The Foot 49 (2021) 101845

Contents lists available at ScienceDirect

The Foot

journal homepage: www.elsevier.com/locate/foot

Review

Tumors and pseudotumors of foot and ankle: Bone lesions

Matheus Martins Cavalcante [a,b,*], Cláudio Régis Sampaio Silveira [a,b], Cristiane Rocha da Costa [b], Daniel Gurgel Fernandes Távora [b], Carlos Henrique Maia Ferreira Alencar [b], Manuel Joaquim Diógenes Teixeira [c], Avneesh Chhabra [d]

[a] Musculoskeletal Imaging Division, São Carlos Imagem/São Carlos Hospital, Fortaleza, Ceará, Brazil
[b] Radiology Department, São Carlos Imagem/São Carlos Hospital, Rua Otoní Façanha de Sá, 69, Fortaleza, Ceará, Brazil
[c] Orthopedics and Traumatology Division, Hospital Geral de Fortaleza, Rua Ávila Goularte, 900, Fortaleza, Ceará, Brazil
[d] Radiology & Orthopeadic Surgery, UT Southwestern, 5323 Harry Hines Blvd, Dallas, TX, United States

ARTICLE INFO

Keywords:
Bone tumor
Pseudotumor
X-ray
CT
MRI

ABSTRACT

Bone tumors and tumor-like lesions (pseudotumors) are not uncommonly encountered as asymptomatic findings on imaging, or as symptomatic lesions clinically. Radiographic imaging is the first diagnostic tool for their management strategy, since the symptoms are commonly non-specific, such as pain, swelling, and redness. Image findings must be analyzed with attention to the specific features such as lesion location, margination, zone of transition, mineralization, size and multifocality, soft tissue component and/or loco-regional extent. Cross-sectional imaging including CT and MRI serve as complementary methods, providing additional information with respect to the lesion characterization, mineralization, extent and involvement of the adjoining soft tissues.

Clinical and/or key imaging features aid in limiting the differential diagnostic possibilities and serve as a guide in determining the benignity or malignancy of the tumor as well as to exclude pseudotumors. This article reviews the key imaging features of foot and ankle lesions. Benign bone lesions include simple and aneurysmal bone cysts, lipoma, hemangioma, chondroblastoma, enchondroma, osteoid osteoma, osteoblastoma, and giant cell tumor. Locally aggressive intermediate category lesion includes hemangioendothelioma. Malignant lesions include osteosarcoma, Ewing's sarcoma, chondrosarcoma. Pseudotumors such as fibrous dysplasia, hemophilic pseudotumor, gout and Madura foot are also discussed with illustrative case examples.

1. Introduction

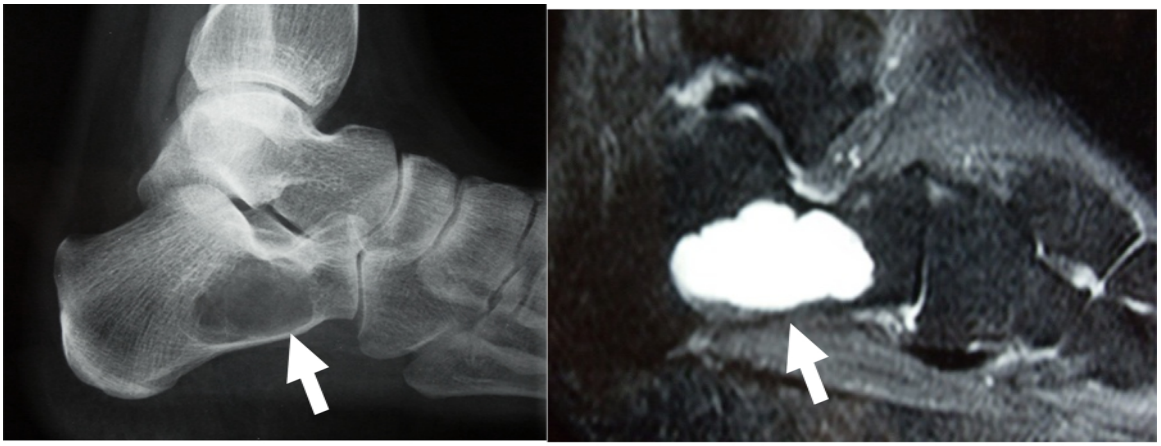
Bone tumors and tumor-like lesions (pseudotumors) are not uncommonly encountered as asymptomatic findings on imaging or as symptomatic lesions clinically. Clinical manifestations of foot and ankle bone lesions are usually nonspecific regardless of their nature, whether pseudotumor, benign or malignant tumors and the common presenting symptoms include pain, trauma and/or swelling [1]. Imaging evaluation is required for further characterization of these lesions, such as size, margination, location, locoregional extension and/or soft tissue involvement. Radiography is the initial method of choice while CT and MRI serve as 2nd line diagnostic modalities that aid in limiting the list of differential diagnoses. Using all pertinent clinical and imaging information, definitive diagnosis can be suggested in many cases and pseudotumors can be correctly identified [2]. Multi-disciplinary collaboration of specialists in the area, such as radiologist, oncologist, orthopedist, pathologist is key to arriving at possible diagnosis and timely management of such lesions. In some cases, histopathology is mandatory to confirm the final diagnosis [3]. This article reviews the key clinical and imaging features of foot and ankle bone lesions. The reader will be able to assist the multi-disciplinary team with the gained knowledge aiding in their timely and accurate diagnosis. The discussion includes key clinical and imaging features of benign and malignant bone tumors, and pseudotumors listed in Table 1.

* Corresponding author.
E-mail addresses: matheuscavalcante@gmail.com (M.M. Cavalcante), claudiosilveira@hotmail.com (C.R.S. Silveira), dracristianerocha@gmail.com (C.R. da Costa), dgtavora@gmail.com (D.G.F. Távora), carloshenriquemaia@gmail.com (C.H.M.F. Alencar), mjdiogenes@secrel.com.br (M.J.D. Teixeira), Avneesh.Chhabra@UTSouthwestern.edu (A. Chhabra).

https://doi.org/10.1016/j.foot.2021.101845
Received 19 February 2021; Received in revised form 22 June 2021; Accepted 24 June 2021
Available online 29 June 2021

Table 1
Concisely shows important features of all tumors and pseudotumors addressed in this study, such as clinical findings, x-ray features, other modality imaging features and other relevant findings.

Lipoma	Incidental finding. Occasional pain	Osteolytic bone lesion with well-defined margins. Internal calcification.	CT- Fatty attenuation T1W and T2W: high signal	Central necrosis, calcification or ossification
Hemangioma	Asyntomatic/mass effect	Lytic lesion. Typical trabecular pattern	CT: trabecular pattern and intermediate density T1W: high signal T2W: high signal	May exhibit honeycomb appearance in calcaneus
Chondroblastoma	Insidious onset of dull pain, worse at night	Lytic expansive lesion. Internal calcifications may sometimes be present	T1W and T2W: low to iso intense. Decreased intensity foci correspond to calcification	Associated periostitis
Enchondroma	Most commonly an incidental finding or may present with pain and swelling due to fracture	Lytic, geographic lesion with chondroid calcification	T1W: low to intermediate signal T2W: typical intense high signal, low intensity foci correspond to calcification	Ollier disease and Maffucci syndrome
Osteoid osteoma	Nocturnal pain, relieved by salicylates	Solid periosteal reaction with cortical thickening	CT better characterizes nidus T1W and T2W: nidus has low to intermediate signal with surrounding edema	Predilection for the talus and calcaneus in foot.
Osteoblastoma	Insidious onset of dull pain, worse at night, with minimal response to salicylates	Lytic, expansive lesion >1,5 cm with a rim of reactive sclerosis	CT shows a well-defined nidus or lytic lesion >1.5 cm T1W and T2W: hypo to intermediate signal	Rapid increase in size with associated cortical expansion, cortical destruction and soft tissue involvement
Giant cell tumor	May present insidiously with bone pain and soft tissue mass due to pathologic fracture	Well-defined lytic expansile lesion with a non-sclerotic margin and reaches the subarticular surface	T1W: low to intermediate T2W: heterogeneous high signal with areas of low signal intensity due to hemosiderin or fibrosis	Soap bubble lesion in X-ray Although rare, benign calcifying lung metastases are possible
Hemangioendothelioma	pain and swelling in the affected area	lytic lesion without matrix mineralization, and osseous expansile remodeling may be seen	T1W — low to intermediate signal T2W — high signal Variable enhance	Is a locally destructive tumor with a variable course. Its behavior cannot be predicted only on basis of histologic features
Osteosarcoma	Pain, soft tissue mass, fracture deformity, swelling.	Bone destruction, sclerotic ossified mass, aggressive periosteal reaction	CT: Codman triangles, sunburst or thick periosteal reaction MRI: Soft tissue mass T1W: intermediate signal T2W: high or mixed signal	Very rare in foot and ankle Can be purely lytic (adults).
Ewing sarcoma	Nonspecific, with pain, mass or swelling. Can clinically mimic infections. Usually young age.	Permeative or moth-eaten pattern of bone destruction and periosteal reaction, Onion skin periostitis, Saucerization of cortex	T1W: low to intermediate signal T2W: heterogeneously high signal	Uncommon in foot, but is the most common malignant neoplasm of foot in children
Chondrosarcoma	Pain, pathological fracture, a palpable lump or local mass effect	Endosteal erosion, cortical destruction and expansion, as well as soft tissue mass and calcifications	**T1W:** low to intermediate signal T2W: very high intensity in non-mineralized/calcified portions	Periosteal reaction and cortical thickening are uncommonly seen as well
Fibrous dysplasia	Incidental finding	Well-circumscribed lesion, no periosteal reaction, cortical thickening, and ground-glass matrix	T1W: intermediate signal T2W: usually low, may have regions of higher signal	McCune-Allbright syndrome Mazabraud syndrome
Hemophilic pseudotumor	Painless expansive mass of insidious growth	Bone destruction and areas of soft tissue enlargement adjacent to the affected bone	T1W and T2W: blood signal in different stages of hemoglobin degradation	Rare complication of hemophilia. Confused with primary bone tumors.
Madura foot	Painless soft tissue swelling, draining sinuses and purulent discharge	Soft tissue swelling, bone sclerosis, bone cavities, moth-eaten appearance, periosteal reaction	T1W and T2W: low signal	Dot-in-circle sign
Bizarre parosteal osteochondromatous proliferation	Mildly painful mass of insidious growth	Exostotic or para-cortical lesions that arise from cortical, without destruction	T1W: intermediate signal T2W: heterogeneous signal with high signal on lesion surface	Lack of medullary involvement is characteristic



a b

Fig. 1. Simple bone cyst. Lateral view of the ankle (a) shows a well-defined lytic lesion in the calcaneus with a sclerotic border and without internal calcification (arrow). MRI STIR (short tau inversion recovery) image (b) shows uniform high signal compatible with simple bone cyst (arrow).

2. Simple bone cyst

Simple bone cyst (SBC) is mostly detected as an incidental imaging finding in young and middle-aged adults with 2−3:1 male predominance. About 80% of patients are in their second decade [4,5]. Uncommonly, the patient may present with a pathologic fracture through the lesion. It is a benign fluid-filled cystic lesion, which may be unicameral or partially septate. It is usually solitary and mainly involves the long bones, especially the proximal humerus followed by the proximal femur; these two locations account for more than 80% of cases [4,5]. Calcaneus is the third common site, accounting for 13% of cases and is the most common location in foot and ankle. Other rare locations include, talus (1.4%), metatarsals and phalanges (0.8%) [6].

On plain X-ray, SBC shows a lucent, well-defined mildly expansile lesion with sclerotic margin and/or thinning of the overlying cortical bone (Fig. 1). With pathologic fracture, there may be a small "fallen fragment" that has migrated in the intralesional fluid cavity.

CT and MRI confirm the fluid and/or internal hemorrhagic signal. Fluid–fluid level is uncommonly present. The periphery and any septa may show thin enhancement on intravenous gadolinium injection. Fractured cyst may contain fluid levels and nodular enhancement may be rarely seen.

The main differential diagnosis is intra-osseous lipoma, which shows internal fatty component +/− calcification [7].

3. Aneurysmal bone cyst

Aneurysmal bone cyst (ABC) is a benign, locally expansile lesion of the bone, occurring as a primary lesion in 79% of cases, or as a secondary lesion arising from other osseous conditions in 20% of cases [8,9]. The peak age of onset is <20 years, and 95% of cases have been reported to occur in the first 3 decades of life [10]. ABC accounts for ~1% of all bone tumors [11] and despite being reported in almost every bone of the body, it is most commonly encountered on the metaphysis of the long bones, especially on the distal part of the femur, proximal part of the tibia, and the posterior elements of vertebrae. Ankle is a rare localization for ABC, with calcaneus comprising about 1.6% of all cases [12]. The lesion is often symptomatic with the patient mostly presenting with chronic heel pain after minor trauma, walking discomfort, and sometimes swelling. Pathologic fracture occurs rarely.

On X-ray, ABC is seen as an expansile osteolytic lesion causing cortical thinning [13]. CT and MRI confirm internal blood–fluid levels (Fig. 2). The densities of these layers vary between 16 and 47 Hounsfield Units (HU) [14]. Densities over 70 (HU) may represent underlying solid lesions, such as fibrous dysplasia or osteoblastoma.

Fluid–fluid levels may also be seen in giant cell tumor, telangiectatic osteosarcoma, myositis ossificans, osteoblastoma and fibrous dysplasia, suggesting presence of a superimposed ABC-like changes.

4. Lipoma

Lipoma is a tumor composed of mature adipose tissue with no cellular atypia. Most common locations include femoral neck, tibia, fibula and calcaneus. The incidence of intraosseous lipoma is thought to be less than 0.1% of all primary bone tumors [15]. Intraosseous lipoma of calcaneus is mostly diagnosed incidentally on imaging [16].

Lipoma demonstrates a well-defined lucency with a sclerotic border. Internal calcification on X-ray differentiates it from SBC. CT demonstrates low density similar to subcutaneous fat and MRI demonstrates signal intensity characteristics similar to subcutaneous fat on both T1 and T2 weighted images. Many lesions also contain areas of infarction, fibrosis, hemorrhage, calcification, or ossification (Fig. 3) [15].

5. Hemangioma

Hemangiomas of the bones account for 1% of all primary bones. They show a marked predilection for skull and vertebrae (75%), with the long bones and ribs less commonly affected (5–10%). Rarely these occur in the foot and ankle. Microscopically, hemangiomas can be divided into capillary, cavernous, or arteriovenous. Osseous hemangioma presents with localized mild pain that may progress over several months. Soft-tissue swelling and a growing mass have been reported. History of trauma does not appear to be a predisposing factor [17,18]. Women are more frequently affected than men. Intraosseous hemangioma presents

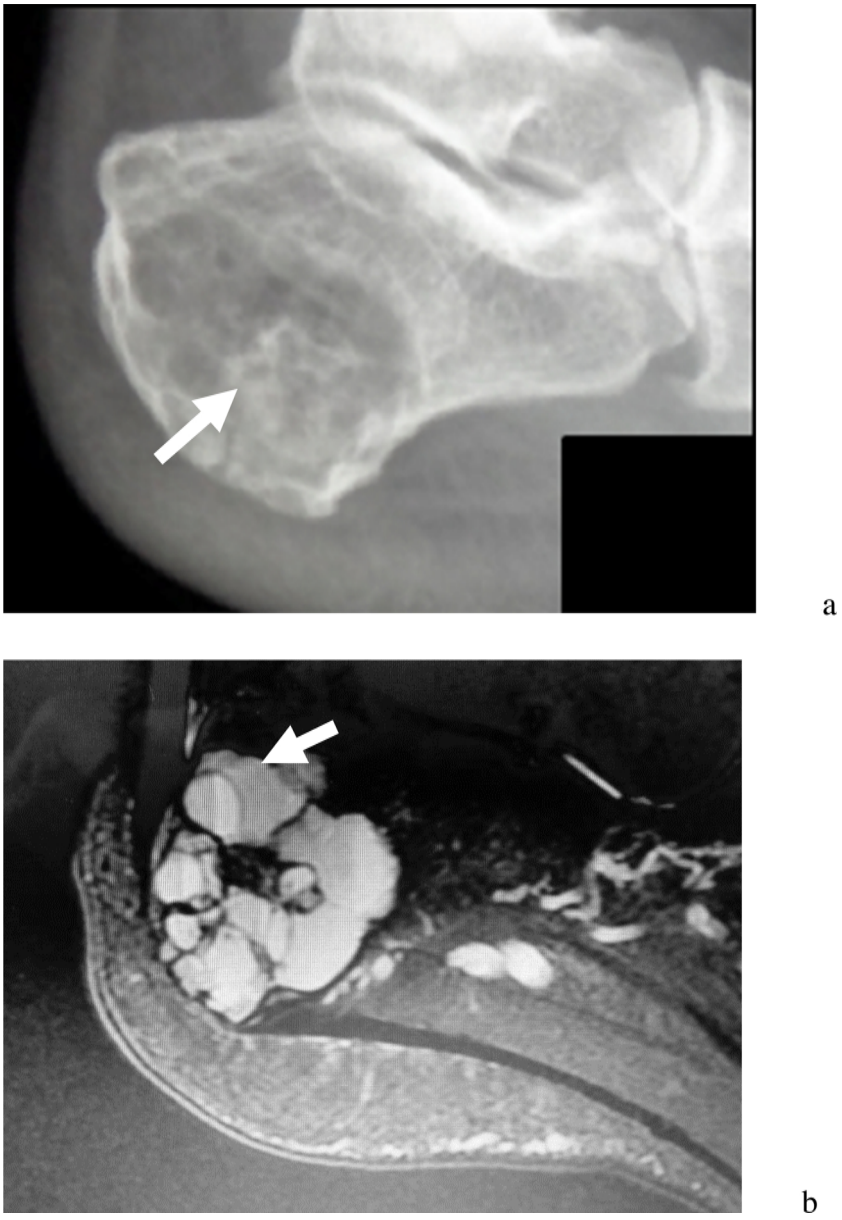
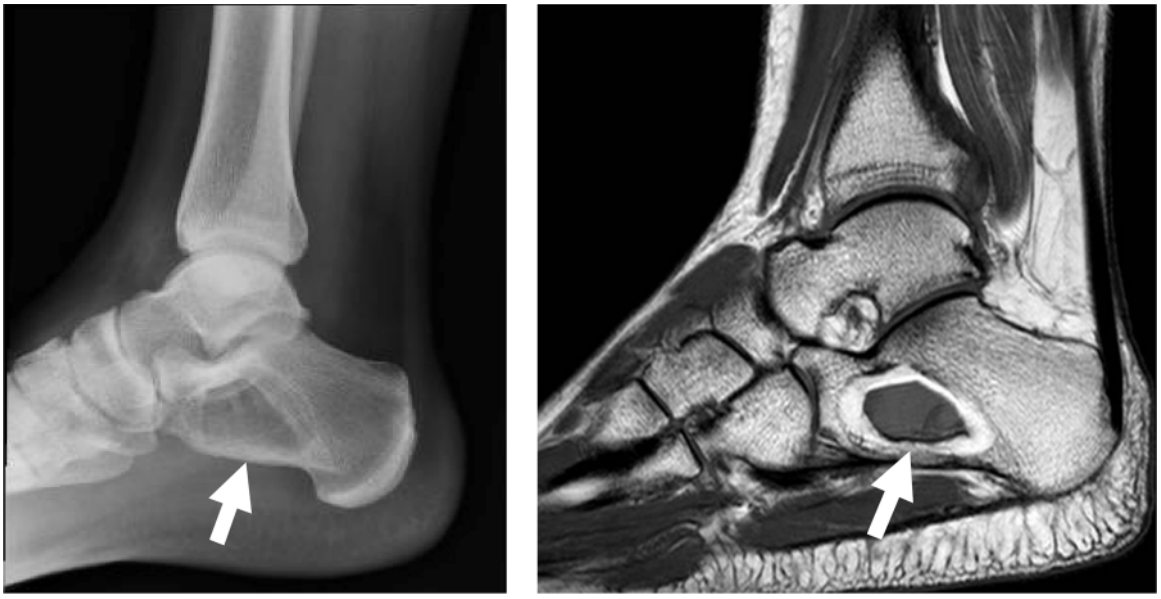


Fig. 2. Aneurysmal bone cyst. Lateral view of the ankle (a) demonstrates a well-defined, heterogeneous, osteolytic lesion with cortical thinning (arrow). MRI STIR image (b) shows fluid–fluid levels (arrow) as well as the presence of a solid component consistent with secondary aneurysmal bone cyst, superimposed on chondroblastoma.

radiographically as a lytic solitary lesion with or without a sclerotic rim. The lytic area may exhibit a honeycomb or reticulated trabecular pattern or a sunburst pattern, with striations radiating from the center. Endosteal scalloping, cortical erosion with absence of hyperostosis, and a reactive shell of periosteal bone have also been reported. CT may show these internal characteristics better. Phleboliths of soft tissue hemangioma are typically not seen in bone hemangioma. MRI may show internal fatty component on T1W images with extremely high intensity signal on T2W images (Fig. 4) [19].

6. Chondroblastoma

Chondroblastoma is a benign tumor of bone that is derived from chondroblasts. Patients with chondroblastoma of foot and ankle are male in 81% cases, with a mean age of 25.5 years, which is older than the mean age of 17.3 years in patients with chondroblastoma of the long bones. About 12% of all chondroblastomas occur in the bones of the foot and they all usually present with pain [20,21]. Chondroblastoma, typically epiphyseal, can affect any bone of the foot, including the short bones, which are in essence, epiphyseal equivalents. However, most



a b

Fig. 3. Lipoma. Lateral view of the ankle (a) shows a well circumscribed radiolucent lesion in the calcaneus, with sclerotic borders (arrow) and no cortical destruction. MRI T1W sagittal view (b) shows a typical fatty lesion of calcaneus with internal cystic changes (arrow).

commonly, it occurs in the posterior subchondral areas of the talus and calcaneus. Radiographically, chondroblastoma appears as a geographic, radiolucent lesion, often with sclerosis, trabeculation, or lobulation. Pathologic subchondral fracture is frequent but is not always obvious on plain films. This contrasts with other areas of the body where pathologic fracture is an uncommon characteristic of a chondroblastoma [22]. On CT imaging, calcified chondroid matrix can be seen in more than 50% of cases. Extensive surrounding edema around a T2 dark lesion is often apparent on MRI with periosteal edema, enhancement and rarely a small soft tissue component, what can represent aggressive behavior or even malignant component (Fig. 5).

7. Enchondroma

Enchondroma is a benign cartilaginous neoplasm located within the medullary cavity of a bone. Enchondromas of the feet account for approximately 5% of all enchondromas, compared with those in the hand, which account for more than 30% [23]. They are composed of mature hyaline cartilage and when occur in the foot, are most frequently found in the phalanges and metatarsals, with the proximal phalanx (80%) the most common site [24]. They can also occur in the long bones of the upper arm and thigh. Enchondromas are usually asymptomatic but can cause sharp pain secondary to a pathologic fracture or pressure resulting from an expanding lesion. Thus far, only a few reports on enchondroma of foot have been published, no doubt — a reflection of the rarity of the tumor [25]. Radiographically, enchondromas present as well-defined, expansile, lytic lesions with varying degrees of stippled or punctate calcifications (Fig. 6). They are located in the diaphysis or metaphyseal-diaphyseal regions of the bone. The typical radiographic finding of “ring and arc” type of calcification might not be present. CT will be useful for detecting subtle matrix calcification within the lesion. It will also be useful for evaluating the cortical integrity status of the small bones and is thus, an essential tool that guides surgical planning. MRI will display the signal intensities of a cartilaginous tumor (i.e. low to intermediate signal intensity on T1-weighted images and an inhomogeneous high-signal intensity with low-signal intensity septa on T2-weighted images). Contrast-enhanced images will typically show septal and peripheral enhancement. Calcific foci exhibit a low-signal intensity on all sequences. MRI is superior to CT and should be the preferred imaging modality to assess the bone marrow and soft tissue edema [26].

8. Osteoid osteoma

Osteoid osteoma is an uncommon benign tumor of the skeleton that usually occurs in the second and third decades of life. This benign tumor causes severe pain, worse at night and responds dramatically to nonsteroidal salicylate medications. It has a characteristic lucent nidus <1.5 cm and a surrounding solid periosteal reaction. These lesions account for ~10% of all benign bone tumors and there is a male predilection (M:F 2–4:1) [27]. Osteoid osteoma constitute 2–11% of all benign bone tumors in the foot and ankle, with a particular predilection for the talus and calcaneus [28]. They can be divided into three types: intracortical, cancellous, and subperiosteal. In long bones, intracortical is more frequent and causes significant periosteal reaction but in the foot, they generally occur in cancellous bone or subperiosteally [29].

Imaging evaluation includes radiography, CT, and MRI. The assessment begins with radiography of a child or mostly an adolescent with foot night pain. X-ray may find only sclerosis and sometimes may appear normal. Cross-sectional CT imaging shows a low-attenuation nidus with

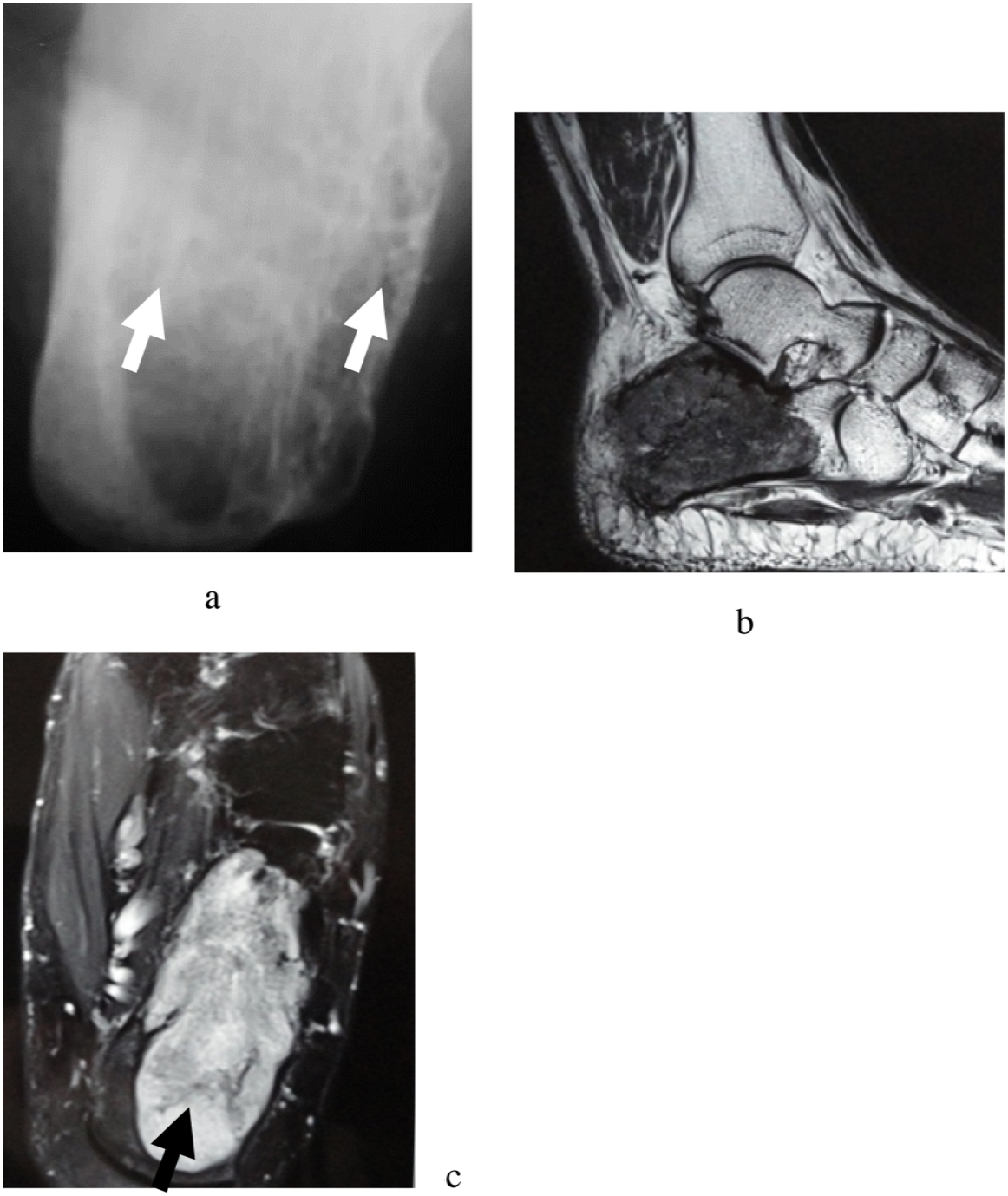


Fig. 4. Hemangioma. Axial view of the calcaneus (a) shows an irregular, lytic lesion with prominent reticulated trabecular pattern (arrows) and sclerotic margins. MRI T1W (b) and fat suppressed T2W (c) images show low signal intensity replacement of calcaneal marrow on T1W and extremely high signal intensity in T2W images. There is minimal internal fatty signal change (arrow).

sometimes internal calcification and surrounding sclerosis (Fig. 7). On MRI, the nidus shows low or intermediate signal intensity on T1-weighted images, variable signal intensity on T2-weighted images and variable enhancement. Radiofrequency ablation is the treatment of choice.

9. Osteoblastoma

Osteoblastoma is a rare bone tumor, representing less than 1% of all bone tumors. Although rare, foot and ankle are common sites for these tumors, with an incidence of 6–15% [30]. Despite the histologic similarities, osteoid osteoma (<1.5 cm) and osteoblastoma (>1,5 cm) are two completely distinct pathophysiologic entities because osteoblastoma is more aggressive and locally destructive. Malignant transformation, albeit rare, has been reported [31]. Most tumors are in the hindfoot and talus, the most commonly involved bone in the foot and ankle. Bone matrix production occurs in 56% of cases and it can be focally punctate or coalesced centrally. A soft tissue mass may be seen in around 24% of patients [30]. Radiologically, the diagnosis of osteoblastoma is usually based on the plain radiograph alone. Matrix is seen in most subperiosteal lesions, especially in the talar neck. Matrix is however scant or absent in most endosteal or intramedullary tumors. Exuberant perilesional sclerosis is generally not evident in a osteoblastoma as compared to periosteal or cortically based osteoid osteomas. CT delineates the degree of

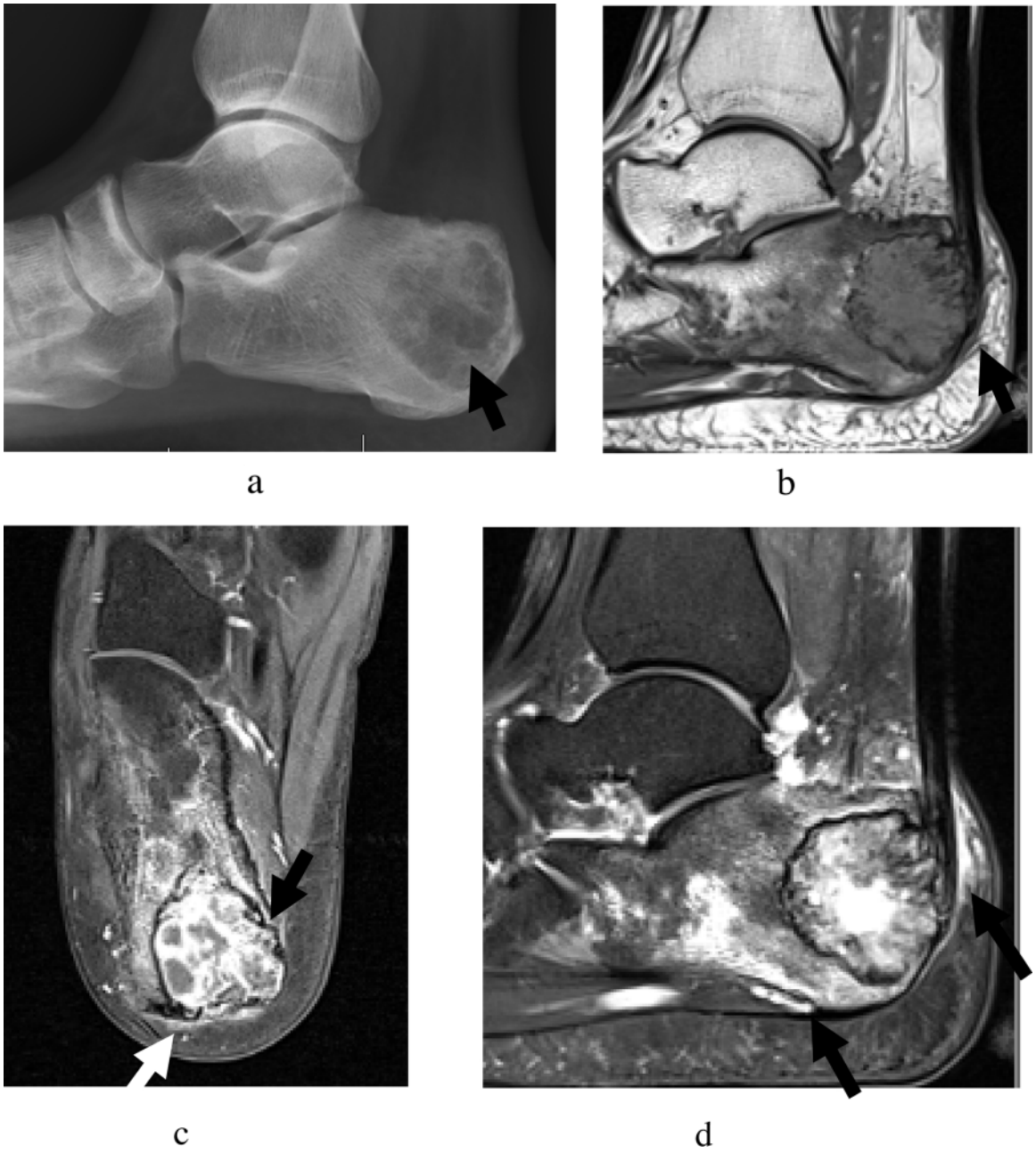


Fig. 5. Chondroblastoma. Lateral view of the ankle (a) shows a lytic, well-defined lesion in the calcaneus with internal chondroid matrix (arrow). T2W Dixon MR imaging with in-phase (b) and water (c) maps show extensive marrow edema and some periosteal edema (white arrows) around a well-defined lesion (black arrow). Sagital post-gadolinium fat-suppressed T1W imaging (d) shows heterogeneous enhancement and periosteal enhancement (arrows).

osseous destruction and presence of internal matrix. MR imaging accurately reveals the soft tissue and intraosseous extent of tumor (Fig. 8).

10. Giant cell tumor

Giant cell tumor (GCT) of bone is a rare neoplasm and accounts for approximately 5% of biopsied bone tumors in the United States. Although GCTs possess limited capacity to metastasize, local aggressiveness and high recurrence rates often lead to significant impairment. GCT typically occurs in the metaphyseal/epiphyseal region of the long bones in young adults. While common in the knee and wrist, they are uncommon in the distal tibia and fibula, and rarely occur in the hand or the foot [32] (4% of all giant cell tumors).

Pathologicaly GCT is very similar and can be indistinguishable to other giant other giant cell-containing lesions such as brown tumor, secondary to hyperparathyroidism. This way, serum calcium levels should be performed to differentiate those differential diagnosis [33].

Primary GCTs of bones of the foot were characteristically eccentric in location, round, expansive, and lytic. They are more aggressive with ill-defined edges. They have higher rate of recurrence than other sites, but generally don`t recur after the second treatment.

Radiography demonstrates the classic appearance and locally aggressive behavior of these tumors. The tumors are purely lytic and foot lesions frequently expand (Fig. 9) and/or break through the cortex. Intra articular and soft tissue extension are rare [34].

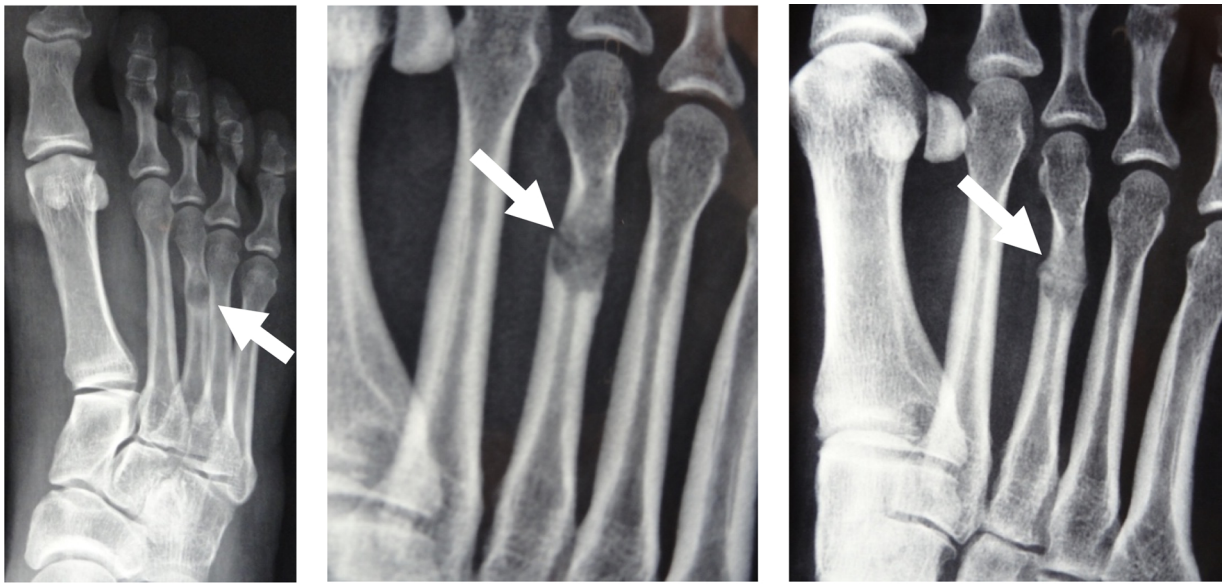


Fig. 6. Enchondroma. Radiography (a) shows lucent, well defined lesion (arrow) on distal third of III metatarsus. 45 day later (b) after reported pain, radiography evidenced pathological fracture (arrow). After another 45 days of immobilization (c) occurred consolidation of the lytic lesion and cortex, suggesting healing of the pathological fracture (arrow).

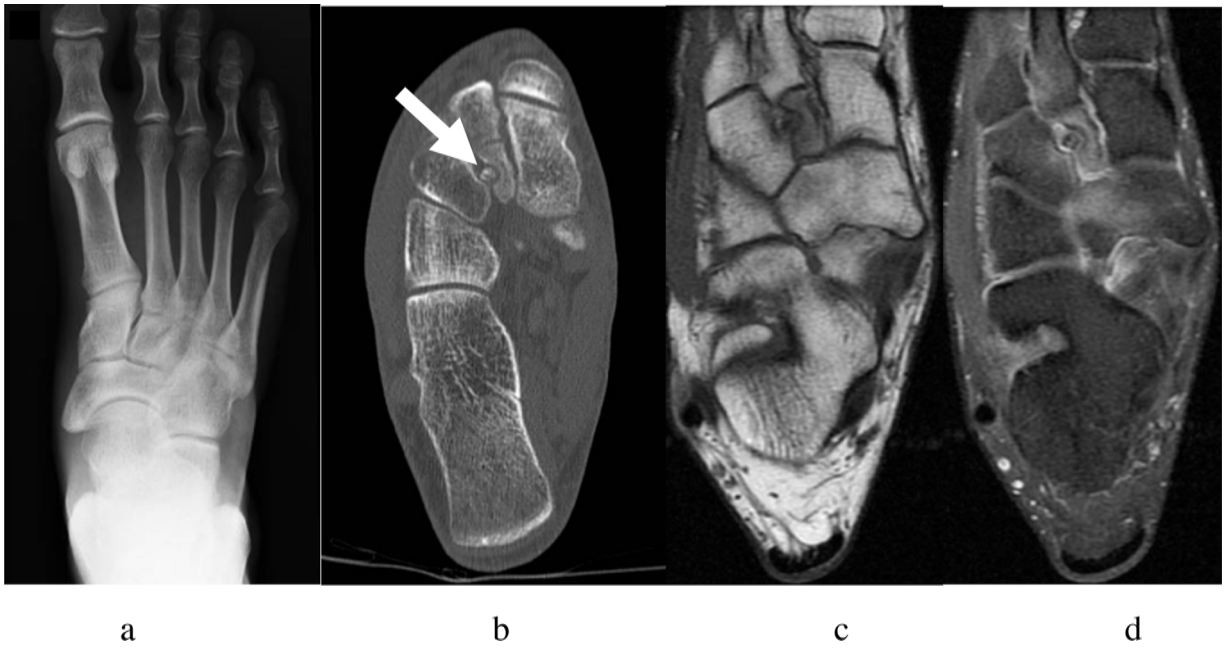


Fig. 7. Osteoid Osteoma. Radiography (a) was reported normal. CT (b) shows a cortical lytic lesion on the lateral aspect of the intermediate cuneiform with small calcification (arrow). MR T1W (c) shows a low signal lesion (nidus) with low signal surrounding edema; T1W-Gad (d) demonstrates contrast enhancement in the intermediate cuneiform and navicular bones.

11. Hemangioendothelioma

Hemangioendothelioma (HE) is a rare endothelial vascular neoplasm that classically involves soft tissue but has been reported in other locations such as liver, lung and bone. It is defined as an intermediate-grade malignant vascular neoplasm whose clinical course is between those of epithelioid hemangioma and angiosarcoma. It most frequently occurs during the 2nd and 3rd decades of life, with a male predilection of approximately 2:1 [35].

HE occurs less commonly in bone, accounting for <1% of all primary bone tumors. Mainly located in the long tubular bones of the lower extremities and pelvis, affecting the upper extremities, vertebrae and other flat bones less frequently [36]. Moreover, they have a tendency to develop multifocal disease and have an unpredictable clinical course. EH is usually considered a low-grade malignant vascular tumor, whereas angiosarcoma is regarded as a high-grade malignant vascular tumor [37].

Radiography and CT of HE usually reveals a lytic lesion without matrix mineralization that is localized in the medullary to cortical bone.

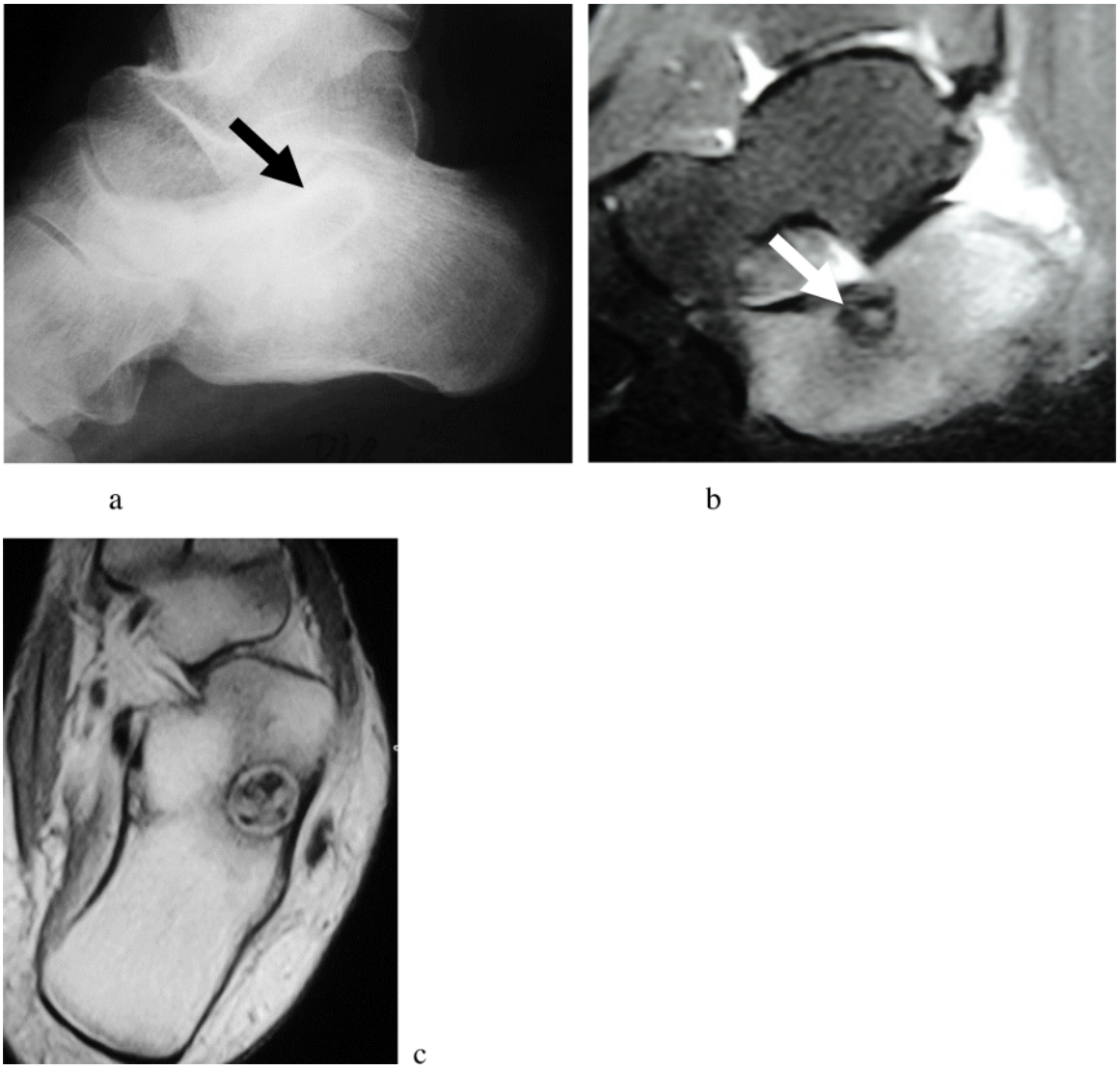


Fig. 8. Osteoblastoma. Radiography (a) shows an ill-defined lytic lesion and peripheral sclerosis (arrow). MRI T2W (b) and T1W (c) show well defined nidus (arrow), larger than 1.5 cm with extensive surrounding edema, consistent with the diagnosis.

Cortical disruption and joint invasion are also common features. However, the signal characteristics on MRI are non-specific. Low to intermediate signal intensity on T1-weighted images and high signal intensity on T2-weighted images, with homogeneous enhancement, are identified following the injection of gadolinium-based contrast material (Fig. 10) [36].

12. Osteosarcoma

After multiple myeloma, osteosarcoma is the most common primary malignancy of bone. The commonest site of involvement is about the knee and accounting for approximately 50% of all cases. Osteosarcoma of the foot is rare and only a few well documented cases have been reported [38]. The reported incidence of pedal osteosarcoma varies between 0.2–2% of all osteosarcomas and this rarity may lead to delayed or misdiagnosis [39]. Osteosarcomas seem to involve either the tarsal region or the tubular bones; in contrast, the phalanges are rarely involved. Because of the rarity of osteosarcomas of the foot, late diagnosis is common, even if these lesions are usually painful. Osteosarcomas may also be misdiagnosed because other types of lesions may mimic their features. On the basis of the published literature, some cases seem to suggest that osteosarcomas of the foot are associated with a favorable prognosis in comparison with the lesions involving more proximal anatomic sites [40]. Radiographically, osteosarcoma appears as an aggressive bone lesion with area of increased bone density and osteolysis, cortical destruction and periosteal reaction. In some cases, the lesion appears purely lytic, with thinning and erosion of the cortex. On MRI, there is replacement of the normal bone marrow signal, peritumoral edema and soft-tissue involvement (Fig. 11). The ossified matrix can be seen as a low signal on all pulse sequences while the soft-tissue component can be heterogeneous with varying signal intensity and enhancement depending on the degree of hemorrhage and necrosis [41].

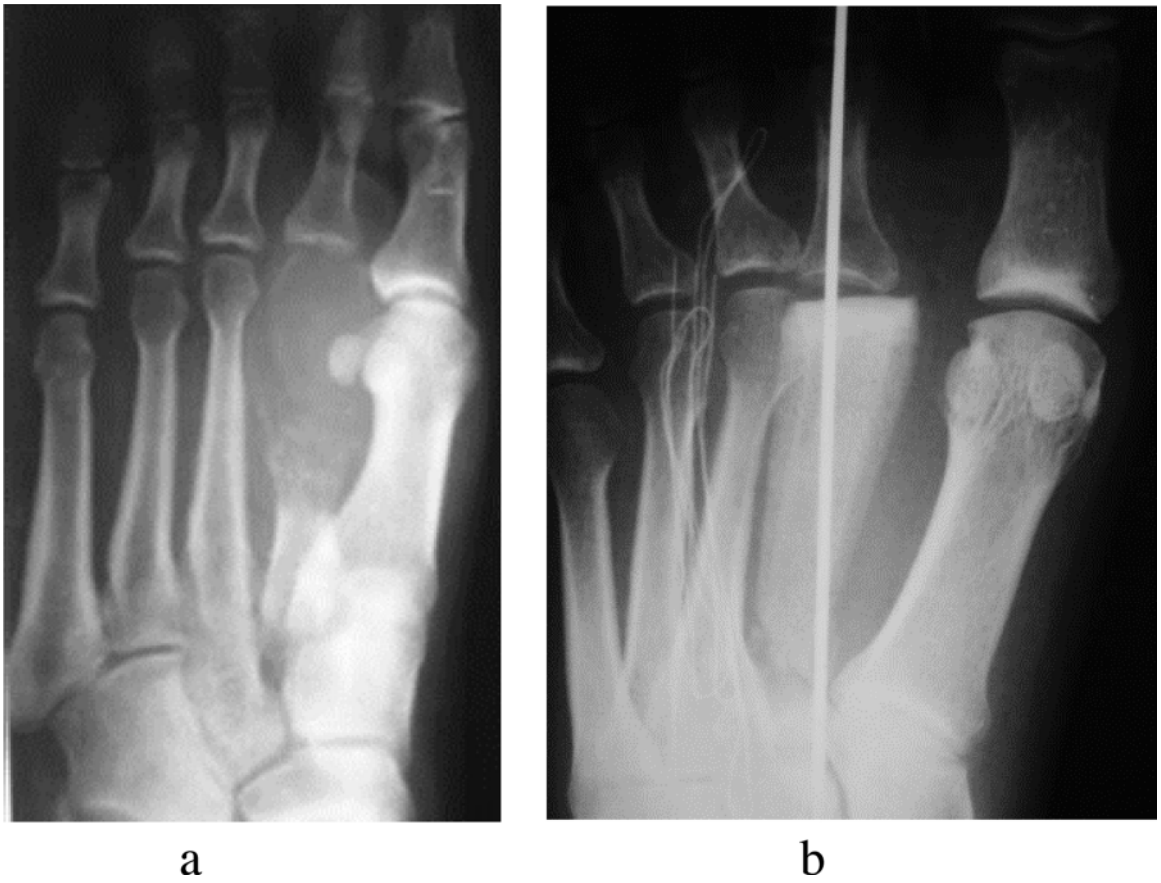


Fig. 9. Giant cell tumor. Radiography (a) shows lytic expansile lesion of the second metatarsal, cortical thinning and no mineralization. Post-treatment radiography (b) shows curettage and bone graft placement.

13. Ewing sarcoma

Ewing sarcoma is a malignant small round blue cell tumor and is the second most common malignant tumor of bone in children after osteosarcoma. It is more frequently diagnosed between the second and third decades of life and affects the hand and foot in 3–6% of cases. The clinical presentation is nonspecific, with pain, mass or swelling [42]. It rarely occurs in the foot but is the most common malignancy of foot bones in children. However, it is very unusual in the small bones of the feet. The talus, calcaneus and the metatarsals are most commonly involved [1]. On plain radiographs, Ewing's sarcoma is often characterized by a 'permeative' or 'moth-eaten' pattern of bone destruction (Fig. 12). The classical 'onion skin' periosteal reaction is more often seen with diaphyseal tumors [15,16]. Cortical saucerization may be seen. MRI shows the intra-osseous and extra-osseous extent of the tumor and diffusion weighted imaging will show marked diffusion restriction, typical finding of small blue round cell tumors [43].

14. Chondrosarcoma

Chondrosarcomas are tumors that develop during adulthood and old age, with maximum incidence between the fourth and sixth decades of life. They account for approximately 20–25% of bone sarcomas and preferentially affect the flat bones, especially the scapula and pelvis, but may also affect the diaphyseal parts of the long bones. They may arise primarily or secondarily, as malignant transformation of enchondroma or, more rarely, from the cartilaginous cap of osteochondroma [44].

A study about chondrosarcomas in hand and foot revealed an incidence of 2.9%. Calcaneus was the most commonly involved bone in the foot. The talus, first metatarsal bone, and distal phalanx of the great toe were also common sites. One chondrosarcoma arose from a sesamoid bone of the great toe [45].

Radiographically, lesions present with endosteal erosions, cortical destruction, and expansion, as well as soft tissue mass and calcifications. Most of them show poor margination, and few show involvement of the whole bone and a well-marginated lesion. Periosteal reaction and cortical thickening are uncommon [46]. On MRI, the soft-tissue extension shows very high signal on T2W imaging and appears more lobulated and thicker than the benign enchondroma [15] (Fig. 13).

15. Fibrous dysplasia

Fibrous dysplasia is a benign medullary fibro-osseous lesion that may involve one (monostotic) or more bones (polyostotic). The monostotic

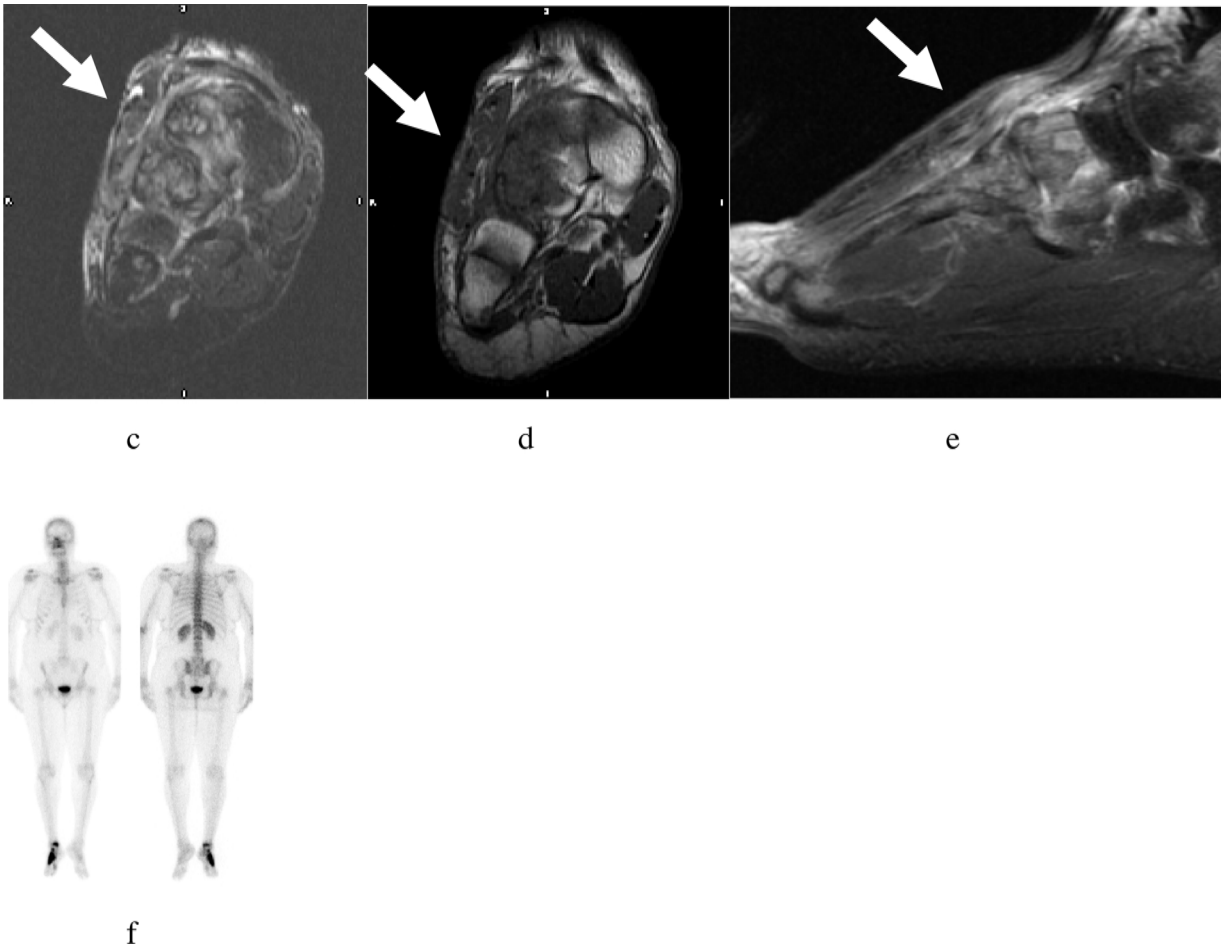


Fig. 10. Hemangioendothelioma. Radiography (a) Lateral view of foot shows multifocal lucencies and demineralization. Corresponding CT reconstruction (b) shows numerous lytic lesions in foot and ankle. MRI T2W (c) T1W (d) and T1W post contrast (e) shows an intermediate to high signal intensity in T2W, low signal intensity in T1 with contrast enhancement and soft tissue extension (arrows). Scintigraphy (f) shows corresponding enhance areas in foot and ankle.

variation is much more common in a ratio of around 10:1. The hallmark of fibrous dysplasia is the inability of bone-forming tissue to develop into mature lamellar bone; thus, the maturation process is arrested at the level of woven bone [47]. The most common locations of monostotic FD of extremity bones are the proximal femoral shaft (40%), tibia (15%), humerus (5%), and radius (5%) [48]. An extensive literature search revealed only 6 case reports that have been published fibrous dysplasia of the foot, the most recent published in 2003. As it commonly occurs in long bones, ribs, skull, it is rare in short bones of foot, occurring in the foot with a frequency of 2% [44]. Plain films shows a radiolucent ground-glass lesion with a sclerotic and thin margin. CT reveals the well-defined lytic lesion, may show thinning of cortical and ossification/calcification within the lesion. MRI shows signal iso to low-intense on T1W and hypo to hyperintense on T2W imaging (Fig. 14) with contrast enhancement. Sometimes, the final diagnosis is established on biopsy to differentiate from low grade osteosarcoma [49].

16. Hemophilic pseudotumor

In 1965, hemophilic pseudotumor was first described as a progressive cystic swelling involving muscle, produced by recurrent hemorrhages and accompanied by radiographic evidence of bone involvement [50]. Clinically, hemophilic pseudotumors usually present as a painless expanding mass growing over years. Their most serious sequel is a pathological bone fracture and uncontrollable bleeding. Gunning estimated that 1% of hemophiliacs with severe disease have pseudotumors [51]. The commonest sites are the long tubular bones and ileum, where repeated and unresolved intramuscular hematomas may lead to encapsulation and calcification, with a progressive enlargement of the mass and subsequent erosion of the adjacent bone. Foot lesions are seen in children and adolescents; direct trauma has been implicated. Bleeding into small cancellous bones, such as the calcaneum, talus and the small bones of the feet is thought to be responsible for the pseudotumors and cysts in these bones. Disappearance of these pseudotumors after a low dose of radiation has been reported [52].

Radiography and CT shows bone destruction with lucent areas and high-density soft tissue mass-like lesion adjacent to the affected bone (Fig. 15). MR imaging confirms the hemorrhagic components of hemophilic pseudotumors. Chronic bled areas show heterogeneous signal, predominating low signal due to hemosiderin deposition. Subacute blood has high signal on T1W and T2W imaging. Underlying history of hemophilia aids in establishing the definitive diagnosis.

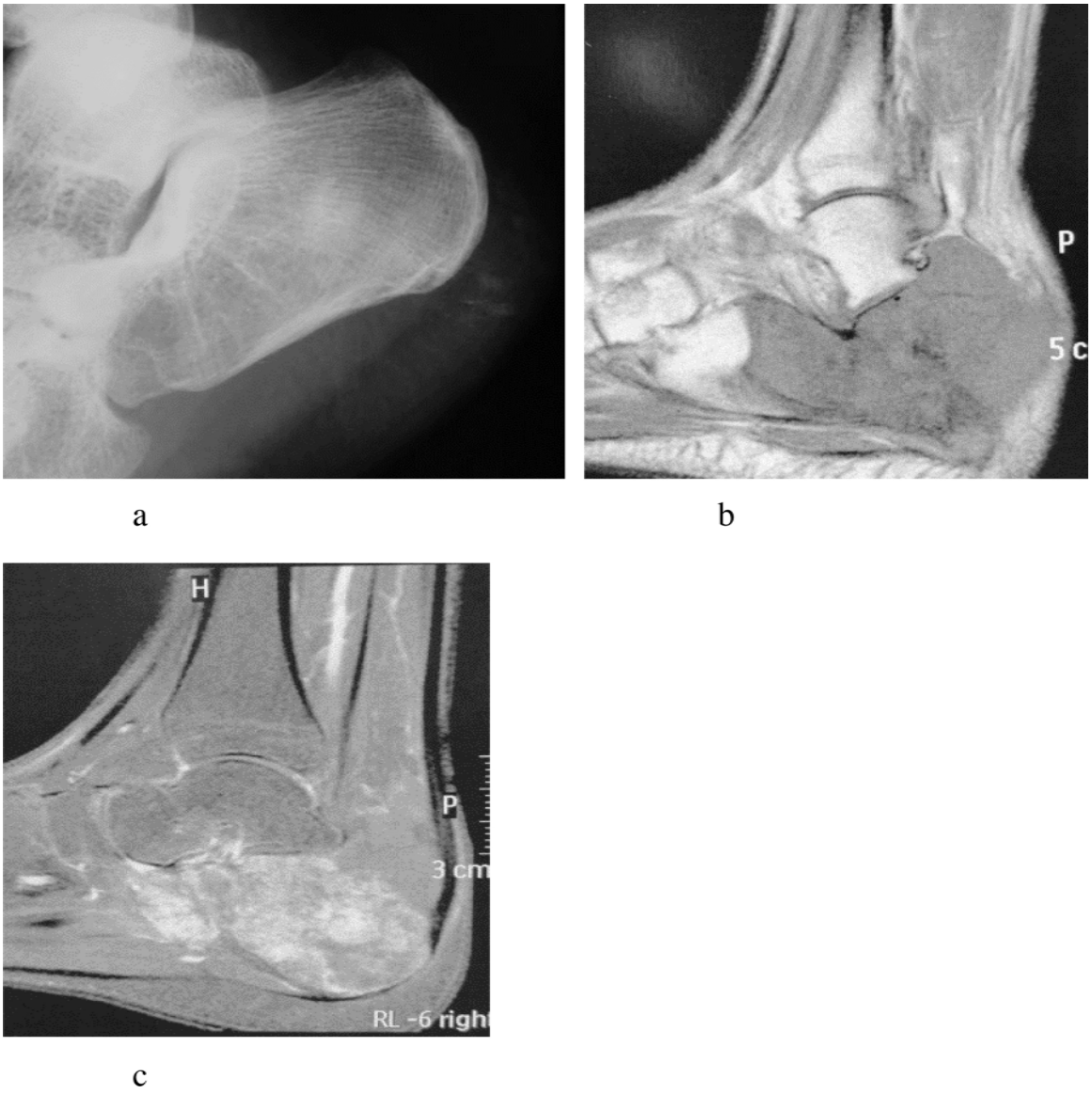


Fig. 11. Osteosarcoma. Radiography (a) shows a ill-defined lytic permeative lesion in calcaneus with ill-defined marrow involvement. MRI was provided two months later. T1W (b) and fat-suppressed T1W-post contrast (c) shows an intermediate signal intensity with contrast enhancement and soft tissue extension.

17. Madura foot

Madura foot occurs as a result of filamentous fungus invasion of the foot, and occasionally other parts of the body. It usually occurs when the fungus is introduced by the prick of an infected thorn or splinter. Typically, bodies of various shapes, resembling small grains which are, in fact, clumps of fungi, are found either in the discharge from the affected area or in a biopsy specimen [53]. Radiographs may be normal or show soft tissue swelling, bone sclerosis, bone cavities with moth-eaten appearance, periosteal reaction, cortical scalloping, fanning of the rays, or osteoporosis. The bones are almost always attacked from the outside, in contrast to bacterial osteomyelitis [54].

Initial reports of the MRI findings described lesions with low signal on T1W and T2W images, which were assumed to be due to susceptibility from the metabolic products of the 'grains'. The "dot-in-circle" sign, seen as tiny hypointense foci within the hyperintense spherical lesions, was initially described by Sarris et al. [55], in 2003 on T2W, STIR, and T1W fat-saturated gadolinium-enhanced images. Correlating the MRI and histology findings, they suggested that the high-signal areas seen on MRI represented inflammatory granulomas, the low-intensity tissue seen

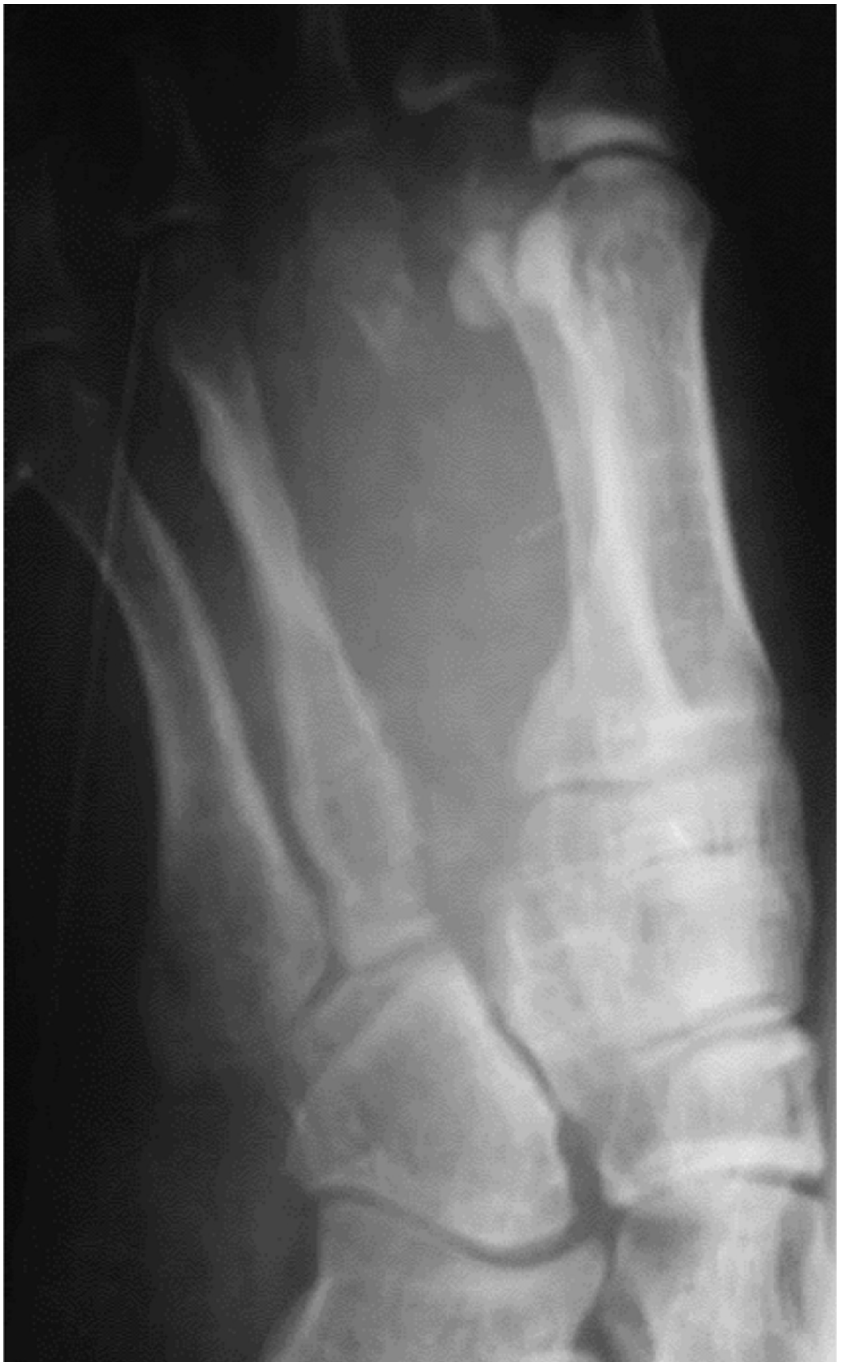


Fig. 12. Ewing sarcoma. Radiography shows a lytic, ill-defined diaphyseal lesion of a third metatarsal, with aggressive pattern. Note sclerosis in the fourth metatarsal due to chronic pressure effect of the soft tissue lesion.

surrounding these lesions represented the fibrous matrix, and the small central hypointense foci within the granulomata represented the fungal balls or grains. They suggested it to be a highly specific sign for this infection [56]. DWI show restricted diffusion in the lesions with target signs on apparent diffusion coefficient maps (Fig.16).

18. Bizarre parosteal osteochondromatous proliferation

Bizarre parosteal osteochondromatous proliferation, as defined by Nora et al. in 1983 (also called Nora lesion) [57], is a rare lesion. It is an exophytic outgrowth from the cortical surface consisting of bone,

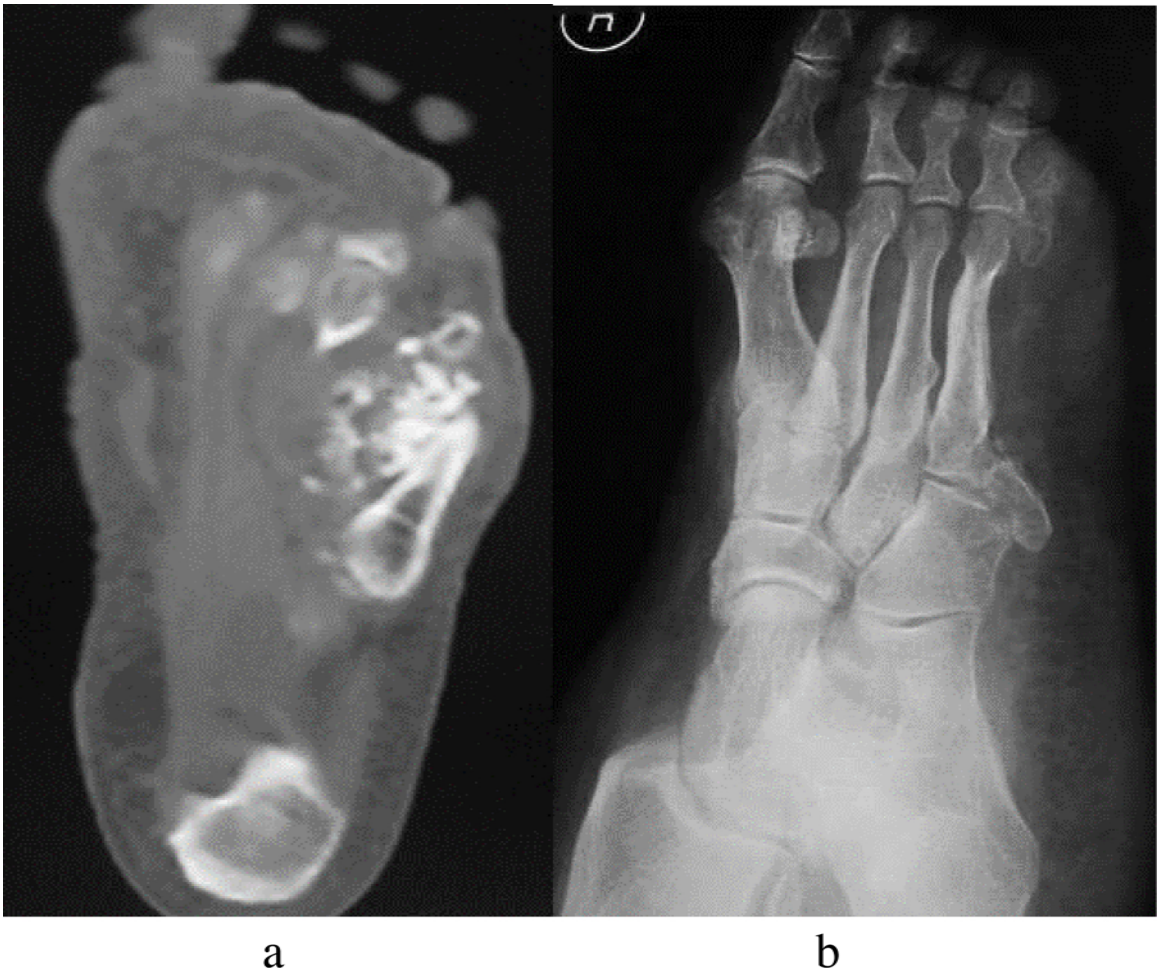


Fig. 13. Chondrosarcoma. CT (a) demonstrates matrix calcification and soft tissue extension of the 5th metatarsal. Post-surgery radiography (b) shows absence of fifth metatarsal diaphysis.

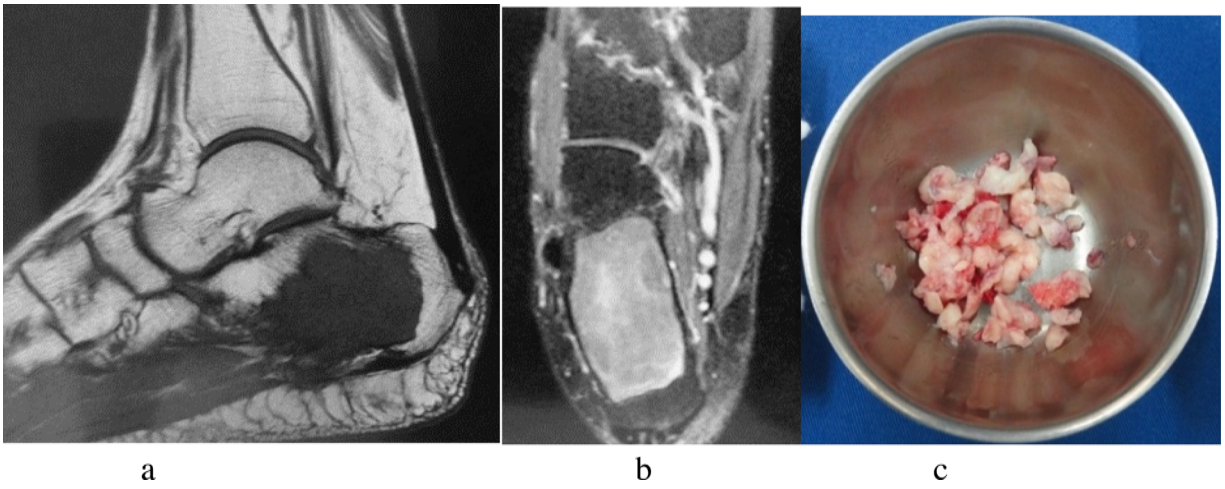


Fig. 14. Fibrous dysplasia. MRI T1W (a) shows a well-defined hypo-intense lesion in calcaneus with homogeneous enhancement on fat suppressed T1W post contrast imaging (b). Appearance of post-surgical curettage material (c).

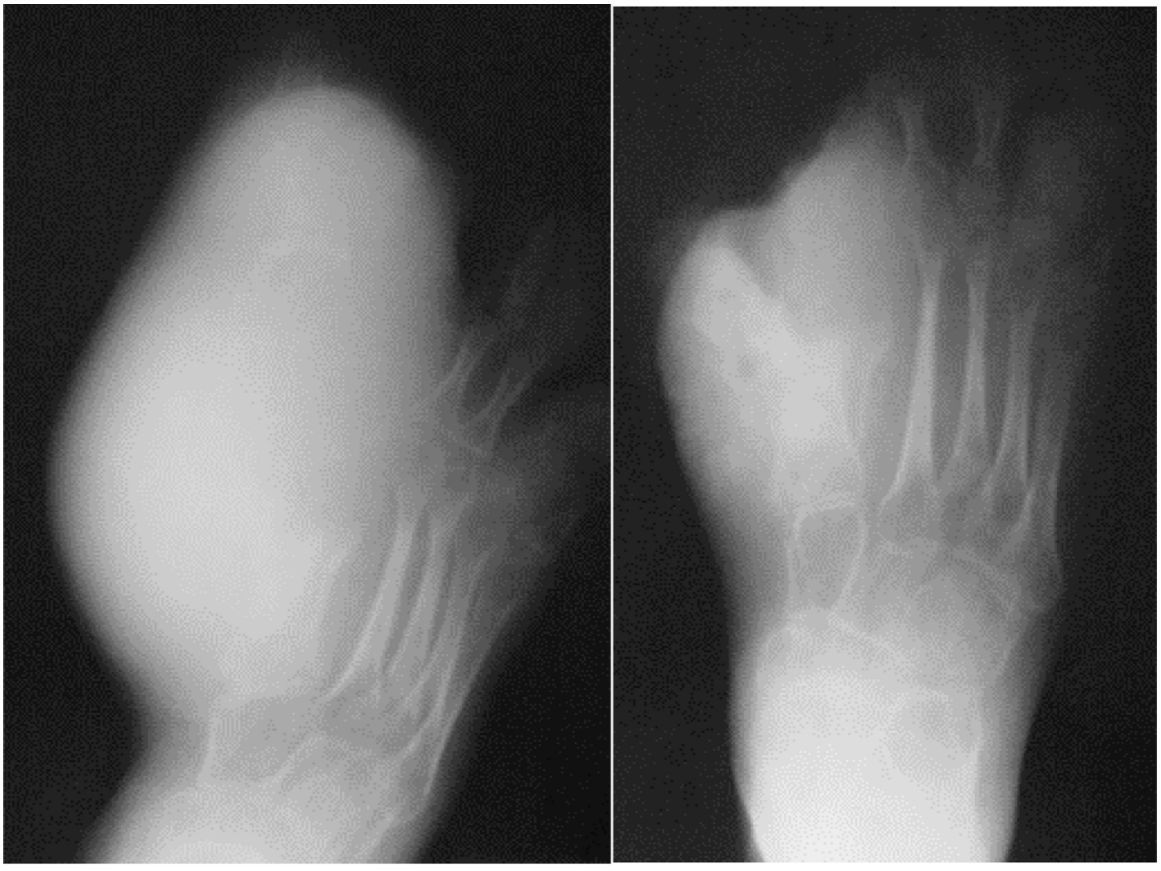


Fig. 15. Hemophilic pseudotumor. Previous radiography (a) shows a hyperdense mass on the medial aspect of the forefoot and midfoot in a known hemophiliac. After a few weeks (b), with resorption of some of the hyperdense content, bone erosions are more apparent in the hallux.

cartilage and fibrous tissue. It usually affects the proximal and middle phalanges, and the metacarpal or metatarsal bones [58].

The commonest presentation is that of a bony swelling arising from the small bones of the hands and feet. The hands are 4 times more commonly affected than the feet [59]; however, lesions in the long bones, skull, maxilla and metatarsophalangeal sesamoid have been reported. Nora's lesion occurs in adults in second and third decade of life (average age 30–33 years, range, 2–73). Males and females are equally affected. There is a history of a mildly painful mass that seems to increase in size over many weeks or a few months [56].

X-ray should be performed as it shows these lesions arise from the cortex without affecting it, a specific finding, differently from cartilage-capper exostoses (osteochondromas) which has continuity of the central part of the tumor with underlying osseous medulla [57]. The lesion is usually located in the metaphysis and may exhibit a spiculated or irregular surface. CT scan helps to distinguish it from osteochondromas by showing the absence of continuity between the medullary cavity and the lesion with intact cortex (Fig. 17) [60]. MRI scans exhibit para-cortical masses, isointense on T1W images. On T2W images, the surface area of the lesions shows high intensity, and the deeper area showed heterogeneous intensity [59].

19. Conclusion

This article exposes the main bone lesions present in the foot and ankle, focusing on the imaging characteristics in order to provide a pictorial sample to help improve radiological knowledge. Some of the key imaging modalities were used appropriately to make the information easily understandable. We also briefly highlighted remarkable clinical and pathological characteristics with the propose to enrich the approach.

Conflicts of interest

The authors declare that they have no conflict of interest.

Disclosures

Avneesh Chhabra serves as a consultant in ICON Medical and Treace 3D Medical Inc. Avneesh Chhabra also receives royalties from Jaypee and Wolters.

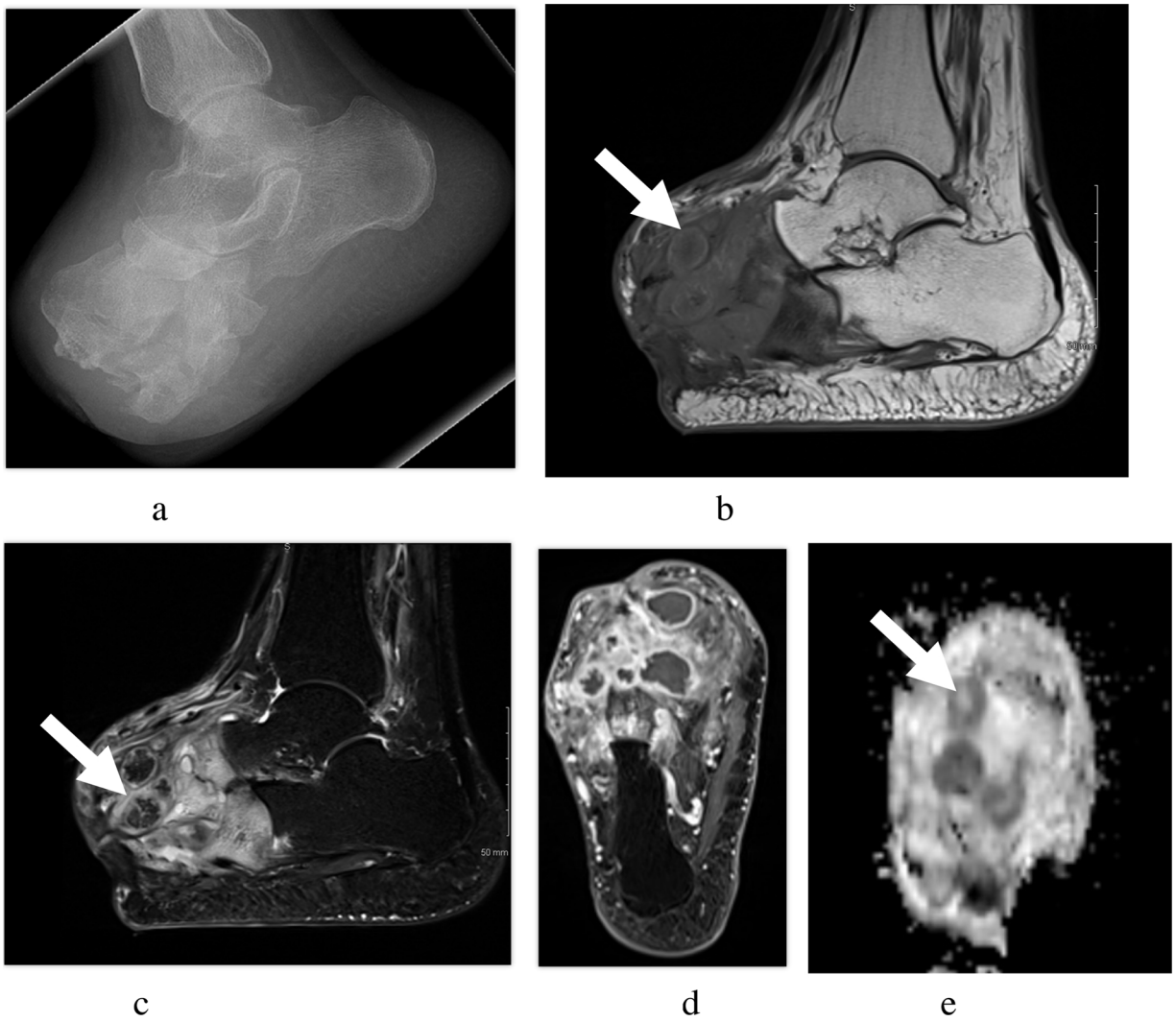


Fig. 16. Madura foot. 29-year-old with foot pain and swelling. Prior partial amputation after foot was beaten with a hammer, complicated with chronic pain and discharge from foot. Lateral Xray (a) of foot shows partial amputation, mixed bone lysis and sclerosis with surrounding soft tissue swelling. Sagittal T1W (b) and STIR (c) images show target lesions (arrows) with surrounding bone osteomyelitis. Axial T1W post contrast images (d) shows rim enhancing lesions of abscesses. Axial ADC map (e) shows the restricted areas with target sign (arrow).

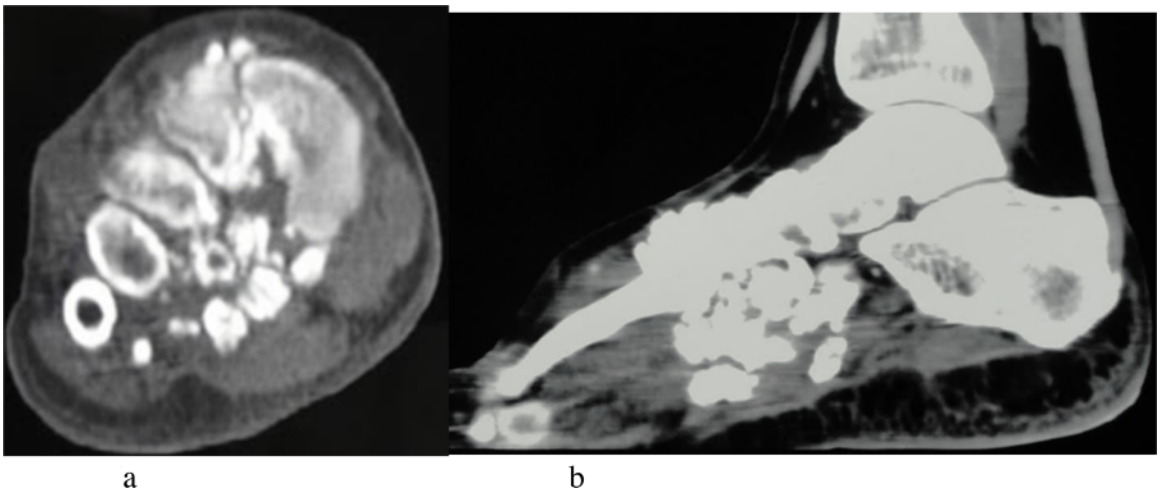


Fig. 17. Bizarre parosteal osteochondromatous proliferation. CT (a,b) shows well-marginated wide based bony growths from midfoot, projecting into the soft tissues, with a lack of medullary involvement.

References

[1] Ruggieri P, Angelini A, Jorge FD, Maraldi M, Giannini S. Review of foot tumors seen in a university tumor institute. J Foot Ankle Surg 2014;53(3):282–5. https://doi.org/10.1053/j.jfas.2014.01.015.

[2] Balach T, Stacy GS, Peabody TD. The clinical evaluation of bone tumors. Radiol Clin North Am 2011;49(6):1079–93. https://doi.org/10.1016/j.rcl.2011.07.001.

[3] Papp DF, Khanna AJ, McCarthy EF, Carrino JA, Farber AJ, Frassica FJ. Magnetic resonance imaging of soft-tissue tumors: determinate and indeterminate lesions. J Bone Joint Surg Am 2007;89:103–15. https://doi.org/10.2106/JBJS.G.00711.

[4] Fletcher JA, Hogendoorn PCW, Mertens F. WHO tumours of soft tissue and bone. IARC; 2013. p. 350–1.

[5] Kaelin A. Kystes essentiels des os Cahiers d'enseignements de la Sofcot Paris: L'Expansion scientifique française. 1995. p. 167–79.

[6] Aycan OE, Çamurcu ÌY, Arikan Y, Özer D, Kabukçuoğlu YS. Unusual localizations of unicameral bone cysts and aneurysmal bone cysts: a retrospective review of 451 cases. Acta Orthop Belg 2015;81(2):209–12.

[7] Jaffe HL, Lichtenstein L. Solitary unicameral bone cyst with emphasis on the roentgen picture, the pathologic appearance and the pathogenesis. Arch Surg 1942; 44:1004–25. https://doi.org/10.1001/archsurg.1942.01210240043003.

[8] Docquier PL, Glorion C, Delloye C. Kyste osseux anévrismal. EMC 2011;6(1):1–11. https://doi.org/10.1016/s0246-0521(11)55890-5. Elsevier Masson SAS.

[9] Lichtenstein L. Aneurysmal bone cyst: a pathological entity commonly mistaken for giant cell tumor and occasionally for hemangioma and osteogenic sarcoma. ACS J 1950;3:279–89. https://doi.org/10.1002/1097-0142(1950)3:2<279::AID-CNCR2820030209>3.0.CO;2-F.

[10] Singh DK, Singh N, Pant MC. Aneurysmal bone cyst: an unusual presentation of back pain. Asian J Neurosurg 2014;9(2):105–7. https://doi.org/10.4103/1793-5482.136727.

[11] Hakim DN, Pelly T, Kulendran M, Caris JA. Benign tumours of the bone: a review. J Bone Oncol 2015;4(2):37–41. https://doi.org/10.1016/j.jbo.2015.02.001.

[12] Kaplanoğlu V, Ciliz DS, Kaplanoğlu H, Elverici E. Aneurysmal bone cyst of the calcaneus. J Clin Imaging Sci 2014;4:60. https://doi.org/10.4103/2156-7514.143732.

[13] Babazadeh S, Broadhead ML, Schlicht SM, Powell GJ, Tymms GM. Pathologic fracture of a calcaneal aneurysmal bone cyst. J Foot Ankle Surg 2011;50(6): 727–32. https://doi.org/10.1053/j.jfas.2011.04.036.

[14] Kuna S, Gudena R. "Soap bubble" in the calcaneus. CMAJ 2011;183(10):1171. https://doi.org/10.1503/cmaj.101525.

[15] Llauger J, Palmer J, Monill JM, Franquet T, Bagué S, Rosón N. MR imaging of benign soft-tissue masses of the foot and ankle. Radiographics 1998;18(6): 1481–98. https://doi.org/10.1148/radiographics.18.6.9821196.

[16] Martínez MR, Corral FJB, García JR, Beltrán MM, Mendoza ACZ. Cystic lesion of the calcaneus, intraosseous lipoma. Reumatol Clin 2007;3(3):139–42. https://doi.org/10.1016/S1699-258X(07)73681-1.

[17] Hoffmann DF, Israel J. Intraosseous frontal hemangioma. Head Neck 1990;12(2): 160–3. https://doi.org/10.1002/hed.2880120212.

[18] Kirchhoff D, Eggert HR, Agnoli AI. Cavernous angiomas of the skull. Neurosurgery 1978;21(2):53–62. https://doi.org/10.1055/s-0028-1090322.

[19] Peterson DI, Murk SE, Story JL. Multifocal cavernous hemangioma of the skull: report of a case and review of the literature. Neurosurgery 1992;30(5):778–81.

[20] Fink BR, Temple HT, Chiricosta FM, Mizel MS, Murphey MD. Chondroblastoma of the foot. Foot Ankle Int 1997;18(4):236–42. https://doi.org/10.1177/107110079701800410.

[21] Huvos AG, Marcove RC. Chondroblastoma of bone: a critical review. Clin Orthop 1973;95:300–12. https://doi.org/10.1097/00003086-197309000-00039.

[22] Dahlin DC, Ivins JC. Benign chondroblastoma. A study of 125 cases. Cancer 1972; 30(2):401–13. https://doi.org/10.1002/1097-0142(197208)30:2<401::AID-CNCR2820300216>3.0.CO;2-B.

[23] Unni KK, Inwards CY, Bridge JA, et al. Tumors of the bones and joints, series 4. Washington DC: Armed Forces Institute of Pathology; 2005.

[24] Cawte TG, Steiner GC, Beltran J, Dorfman HD. Chondrosarcoma of the short tubular bones of the hands and feet. Skeletal Radiol 1998;27:625–32. https://doi.org/10.1007/s002560050448.

[25] Chun KA, Stephanie S, Choi JY, Nam JH, Suh JS. Enchondroma of the foot. J Foot Ankle Surg 2015;54(5):836–9. https://doi.org/10.1053/j.jfas.2015.01.002.

[26] Chou LB, Malawer MM. Analysis of surgical treatment of 33 foot and ankle tumors. Foot Ankle Int 1994;15(4):175–81. https://doi.org/10.1177/107110079401500404.

[27] Greenspan A, Jundt G, Remagen W. Differential diagnosis in orthopaedic oncology. second ed. Lippincott Williams & Wilkins; 2006.

[28] Gurkan V, Erdogan O. Foot and ankle osteoid osteomas. J Foot Ankle Surg 2018;57 (4):826–32. https://doi.org/10.1053/j.jfas.2017.11.019.

[29] Shukla S, Clarke AW, Saifuddin A. Imaging features of foot osteoid osteoma. Skelet Radiol 2010;39(7):683–9. https://doi.org/10.1007/s00256-009-0737-3.

[30] Temple HT, Mizel MS, Murphey MD, Sweet DE. Osteoblastoma of the foot and ankle. Foot Ankle Int 1998;19(10):698–704. https://doi.org/10.1177/107110079801901009.

[31] Singer AD, Datir A, Tresley J, Langley T, Clifford PD, Jose J, et al. Benign and malignant tumors of the foot and ankle. Skeletal Radiol 2016;45(3):287–305. https://doi.org/10.1007/s00256-015-2278-2.

[32] Minhas MS, Khan KM, Muzzammil M. Giant cell tumour of foot bones — 25 years experience in a tertiary care hospital. J Pak Med Assoc 2015;65(11):67–71. Jinnah Postgraduate Medical Centre, Pakistan.

[33] Aghaghazvini L, Sharifian H. Rasuli B, primary hyperparathyroidism misdiagnosed as giant cell bone tumor of maxillary sinus: a case report. Iran J Radiol 2016;13(1): e13260. https://doi.org/10.5812/iranjradiol.13260.

[34] Campanacci M. Bone and soft tissue tumors. Giant cell tumor. New York: Springer-Verlag; 1990. p. 117–51.

[35] Tsuneyoshi M, Dorfman HD, Bauer TW. Epithelioid hemangioendothelioma of bone: a clinicopathologic, ultrastructural, and immunohistochemical study. Am J Surg Pathol 1986;10(11):754–64. https://doi.org/10.1097/00000478-198611000-00002.

[36] Zhang H, Fu Y, Ye Z. Bone multicentric epithelioid hemangioendothelioma of the lower and upper extremities with pulmonary metastases: a case report. Oncol Lett 2015;9(5):2177–80. https://doi.org/10.3892/ol.2015.3018.

[37] Bisbinas I, Karabouta Z, Georgiannos D, Lampridis V, Badekas A. Multifocal epithelioid hemangioendothelioma of the foot and ankle: a case report. J Orthop Surg 2014;22(1):122–5. https://doi.org/10.1177/230949901402200130.

[38] Campanacci M. Classic osteosarcoma. Bone and Soft tissue tumors. New York: Springer-Verlag; 1990. p. 455–505.

[39] Unni KK. Dahlin's bone tumors: general aspects and data on 11,087 cases. 5th ed. Lippincott-Raven: Philadelphia; 1996. p. 143–96.

[40] Choong PFM, Qureshi AA, Sim FH, Unni KK. Osteosarcoma of the foot: a review of 52 patients at the Mayo Clinic. Acta Orthop Scand 1999;70(4):361–4. https://doi.org/10.3109/17453679908997825.

[41] Biscaglia R, Gasbarrini A, Böhling T, Bacchini P, Bertoni F, Picci P. Osteosarcoma of the bones of the foot — an easily misdiagnosed malignant tumor. Mayo Clin Proc 1998;73(9):842–7. https://doi.org/10.4065/73.9.842.

[42] Unni KK, Inwards CY, Bridge JA, Kindblom L, Wold LE. AFIP atlas of tumor pathology series 4, Tumors of the bones and joints. first ed. ARP Press; 2005. Silver Spring.

[43] Murphey MD, Senchak LT, Mambalam PK, Logie CI, Klassen-Fischer MK, Kransdorf MJ. From the radiologic pathology archives: Ewing sarcoma family of tumors: radiologic-pathologic correlation. RadioGraphics 2013;33(3):803–31. https://doi.org/10.1148/rg.333135005.

[44] Kilgore KB, Parrish WM. Calcaneal tumors and tumor-like conditions. Foot Ankle Clin 2005;10(3):541–65. https://doi.org/10.1016/j.fcl.2005.05.002.

[45] Ogose A, Unni KK, Swee RG, May GK, Rowland CM, Sim FH. Chondrosarcoma of small bones of the hands and feet. Cancer 1997;80(1):50–9.

[46] Patil S, de Silva C, Crossan J, Reid R. Chondrosarcoma of the Bones of the Feet. J Foot Ankle Surg 2003;42(5):290–5. https://doi.org/10.1016/S1067-2516(03)00306-5.

[47] Bartley J, Munroe SM, Ward RA. Fibrous dysplasia in the calcaneus. Foot Ankle Spec 2016;10(1):72–4. https://doi.org/10.1177/1938640016656237.

[48] Czerniak B, Dorfman HD. Fibroosseous lesions, Bone tumors. St Louis: Mosby; 1998. p. 441–77.

[49] Isefuku S, Hatori M, Ehara S, Hosaka M, Ito K, Kokubun S. Fibrous dysplasia arising from the calcaneus. Tohoku J Exp Med 1999;189(3):227–32. https://doi.org/10.1620/tjem.189.227.

[50] Valderrama FAF, Spain M, Matthews JM. The haemophilic pseudotumour or haemophilic subperiosteal haematoma. J Bone Joint Surg 1965;47:256–65.

[51] Gunning AJ. The surgery of hemophilic cysts. In: Biggs R, Macfarlane RG, editors. Treatment of haemophilia and other coagulation disorders. Oxford: Blackwell Science Ltd; 1966.

[52] Merchan ECR. The haemophilic pseudotumour. Int Orthop 1995;19:255–60. https://doi.org/10.1007/BF00185235.

[53] Abbott P. Mycetoma in the Sudan. Trans R Soc Trop Med Hyg 1956;50(1):11–23. https://doi.org/10.1016/0035-9203(56)90004-9.

[54] Abd El-Bagi ME, Fahal AH. Mycetoma revisited. Incidence of various radiographic signs. Saudi Med J 2009;30:529–33.

[55] Sarris I, Berendt AR, Athanasous N, Ostlere SJ. MRI of mycetoma of the foot: two cases demonstrating the dot-in-circle sign. Skeletal Radiol 2003;32(3):179–83. https://doi.org/10.1007/s00256-002-0600-2.

[56] Sen A, Pillay RS. Case report: dot-in-circle sign — an MRI and USG sign for "Madura foot". Indian J Radiol Imaging 2011;21(4):264–6. https://doi.org/10.4103/0971-3026.90684.

[57] Nora FE, Dahlin DC, Beabout JW. Bizarre parosteal osteochondromatous proliferations of the hands and feet. Am J Surg Pathol 1983;7(3):245–50. https://doi.org/10.1097/00000478-198304000-00003.

[58] Gruber G, Giessauf C, Leithner A, Zacherl M, Clar H, Bodo K. Bizarre parosteal osteochondromatous proliferation (Nora lesion): a report of 3 cases and a review of the literature. Can J Surg 2008;51(6):486–9.

[59] Torreggiani WC, Munk PL, Al-Ismail K, O'Connell JX, Nicolaou S, Lee MJ, et al. MR imaging features of bizarre parosteal osteochondromatous proliferation of bone (Nora's lesion). Eur J Radiol 2001;40(3):224–31. https://doi.org/10.1016/s0720-048x(01)00362-x.

[60] Meneses MF, Unni KK, Swee RG. Bizarre parosteal osteochondromatous proliferation of bone (Nora's lesion). Am J Surg Pathol 1993;17(7):691–7. https://doi.org/10.1097/00000478-199307000-00006.