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Distinctive Radiological Characteristics of Bone Tumors: An Overview

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ABSTRACT
Bone tumors are abnormal growth within the musculoskeletal system. Tumors originating directly from the bone are classified as primary bone tumors, whereas those that spread to the bone from other parts of the body are known as metastatic bone tumors. These tumors may be benign or malignant, with malignant types capable of invading and destroying bone tissue, unlike benign tumors which do not exhibit such aggressive behavior. Effective management of bone tumors depends on accurate diagnosis, which involves thorough patient history, pathological analysis, and radiological assessment. Among these, radiology holds a crucial role in diagnosis, primarily utilizing plain radiographs as the standard initial imaging method. To evaluate the extent of tumor spread or its relationship with adjacent tissues, advanced imaging techniques such as computed tomography (CT) or magnetic resonance imaging (MRI) are employed

INTRODUCTION

A tumor is an abnormal growth of tissue that indicates inflammation. Bone tumors form when bone cells divide uncontrollably, forming lumps or masses of abnormal tissue (Brown et al. 2023).

Bone tumors are generally classified into two types: benign and malignant. Benign tumors are more common, but malignant tumors typically have a poor prognosis. Malignant tumors tend to grow significantly and spread irregularly. The incidence of primary bone tumors is approximately 65.8% benign and 34.2% malignant. Prevalence by gender is similar between men and women. The most common benign tumors are Osteoid Osteoma, Giant Cell Tumor, and Osteochondroma, while malignant tumors include Osteosarcoma (35%), Ewing Sarcoma (16%), and Chondrosarcoma (30%). Chondrosarcoma typically affects the elderly, while osteosarcoma and Ewing sarcoma develop in children and young adults (Ferguson J and Turner S 2018).

Early detection is crucial for prognosis, as most tumors do not exhibit symptoms until the condition reaches its peak severity, which can lead to residual symptoms such as pathological fractures. Therefore, it is important to identify bone lesions at an early stage of development (Shojaie and Afzali 2023).

Bone tumor diagnosis is performed through a three-step diagnostic procedure consisting of clinical examination, radiological examination, and subsequent pathological examination (Plant and Cannon 2016).

Furthermore, the diagnostic results from these three examinations are correlated to obtain an accurate diagnosis. Radiology plays a role as one of the stages in the diagnosis of bone tumors. Radiological examination of bone tumors begins with conventional X-rays, followed by further examinations if necessary to determine the severity of the tumor or the involvement of surrounding tissues, in which case a CT scan or MRI may be performed (Costelloe and Madewell 2013).

Radiology plays a role in evaluating bone tumors, whether to detect the presence of lesions, assess their benign or malignant nature, or determine the extent of their spread. Radiological characteristics such as bone damage patterns, periosteal reactions, tumor matrix type, and soft tissue involvement are key indicators in assessing malignancy (Shojaie and Afzali 2023).

The study aims to provide a comprehensive examination of the key imaging features that help in identifying and differentiating bone tumors. This includes analysis of tumor location within the bone, the nature and definition of tumor margins, patterns of bone destruction, periosteal reactions, and the characteristics of tumor matrix mineralization. The study also addresses how advanced imaging techniques such as CT and MRI contribute to assessing tumor extent, involvement of surrounding soft tissues, and marrow infiltration to support accurate diagnosis and classification of both benign and malignant bone tumors

METHODS

This article was written using a literature review method through searches on the Google Scholar and PubMed databases with the keywords “bone tumor radiology,” “radiological signs of bone tumors,” “malignant bone tumors,” and “benign bone tumors”.

The literature found in the subsequent search was rescreened based on the established inclusion and exclusion criteria. The inclusion criteria included literature published in the last 10 years, namely from 2015 to 2025, and literature with complete texts. The exclusion criteria included literature with complete texts that were inaccessible and literature with irrelevant topics. Literature screening was conducted until 15 pieces of literature were found to be discussed in this review.

RESULTS AND DISCUSSION

Bone tumors present specific radiological signs that are essential for their identification and evaluation. Important imaging features include the tumor's anatomical location within the bone, the clarity and nature of tumor margins, and the condition of the cortical bone. Benign bone lesions generally exhibit clear and well-defined edges with

intact or minimally affected cortex, whereas malignant tumors often display irregular, poorly demarcated borders accompanied by cortical destruction or infiltration.

1) **Osteochondroma**

Osteochondroma is defined as a bony protrusion (exostosis) accompanied by cartilage closure originating from the outer surface of the bone. Osteochondroma accounts for more than 30% of all benign bone tumors and is found in 10-15% of all bone tumor cases. Based on age group prevalence, osteochondroma typically affects younger individuals, such as children, and is very rare in neonates. In Figure 1, the protrusion is visible on the outer surface of the right femur (right) and the protrusion on the outer surface of the tibia (left) (Tepelenis et al. 2021).

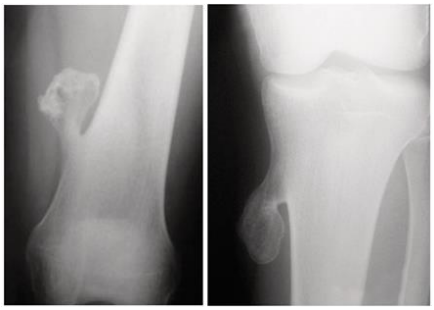

Figure 1. Osteochondroma on Plain Radiograph

Nearly half of these tumors are located around the knee. Long bones are more commonly affected, particularly the distal femur (30%), proximal tibia (15-20%), and humerus (10-20%), followed by the feet and hands (10%) (9). Osteochondroma is usually diagnosed solely by radiography, especially if it is in the metaphysis of a long bone. Typically, osteochondroma appears as a protrusion visible on the outer surface of the bone. These lesions vary in size from 1 to 10 cm and consist of cortex and medulla, which are connected to the underlying bone. These lesions can be sessile or pedunculated (Tepelenis et al. 2021).

If the tumor protrudes from the bone via a stalk, it is referred to as pedunculated. Osteochondromas with a pedunculated structure typically extend away from the joint. If not, the tumor lacks a stalk and is attached to the bone via a broad base. In this case, the structure is termed sessile. Another finding is the presence of calcified flakes or linear interruptions within the cartilage component (Tepelenis et al. 2021).

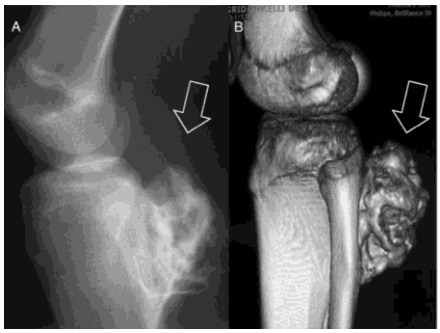

Figure 2. Comparison of Osteochondroma on Plain X-ray and 3D CT scan

Figure 2 above shows a comparison of osteochondroma on plain radiography and 3D CT scan.A plain bone X-ray will show enlargement of certain areas of the bone with a cortex accompanied by normal-appearing cancellous bone. Cartilage is rarely visible here because it is located outside the

bone. This area will be visible on a CT scan. As the patient ages, there is an ongoing process of increasing calcification. Two pathognomonic features that confirm the diagnosis are the continuity of the cortical and medullary layers with the parent bone and the cartilage cap. Most lesions are solitary, but approximately 15% of patients have multiple tumors (Tepelenis et al. 2021).

2) Osteoid Osteoma

Osteoid osteoma is a common benign neoplasm, accounting for 3% of primary bone tumors. It is usually localized in the diaphysis or metaphysis of long bones, most commonly in the lower limbs. This condition most commonly affects young people, typically between the ages of 5 and 25. It is three times more common in males. Osteoid osteoma is most frequently found in the femur (25%), tibia (25%), and in rare cases, in areas such as the spine (Napora, Wałejko, and Mazurek 2023).

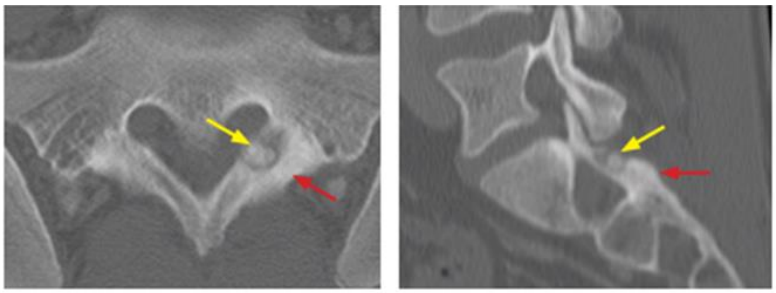

Figure 3. CT Scan Image of Osteoid Osteoma

Osteoid osteoma is a benign osteoblastic lesion characterized by a nidus of osteoid tissue surrounded by reactive bone sclerosis. Its etiology remains controversial, with possible causes including inflammation and vascular factors. Osteoid osteoma most commonly occurs in the diaphysis of long bones in the legs (femur and tibia).

Figure 3 CT scan shows a radiolucent nidus in the left sacrum with large central calcification (yellow arrow) with adjacent sclerosis (red arrow). Approximately 20% occur in the posterior elements of the spine. On radiographs and CT scans, the lucent nidus is surrounded by sclerosis. Central calcification is often present within the nidus. Bone scans are positive, showing a double density pattern representing intense central uptake in the nidus area and reactive uptake adjacent to the sclerosis (Napora et al. 2023).

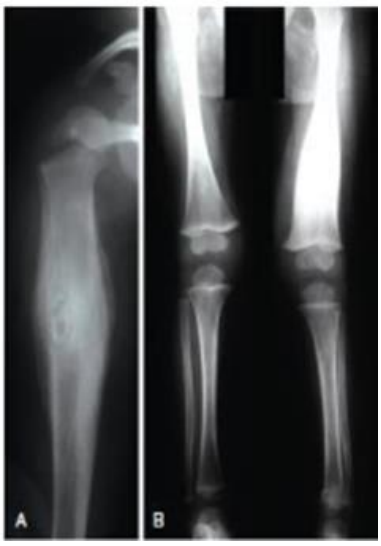

Figure 4. Osteoid Osteoma on Plain Photograph

Plain radiographs will show a radiolucent nidus surrounded by a sclerotic rim. The lesion is found in the center of the bone line and measures less than 1-2 cm. The lesion can be found in the radiolucent area called the nidus. This finding is located in the diaphysis surrounded by an area of dense sclerosis, as well as cortical thickening indicating bone formation. Figure 4 View of the proximal humerus with diffuse sclerosis and periosteal reaction, bone contour deformation (B) diffuse sclerosis and mismatch in bone length (Brown et al. 2023).

3) Giant Cell Tumor

Giant cell tumors are benign lesions but can be locally aggressive and destructive, characterized by abundant vascularization in connective tissue, including proliferation of mononuclear cells in the stroma and numerous scattered giant cells. GCTs account for 4–5% of primary bone tumors and 18.2% of benign bone tumors.

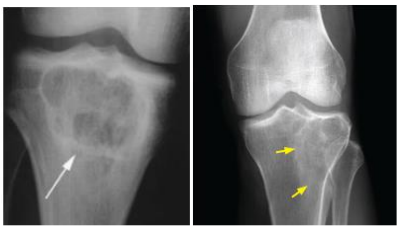

Figure 5. Giant Cell Tumor on Plain Photograph

Giant cell tumors are commonly found in the proximal tibia, distal radius, and distal femur. These tumors can also be found in non-extremity bones such as the sacrum (Bawantika Adi Putra et al. 2021) . Figure 5 (right) plain photograph of a patient with a geographic lesion with sclerotic borders (white arrow) in the proximal tibia (left) eccentric lucent lesion (arrow) in the lateral tibial epiphysis and metaphysis extending to the articular surface

Other imaging modalities, such as MRI, may be used if there is suspicion of soft tissue involvement, intraarticular spread, or changes in bone marrow. However, plain radiographs are typically chosen as the first modality for determining location, matrix, edge condition, periosteal reaction, and soft tissue involvement (Putra and Magetsari 2019).

4) Osteosarcoma

Osteosarcoma is a malignant tumor of mesenchymal cells that contribute to the formation of bone and osteoid matrix. Osteosarcoma is a primary malignant bone tumor that predominantly affects people in their second decade of life, with more than 60% of cases occurring in people under the age of 25. The incidence of osteosarcoma may increase again after the age of 60, making it bimodal, and it is more common in males than females, with a ratio of 2:1 (Kementrian Kesehatan Republik Indonesia 2019).

Osteosarcoma presents as an aggressive and destructive bone mass with cloud-like bone formation and permeative osteolysis, classified as types II and III according to the Lodwick classification, and as a mass arising from a pre-existing condition (Cromb et al. 2024).

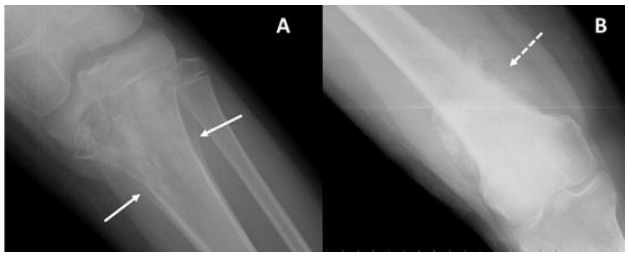

Figure 6. Osteosarcoma on Plain Photograph

On conventional radiography as the first line of imaging, osteosarcoma manifests as a permeative or mixed lytic lesion with cortical erosion; periosteal reactions such as Codman's triangle, sunburst, or hairline pattern at the tip; and no sclerotic margins (instead, blurred and irregular), reflecting its aggressive malignant nature (Cromb et al. 2024). Figure 6 show Lateral radiograph of the distal femur in a patient with osteosarcoma showing several aggressive findings: Codman triangle, and a soft-tissue mass (white arrow).

5) Ewing's Sarcoma

A rare malignant tumor with tumor cells located in the bones and soft tissues. This tumor is the second most common pediatric tumor after osteosarcoma. Radiographic findings include aggressive lesions with permeative bone destruction, aggressive periosteal reaction, and often accompanied by soft tissue masses (Attia 2017).

The tumor typically occurs in the diaphysis of long bones and the pelvis. This predilection is influenced by the absence of bone that is resistant to tumor development. In long bones, the tumor is almost always metaphyseal or diaphyseal but often extends into the diaphysis (Attia 2017).

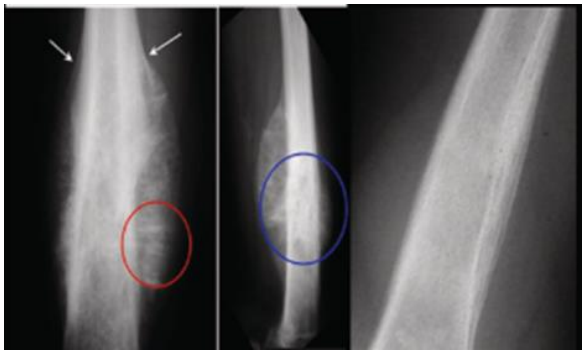
Figure 7. Ewing's Sarcoma in the Femur

Tumors are generally located in the diaphysis of long bones and the pelvis. This predilection is influenced by the absence of bone that is resistant to tumor development. In long bones, tumors are almost always metaphyseal or diaphyseal but often extend into the diaphysis (Attia 2017). Figure 7 Appearance of Ewing's sarcoma in the femur showing an onion peel appearance

On plain radiographs, destructive infiltrative lesions originating in the medulla appear as radiolucent areas. The tumor predominantly affects the cortex and involves the periosteum. Occasionally, this tumor may present with a characteristic onion peel appearance (Attia 2017).

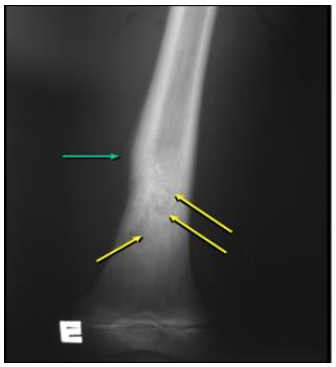

Figure 8. Ewing's Sarcoma on Plain Photograph

Figure 8 show of Ewing's sarcoma in the femur showing onion peel appearance. Ewing's sarcoma is characterized by the presence of a radiolucent area (yellow arrow) and periosteal reaction in the distal diaphysis of the left femur (green arrow).

3) Chondrosarcoma

Chondrosarcoma originates from primitive cartilage forming mesenchyme, which then produces hyaline cartilage, resulting in abnormal growth of bone or cartilage. The incidence of chondrosarcoma ranges from 20% to 27% of all primary malignant neoplasms (Kim and Lee 2023). Figure 9 shows intramedullary lesions with ring and arc chondroid calcifications. Periosteal reaction (yellow arrow) and cortical disruption (red arrow) indicate aggressive behavior.

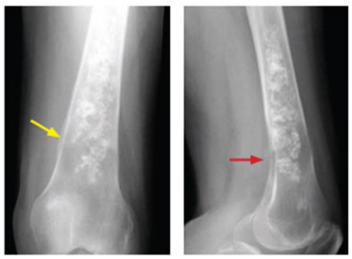

Figure 9. Chondrosarcoma on Frontal and Lateral Radiographs of the Distal Femur

Figure 9 Intramedullary lesion with ring and arc chondroid calcifications. Periosteal reaction (yellow arrow) and cortical disruption (red arrow) indicate aggressive behavior. Chondrosarcoma often occurs in the third to sixth decade of life, with males being at higher risk than females. The diagnosis of chondrosarcoma is based on findings on plain radiographs showing lesions with a typical chondroit matrix ring and arc pattern with aggressive growth characteristics (Kim and Lee 2023).

Additional imaging modalities, including computed tomography, MRI, and bone scintigraphy, are required for disease evaluation, staging prediction, and as a determinant of surgical resection (Gazendam et al. 2023).

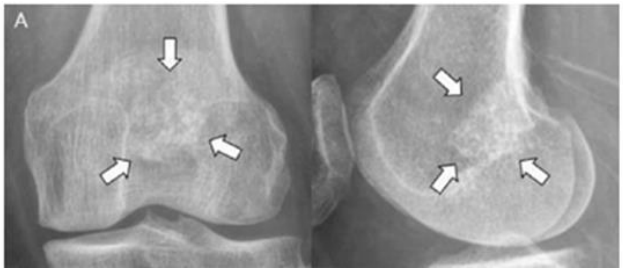

Figure 10. Chondrosarcoma on Plain Radiograph

The figure 10 above is an anteroposterior and lateral radiograph showing mixed lytic and sclerotic lesions in the distal femur (arrow) with typical ring and arc calcification. Conventional radiography of chondrosarcoma typically shows a mixed lytic and sclerotic appearance. Sclerotic areas represent mineralization of the chondroid matrix, which is seen in 60–78% of lesions. Well-differentiated tumors tend to have a ring-and-arc pattern, whereas chondrosarcomas with a higher grade often contain relatively less matrix mineralization and have an amorphous or tippled appearance (Gazendam et al. 2023).

CONCLUSION

Radiology plays a crucial role in evaluating bone tumors, whether for detecting the presence of lesions, assessing their benign or malignant nature, or determining the extent of spread. Radiological features such as bone destruction, periosteal reaction, tumor matrix type, and association with soft tissue are key indicators in assessing malignancy. Benign lesions typically have smooth borders and slow growth, while malignant tumors exhibit indistinct borders, aggressive destructive patterns, and are often accompanied by soft tissue masses. Modalities such as X-rays, CT scans, MRI, and bone scintigraphy are used complementarily for diagnosis, staging, and treatment planning.].

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