** process that has broken through the periosteum.

- **A spiculated, or "hair-on-end"** (perpendicular to the cortex) or sunburst pattern, is the **most aggressive** appearance and is highly suggestive of malignancy (Fig 10).

- **A Codman triangle** refers to elevation of the periosteum away from the cortex, with an angle formed where the elevated periosteum and bone come together; although the Codman triangle is often associated with conventional osteosarcoma, any aggressive
process that lifts the periosteum may produce this appearance, even benign entities such as infection and subperiosteal hematoma.

Sometimes periosteal reaction occurs as a result of pathologic fracture through a bone tumor and not because of the tumor itself, such as in the case of a simple bone cyst.

5. Opacity and Mineralization

- Tumors may be lytic, sclerotic, or mixed and usually have a typical opacity.

For example:

- simple bone cysts and giant cell tumors are **lytic**,
- bone islands are sclerotic, and
- adamantinomas are often mixed.

Lucency and sclerosis associated with true neoplasms are due to stimulation of osteoclasts or osteoblasts, respectively, by the tumor. Sometimes the destructive process will cause a fragment of bone to become sequestered within the lytic region; such a sequestrum may be seen in both benign and malignant processes.

- Occasionally, **the trabecular pattern** within the lesion is the clue to its diagnosis.

- an aneurysmal bone cyst and a desmoplastic fibroma: honeycomb appearance

- Paget disease can have coarsened trabeculae.

- A hemangioma in a long bone may have a sunburst or spoke-and-wheel pattern of trabeculation, while this same entity in a vertebral body will have a vertically oriented, coarsened, "corduroy" trabecular pattern.

- The radiographic opacity of a lesion can also be affected by the mineralization of its matrix. The term **matrix** refers to the type of tissue of the tumor (such as osteoid, chondral, fibrous, or adipose, all of which are radiolucent) and **mineralization** refers to calcification of the matrix. This concept of matrix mineralization is important to understand, because the pattern of mineralization can be a clue to the type of underlying matrix and, thus, the diagnosis.

- calcification of chondral tissue often produces punctate, flocculent, commashaped, or arclike or ringlike mineralization, indicating that the lesion is cartilaginous, such as an enchondroma, chondrosarcoma, or chondroblastoma, but all of these lesions vary in the frequency of radiographically evident mineralization.
- Bone-forming tumors have fluffy, amorphous, cloudlike mineralization, causing an opaque radiographic appearance, but the distinction between chondral and osseous mineralization can sometimes be difficult.

- Some tumors are completely nonmineralized, making determination of their tissue of origin difficult.

Faint mineralization in a lesion is best assessed by using CT, which is more sensitive than radiographs for differences in attenuation.

6. Size and Number

The **size** of a lesion can also be a clue to its diagnosis, since some entities have size criteria. For example,

- osteoid osteoma and osteoblastoma are histologically similar lesions, but they differ in size: The **nidus of an osteoid osteoma is less than 1.5 cm in diameter**, while the **osteoblastoma is larger than 1.5 cm**.

- a well-defined lytic lesion in the cortex of a long bone with a sclerotic rim has been termed a **fibrous cortical defect** if it is **less than 3 cm** in length and a **nonossifying fibroma** if it is **larger than 3 cm**.

- A 1-2-cm chondral lesion in a long bone is most likely to be an enchondroma, while the risk of it being a low-grade chondrosarcoma increases if it is greater than 4 or 5 cm.

Primary bone tumors are **solitary** occurrences, while other abnormalities may be multiple. **Multiple** sclerotic lesions might represent metastatic disease or osteopoikolosis (multiple bone islands); the latter are usually similar in size and are centered around joints. The most common causes of multiple luencies in someone older than 40 years are metastatic carcinoma, multiple myeloma, and metastatic non-Hodgkin lymphoma, but benign entities such as multiple brown tumors may look similar.

7. Cortical Involvement

- In addition to lesions that specifically arise within the cortex, the cortex may be affected by processes that originate in the medullary canal or the periosteum or surrounding soft tissue.

For example,

- as a medullary process expands, it may cause erosion of the inner surface of the cortex, called **endosteal scalloping**.
- If the medullary lesion is so aggressive that it erodes the inner aspect of the cortex without giving the periosteum a chance to lay down new bone, the cortex will eventually be completely destroyed and breached by the lesion.

- On the other hand, if the bone has time to lay down new periosteum on the outer surface of the cortex as the inner surface is being eroded, the bone may look expanded owing to the outward ballooning of the cortex.

Depending on the aggressiveness of the lesion, the ballooned cortex may have normal thickness or be thin. The ballooned cortex gives rise to the categories of lytic expansile and "soap bubble" lesions.

- A process that starts on the outer surface of the cortex, either in the periosteum or adjacent soft tissue, may erode the outer surface of the cortex; this process is called saucerization.

- If the tumor is not mineralized, saucerization may be the only radiographic indication of its presence.

- Sometimes the periosteum will react at the site adjacent to the saucerization, giving a buttressed appearance but not necessarily indicating the benign or malignant nature of the lesion.

- The buttressed appearance may also occur when a slowly growing intramedullary process becomes more aggressive and breaks through (ie, interrupts) an area of solid periosteal reaction.

8. Soft-Tissue Component

The presence of a soft-tissue component with a bone lesion suggests a malignant process. The tumor may have frankly destroyed the cortex as it expanded, or it may have permeated through the haversian canals of the cortex to reach the surrounding tissue.

The soft-tissue component may displace adjacent fat planes.

Tumors that often have a soft-tissue component are osteosarcoma, Ewing sarcoma, and lymphoma.
**Fig. 1**

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Fig. 2

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Fig. 3: a: Type 1a geographic lesion b: Type 1b geographic lesion c: Type 1c geographic lesion
d: Type 2 moth-eaten lesion. e: Type 3 permeated lytic lesion

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Fig. 4: a: Unilamellated periosteal reaction b: Multilamellated periosteal reaction c: Codman triangle d: Perpendicular periosteal reaction: spiculated or hair-on-end periosteal reaction e: Perpendicular periosteal reaction: radial or sunburst periosteal reaction f: Buttress periosteal reaction

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Findings and procedure details

Osteoid osteoma (fig 5)

The typical radiographic findings: include

- an intracortical nidus, which may display a variable amount of mineralization,
- cortical thickening
- reactive sclerosis in a long bone shaft.

The radiolucent focus often is referred to as the nidus because the focus usually is located in the center of an area of reactive sclerosis.

The nidus: is round or oval and usually smaller than 2 cm.

Bone density may be decreased because of disuse due to pain

At CT, the nidus is well defined and round or oval with low attenuation.

An area of high attenuation may be seen centrally, a finding that represents mineralized osteoid.

Reactive sclerosis is apparent and ranges from mild cancellous sclerosis to extensive periosteal reaction and new bone formation, which may obscure the nidus. Enhancement of a hypervascular nidus may be seen at dynamic CT.

MRI: depicts not only the nidus and accompanying sclerosis but also adjacent bone marrow and articular abnormalities.

The nidus: low to intermediate signal intensity on T1 and variable signal intensity on T2, depending on the amount of mineralization present in the center of the nidus.

Because of the recent increases in spatial resolution, a partially mineralized nidus generally has a targetlike appearance, with a high-signal-intensity periphery (the unmineralized portion) and a central area of low signal intensity (the mineralized portion). The nidus also may demonstrate strong enhancement after the administration of gadolinium-based contrast material.

Edema in adjacent bone marrow and soft tissue and joint effusion also may be seen.

Simple / Solitary Bone Cyst (fig 6)

- Arises in under 30 year age group
• Begins within the physeal growth plate and extends into diaphysis
• Centrally located within a long bone
• Most commonly occurs in the proximal humerus
• In the calcaneum it is triangular, and located antero-inferiorly as this is an area that does not receive stress, and therefore develops atrophy of the bony trabeculae
• Also called unicameral bone cyst, however there is not always just one compartment
• Asymptomatic, unless it is fractured, which often occurs
• "Falling fragment sign": cortical fragments produced from pathological fracture, that have sunk to the bottom of the fluid filled lesion

**Aneurysmal Bone Cyst (fig 7)**

• Arises in under 30 year age group
• Presents with pain
• Expansile
• Differential diagnosis: osteoblastoma, as very similar in appearance

**Osteochondroma (fig 8)**

Long bones++

The lesion is composed of cortical and medullary bone protruding from and continuous with the underlying bone.

The areas of osseous continuity between parent bone and osteochondroma may be broad, involving a large portion of the bone circumference (dimension of the lesion base exceeding its length-sessile osteochondroma), or narrow, with a bulbous tip (pedunculated osteochondroma).

Identifying the characteristic cortical and medullary continuity between lesion and parent bone on radiographs is dependent on lesion type (sessile or pedunculated), location, and image projection.

This relationship is usually well delineated in lesions of long bones, particularly pedunculated osteochondromas, with standard radiographic projections (although often only on one view).

However, in osteochondromas of flat bones with complex anatomy (ie, pelvis, spine, scapula) and sessile lesions, the continuity and thus the diagnosis may not be apparent on radiographs alone. Pedunculated lesions usually point away from the nearest joint owing to the forces of the overlying tendons and ligaments (although not typically attached to the osteochondroma).
CT often allows optimal depiction of the pathognomonic cortical and marrow continuity of the lesion and parent bone in osteochondromas. This is particularly true for lesions in complex areas of anatomy, such as the pelvis or spine, and for those with a broad stalk of attachment.

CT is usually accurate in measuring cartilage cap thickness.

Increased thickness of the cartilage cap is a recognized feature in young patients in response to continued active growth and should not be viewed as a finding of malignant transformation in skeletally immature patients.

MRI also demonstrates cortical and medullary continuity between the osteochondroma and parent bone, and this distinctive feature is often better seen with this modality as opposed to radiography in complex areas of anatomy.

MRI is the best radiologic modality for visualizing the effect of the lesion on surrounding structures and evaluating the hyaline cartilage cap. Mineralized areas in the cartilage cap remain low signal intensity with all MR pulse sequences, although as enchondral ossification proceeds, yellow marrow signal is ultimately apparent. The high water content in nonmineralized portions of the cartilage cap had intermediate to low signal intensity on T1-weighted images and very high signal intensity on T2-weighted MR images.

Low signal intensity at the periphery of the lesion represents the perichondrium.

Enhancement after the intravenous administration of gadolinium-based contrast material reveals septal and peripheral enhancement in the cartilage cap.

**Enchondroma**

- Most commonly seen in the phalanges
- Asymptomatic but commonly fractures
- Well-defined with narrow zone of transition
- Lobulated
- Can become slightly expansile
- Causes endosteal scalloping and cortical thinning
- Ollier's Disease = Multiple enchondromas
- Maffucci's Syndrome = Multiple enchondromas with soft tissue haemangiomas
- Contain calcified chondroid matrix (irregular, speckled) when located away from phalanges

**Haemangioma (fig 9)**

- Benign vascular tumour
Vertebral haemangioma; solitary lesion within vertebral body typically demonstrates coarse vertical trabecular pattern
- Usually asymptomatic and incidental finding
- However, within vertebral body occasionally causes symptoms of spinal cord compression

### Giant Cell Tumour (fig 10)
- Epiphyses must be closed
- Must be epiphyseal and abut the articular surface
- Well-defined with narrow zone of transition
- Must have a non-sclerotic margin
- Eccentric within the bone
- Usually occurs within the distal femur or proximal tibia
- 15 per cent become malignant based on recurrence rate or subsequent metastases

### Fibrous Dysplasia (fig 11)
- Long lesion in a long bone (often occurs in proximal femur)
- Expansion and bone deformity
- Lytic but becomes ground-glass in appearance as the matrix calcifies, and then becomes sclerotic
- Asymptomatic, but can fracture
- No periosteal reaction
- May be single or multiple lesion in different locations

### Non-Ossifying Fibroma / Fibrous Cortical Defect
- One of the most common benign lytic lesions seen
- Asymptomatic and usually an incidental finding
- Most often seen around the knee and distal tibia
- Non-Ossifying fibroma generally bigger than 2cm
- Fibrous Cortical Defect generally smaller than 2cm
- Arises in under 30 year age group
- Develops from cortex of metaphysis; is eccentric within the bone
- Bubbly
- Usually has thin, sclerotic border that is often scalloped and slightly expansile
- Become sclerotic as healing occurs and "disappears" as it ossifies
- Therefore not seen in over 30 age group

### MALIGNANT BONE TUMOURS

**Osteosarcoma**
Most common malignant primary bone tumour
- Arises in under 30 year age group, but also has a second peak at 60 years
- Presents with pain
- Usually occurs towards end of long bone
- Aggressive with a wide zone of transition
- Often demonstrates cortical destruction
- Sclerosis present from either tumour new bone or reactive sclerosis

Ewing's sarcoma
- Arises in under 30 year age group
- Permeative lesion usually in diaphysis of long bone
- Often have "onion-skinned" or "sunburst" type of periostitis

Chondrosarcoma (fig 12)
- Looks similar to enchondroma, but is painful
- Seen in over 40 year age group
- Lytic, destructive lesion with calcified chondroid matrix that looks amorphous and irregular with "snowflake"-like calcification

Metastatic Disease
- May demonstrate single or multiple, lytic or sclerotic lesions
- Can look benign or aggressive
- When aggressive, often is described as having moth-eaten or permeative appearance
- Difficult to ascertain origin of primary
- Metastases from a primary renal tumour will always demonstrate lytic lesions
- Breast primary often develops lytic metastases
- Multiple sclerotic lesions, particularly in the pelvis (in an elderly man) will usually have prostate primary
- Painful, and often develops pathological fracture with little trauma

Multiple Myeloma
- May be solitary or multiple lytic lesions (plasmacytomas)
- Radiologically, often precedes clinical or haematological presentation of myeloma
- Not always "hot" on radionuclide imaging; skeletal survey more useful for diagnosis
- Diffuse and permeative lytic lesions
- Usually age range over 35 years
Chordoma (fig 13)

- Uncommon malignant tumours: 40% of all sacral tumors
- Location
- 50% occur in sacrum
- • 40% of all sacral tumors
  • Most common in 4th or 5th sacral segment
- 35% at skull base around clivus (Benign tumors but may locally invade and compress)
- 15% in remainder of spine: Cervical spine most common
- Occurs between the ages of 30-70 with a 2:1 male:female ratio

**Imaging Findings**
- Large presacral mass (>10cm) with displacement of the rectum and/or bladder
- Solid tumor with cystic areas in 50%
- Destroys multiple sacral and coccygeal segments
  - Sequestered bone fragments are common
- Sclerotic rim in 50%
- May have amorphous calcifications, especially peripherally
- May cross the sacroiliac joint

**CT findings**
- CT is helpful in defining bone destruction and calcification within lesion
- With contrast, the pseudocapsule may enhance
- Usually low attenuation soft tissue mass with destruction of the sacrum and/or coccyx
- May show sequestered bone fragments or calcifications within tumor

**MRI findings**
- Modality of choice, especially for clival lesions
- Low to intermediate intensity on T1
  - Those lesions that show high signal intensity on T1 have a larger mucinous component
- Very high signal intensity on T2
  - High water content
- Following gadolinium injection, chordomas may show a honeycomb appearance
  - Heterogeneous on T1 and T2
  - Lesions may rim enhance
Images for this section:

Fig. 5

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Fig. 10

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Conclusion

Conventional radiography is the first line of diagnosis for bone tumors. The radiograph can localize the lesion and determine its degree of aggressiveness enabling the radiologist to make an informed differential diagnosis and in many cases a specific diagnosis. MRI is the preferred modality to image musculoskeletal tumors and should be obtained after radiographic evaluation. Its multiplanar imaging capability helps delineation of tumor and its extent in bone and soft tissues with high contrast resolution. It is an excellent modality to determine neurovascular bundle involvement, joint involvement, local extent and staging.
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