



“Periosteum: An imaging review”

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ARTICLE INFO

Keywords:

Periosteum

Bone formation

Bone resorption and periosteal reaction

ABSTRACT

Periosteum is a fibrous sheath, coating the external bone, except in the articular surfaces, tendon insertions and sesamoid bone surface¹. It changes its aspects and characteristics with aging, becoming progressively less elastic and more firm. It is composed of two different layers: outer fibrous (firm, collagen-filled) and inner proliferative (cambium, containing osteoprogenitor cells)². Four vascular systems are responsible for the blood supply of the periosteum: the intrinsic periosteal system, located between fibrous and proliferative layer; the periosteocortical, the main nutritional arteries of the periosteum; the musculoperiosteal, responsible for the callus formation after fractures; the fascioperiosteal, specifically for each bone.³ It is crucial to bone formation and resorption, reacting to insults in the cortical bone, such as tumors, infections, traumas, medications and arthritic diseases. The aggressiveness of the reaction can be suggested by its radiological aspect and appearance⁴. The periosteum in children is looser compared to adults, resulting in earlier and more exuberant reactions. All these aspects will be detailed, so the essential information all radiologists need to know will be discussed.

1. Introduction

The periosteum is an important component of the bone growth, composing tissue unceasingly. This simplistic approach was refined into deeper knowledge of the periosteum-osteogenic capabilities, and its involvements in diseases. In this article, it will be discussed anatomically, histologically, radiologically – specifically the periosteal reaction patterns – all the main aspects every radiologists need to know about the periosteum.

2. Anatomy

The periosteum is a tissue of fibrous origin, composing a sheath, which coats the external surface of most bones, but is nonexistent in

articular surfaces, tendon insertions, or sesamoid bone surfaces [1–32, 31] (Fig. 1). Sharpey's fibers connect the periosteum to the bone, penetrating the entire cortex, and its directions are based in tension forces [1,2,5]. The greater the tension forces, the tighter are the junctions of tendons and bones. As an example, in long bones' diaphysis, the periosteum is approximately 2–3 mm, and can be separated from the bone. In metaphysis and epiphysis, however, it is extremely bonded.

Periosteum's structure changes with aging. In children's bone, it is firm, but elastic, allowing different biomechanical fractures, for example: subperiosteal or greenstick fractures, which disrupts or keeps intact one side of the periosteum. With aging, it loses elasticity, gains toughness, and becomes more innervated and vascularized [5]. The innervation is divided in two groups: vasomotor and sensory [6]. The first one regulates vessel tone based on the capillary blood flow. The

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<https://doi.org/10.1016/j.ejro.2020.100249>

Received 31 May 2020; Accepted 14 August 2020

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second is tightly present, explaining strong pain after periosteal injuries.

3. Microscopy

Periosteum is composed of two different layers: outer fibrous (firm, collagen-filled) and inner proliferative (cambium, containing osteoprogenitor cells) [7] (Table 1).

There are differences in periosteal anatomy and activity along the skeleton. Calvarial periosteum, for example, is regulated differently from the bones which are part of the axial skeleton. It is possible to see differences in periosteal layers in the same bone, as happens in young adults' femurs, where the femoral neck has considerably lower cellularity compared to the diaphyseal region [23]. Osteoblasts in periosteum are more mechanosensitive to strain than endosteal osteoblasts. Besides that, periosteal's osteoblasts are more susceptible to changes of parathyroid hormone levels, have greater levels of protein expression, such as periostin, and have more estrogen receptors [5,7,20].

4. Vascular supply

Four vascular systems are responsible for the blood supply of the periosteum [3,26,27].

The *intrinsic periosteal system* is located between fibrous layer and proliferative layer. It is formed from a net of longitudinal blood vessels running along the bone, circular vessels spiraling the bone, and short vessels without direction connecting both. The *periosteocortical (cortical capillary) anastomoses* are represented by small thin vessels which run longitudinally along the bone and are perpendicular to the main periosteal vessel. It is responsible for the nutritional arteries of the periosteum. When these vessels are close to the central portion of the outer third bone cortex, they anastomose with the medullar system, therefore the quantity of anastomoses increases from the diaphysis to the metaphysis. Another vascular system is the musculoperiosteal, which is surrounded by muscle and is mostly responsible for the callus formation after fractures, for example, and nutritive circulation in situations of insufficient intrinsic periosteal circulation. The last system is the nutritive periosteal or fascioperiosteal, which changes in each bone, because of different tendons and fascia insertions. It is represented by many small segmental arteries, and two veins for each artery. In the tibia, for example, this nutritive system has four distinct regions, connected at the capillary level [3,8,9].

5. Periosteal bone formation and resorption

As the length of the bone is increasing due to the coordinated process of endochondral ossification and physal-metaphyseal proliferation, osteoblasts from the inner periosteal layer (cambium) are causing radial growth by apposition of new bone, through the intramembranous bone formation [10]. The Haversian canals are periosteal vessels united and surrounded by bone or periosteal ridges during the intramembranous bone formation. Many factors are involved in bone formation, such as hormones (growth factor, insulin-like growth factor I, sex steroids, etc.), mechanical forces, nutrition and environmental elements (alcohol,

Table 1

Periosteum's microscopic layers and functions.

Fibrous Layer	Proliferative Layer (Cambium)
Grants elasticity and flexibility	Forms lamellar bone, growing in width Forms bone tissue after fracture

tobacco, medications), and others [11,21,22]. There are differences in bone thickness around the world, because of the genetic influences [10]. In females, after the menopause and the fall of estrogen levels, periosteal apposition decreases considerably, increasing bone fragility [20]. Besides that, males usually have greater bone diameter compared to females, although the cortical thickness is the same [12,32]. As a generalization, the bone grows wider, as it grows longer [29]. Recent studies suggest intramembranous bone formation may be active throughout life, although endochondral ossification stops in adulthood [10,24].

Periosteal resorption is still considered controversy [12,24,25]. However, periosteal resorption of the metaphysis sometimes follows longitudinal growth of many appendicular bones ("tapering"), creating a thinner diaphysis [13,30]. Strength during this process is sustained because of the cortical hardening due to endocortical bone apposition. It is unclear if the reduction of the bone diameter will necessarily diminish its resistance to fracture [14]. Besides, it is unknown the rate of periosteal remodeling and which factors influence it at critical skeletal sites, as vertebrae [15].

6. Periosteal reaction

As the name suggest, periosteum reacts to an insult in the cortical bone, such as tumors, infections, traumas, medications and arthritic diseases [4]. The aggressiveness of the reaction can be suggested by its radiological aspect and appearance [16]. The periosteum in children is looser compared to adults, resulting in earlier and more exuberant reactions.

Periosteal reaction is a non-specific radiographic finding that occurs with periosteal irritation. It can be divided in two groups: non-aggressive and aggressive. [17,18]

Non-aggressive periosteal reactions are slower, with enough time to organize the response. They are often presented as thin, solid, thick, irregular or septate reactions [16–18].

Aggressive periosteal reactions are, however, a consequence of fast bone deposition, in a short period of time, as in malignant tumors or in severe infections, for example; and are often laminated, with onion skin or spiculated, the latter being divided into perpendicular, sunburst or velvet [3,16].

Osteoma osteoid and consolidated fractures may present with a solid periosteal reaction, appearing as thin or thick sheets adjacent to the bone cortex. Laminated or onionskin periosteal reaction, however, can appear as multiple layers of new bone concentrically around the cortex, created by the modulation of fibroblasts and osteoblasts in the tissue. Another theory suggests that, as the insult lifts off the cortex, the inner proliferative layer, cambium, is stimulated to form a new bone layer. Sarcomas, osteomyelitis and chondroblastomas may present with laminated periosteal reaction [16].

An aggressive example of periosteal reaction is the spiculated, represented by two subtypes: the hair-on-end, which is characterized by new bone formed perpendicularly to the periosteal surface; and sunburst, with spicules of new bone radiating in a divergent standard to the cortex, not perpendicular [17,18]. The first one is typical to the Ewing's Sarcoma, while the second is more common in usual osteosarcomas [3, 16,17].

Codman triangle is a different kind of aggressive periosteal reaction, in which the periosteum is lifted off of the cortex at a bone extremity. It is usually seen in osteosarcomas, and seldom in infections and metastases [17,18].

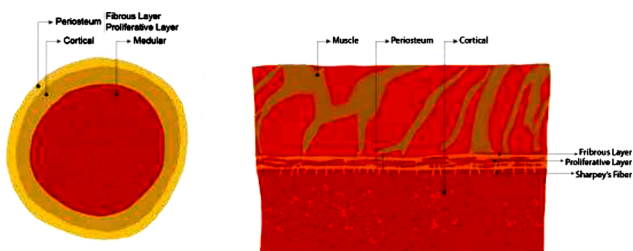


Fig. 1. Illustration demonstrates the usual aspect of the periosteum, coating the bone, and the Sharpey's fibers connecting it to the adjacent bone.

In a radiograph, periosteal reaction will only be seen posterior its mineralization, which usually happens one to three weeks after the beginning of the bone insult [18,19]. Computed tomography increases sensibility, when compared to radiograph, and is especially effective in cortical lesions with nidus. The main advantage of the magnetic resonance is the capacity to demonstrate non-mineralized periosteal reaction, and is more precise in determining the extension of local tumors [18]. If the periosteal reaction is diffuse, seen in different bones, a systemic process might be suggested [17].

7. Periosteal reaction: patterns

7.1. Solid-Compact

In this pattern, the reaction is localized, caused by a focal insult. Usually its form is elliptical and dense, resulting in cortical thickening or hyperostosis. It happens because of successive and gradual addition of compact bone to the surface, until merging layers. It suggests a chronic non-aggressive process, seen in osteoid osteoma, for example [17,18]. In Fig. 2 and in Fig. 3, we can see the merging layers, in a solid appearance, in a radiograph of a patient with osteoid osteoma.

7.2. Shell – eggshell

This pattern is characterized by a continuous (or almost continuous) reaction, in which the cortical bone is reabsorbed as the new periosteal is formed [17]. It is associated with cortex destruction, but also increasing bone width, because of the periosteal reaction. Shells are due to an active process that is sufficiently slow to allow the creation of periosteal appositions [18] (Fig. 4).

7.3. Lamellar (Unique)

A new bone layer is produced usually in response to inflammatory stress [18]. It is unique, usually thin, consequence of osteomyelitis, pulmonary osteoarthropaty, leukemia and osteosarcomas. When it is more thick, but still simple, it is more associated with active benign process, like stress fractures or osteomyelitis. Fig. 5 shows a radiograph of a patient who was diagnosed with osteomyelitis. It is possible to see a thin bone layer in the lateral aspect of the tibia, adjacent to an area of radiolucency.

7.4. Lamellar (multiple) – multilamellar – onionskin

In this pattern, a strong local reaction, usually due to inflammation,

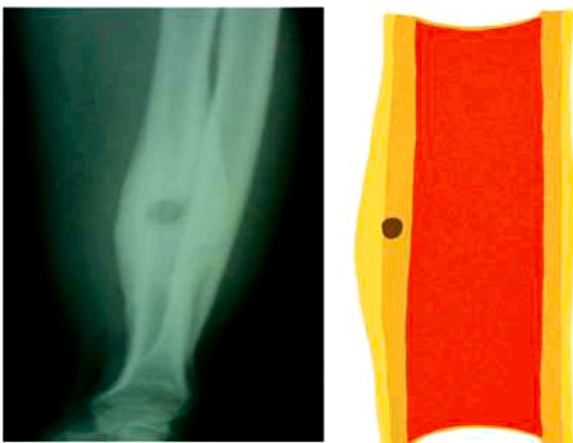


Fig. 2. Anterior-posterior radiograph of an adult radio demonstrates a solid periosteal reaction caused by an osteoid osteoma, and the following illustration representing the same pattern.

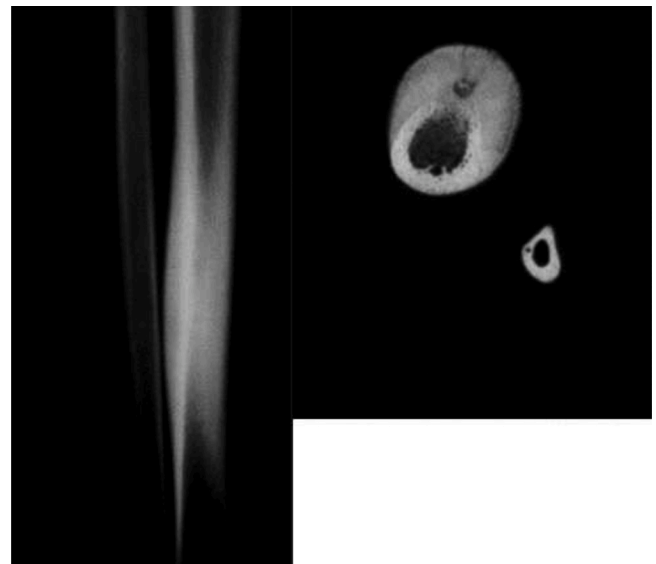


Fig. 3. Another case on osteoid osteoma in an adult patient. The first image is an amplified anterior-posterior radiograph of the tibia, showing the solid periosteal reaction in the bone's medial and anterior aspects. The following image is an axial slice of a computed tomography of the same patient, in which it is possible to see the focal round lucent osteoid osteoma's nidus, and the solid periosteal reaction around it. Case kindly provided by Dr. Armando de Abreu, Hospital Mãe de Deus, Porto Alegre, Brazil.

causes new bone deposition by means of multiple concentric layers in a loose conjunctive tissue [17]. Every bone layer that is removed from the cortex serves as stimulation for the proliferative layer (cambium) to form a newer one [18,19]. It is associated with variable aggressiveness, possibly caused by malignant or benign pathologies. Image shows radiolucent areas along the multiple layers of dense periosteal reaction. These lucent spaces may be occupied or not by tumors or inflammation. Fig. 6 demonstrates the image aspect of a multilamellar periosteal reaction in a radiograph.

Another patient diagnosed with Ewing Sarcoma (Fig. 7) is an example of the magnetic resonance aspect of the multilamellar periosteal reaction. In Fig. 8, we see a magnified image of a radiograph, demonstrating the multiple layers of periosteal reaction, of another patient with Langerhans Cell Histiocytosis.

7.5. Spiculate

This periosteal reaction pattern is seen in fast aggressive bone growth, frequently in malign pathologies, in which reaction process creates a new space where osteogenesis occurs perpendicular to the cortex. It is divided in three aspects: hair-on-end, sunburst and velvet [17,18].

Hair-on-end is characterized by spicules that are parallels to one another, and their height decreases gradually in both directions from the mid-zone of the reaction (Fig. 9). Sunburst, however, has a more complex, irregular and divergent distribution of the spicules, because of the rapid growth process (Fig. 10). In the velvet pattern, the spicules are short, focal, gently sloped, which gives it a more smooth appearance as seen in Fig. 11 [16–18].

7.6. Interrupted reactions

This periosteal reaction pattern is seen in aggressive bone lesions, frequently in malign pathologies. It is divided in two types: Buttress and and Codman's Triangle.

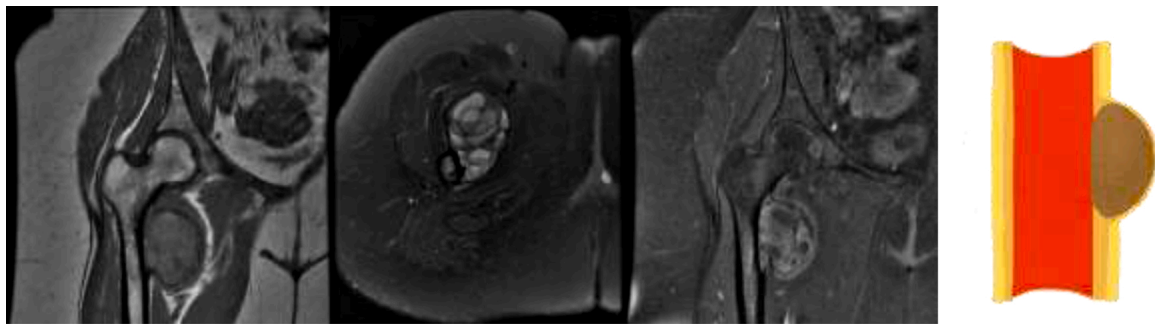


Fig. 4. Female patient presenting an Aneurysmal bone cyst in the right femur underwent magnetic resonance, which evidenced exofitic expansive formation arising from the bone cortex, with lobulated shape, as can be seen in a coronal T1 sequence, and liquid-liquid levels, better demonstrated in a axial T2 fat saturated image. It also showed heterogeneous post gadolinium contrast enhancement. Illustration shows the egg-shell pattern, which is associated with cortex destruction, and also increasing in bone width.



Fig. 5. Anterior-posterior radiography of an adult leg evidenced an area of radiolucency in the lateral aspect of the tibia. A periosteal lamellar reaction adjacent to it can be seen, and is better characterized in the amplified image on the right. Illustration shows the unique lamellar pattern. This patient was diagnosed with osteomyelitis.



Fig. 6. Patient with Ewing's sarcoma causing a multilamellar periosteal reaction in an onionskin pattern. Anterior-posterior radiograph of the right femur exhibits diaphysial radiolucent area with thin multilamellar periosteal reaction.

7.6.1. Buttress reaction

This periosteal reaction a solid-appearing wedge of reactive bone can be seen at the lateral extraosseous margin. It is usually associated with rapid aggressive lesions, which suddenly stops its progression in the bone cortex and there is no continual mineralization [18,28].

As an example, in Fig. 12, we see a patient with osteosarcoma in the femur, causing buttress periosteal reaction.

7.6.2. Codman's triangle

This is a characteristic aggressive periosteal interrupted reaction, frequently seen in osteosarcoma, osteomyelitis and hematomas [17–19]. It has a triangular shape, caused by a space between the neoplastic mass or blood, for example, and the periosteal thin line. In Fig. 13, a patient with malignant femoral fibrohistiocytoma shows the distinctive aspect of this periosteal reaction, in which the bone cortex is raised in one of the extremities of the lesion.

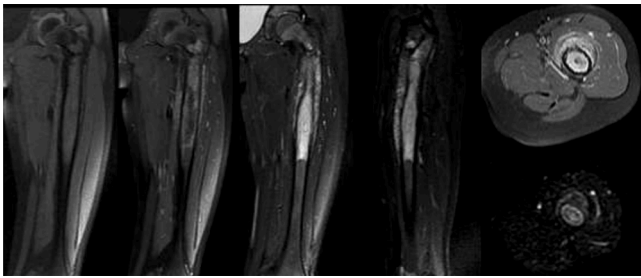


Fig. 7. In this case, a young adult presents with chronic pain in the left leg. Magnetic resonance demonstrates an important bone marrow edema, caused by a Ewing Sarcoma. It is possible to visualize the multiple layers of periosteum almost completely circulating the bone, especially in the axial images.



Fig. 8. Two magnified images of anterior-posterior femur radiographies in a patient diagnosed with Langerhans Cell Histiocytosis. It is possible to see the multiple layers in both medial and lateral aspects of the cortical bone.

8. Others

8.1. Periosteal elevation

This aspect is usually seen in benign process, frequently in



Fig. 9. Female patient diagnosed with osteosarcoma in the distal metaepiphysal portion of the femur. The new bone layer of this periosteal reaction develops perpendicular to the cortex and parallels to one another, in a *hair-on-end* aspect.

cranioencephalic traumas [18,19]. There is an elevation of the periosteum after blood, like in cephalohematomas, as seen in Fig. 14.

8.2. Saucerization

This process is usually seen in aggressive soft tissue lesions, which progressively affect the bone cortex, as an outside effect, causing bone remodeling, frequently as an excavation or a depression [17,18] (Fig. 15). It is a response to ease the straining induced in the bone cortex. Most of the cases will present as a scalloped depression in the cortex adjacent to a soft tissue lesion.

8.3. Periosteal alterations in multiple bones

If there is a systemic cause for periosteal reaction in multiple bones, it will probably present as a solid, compact, continuous pattern, affecting mainly long bones. Periostitis, for example, is described as new periosteal bone, normally presenting as smooth bilateral diaphyseal new layer. It is usually seen associated with drugs (Fig. 16) and multiple endocrinological disorders. Clinical features and information are essential to adequate diagnose, as it can be a discrete and affect multiple bones. Although rare, there is a disorder called primary hypertrophic osteoarthropathy, also denominated, paquidermoperiostitis, which causes lamellae periosteal neosteogenesis in multiple bones that gradually progresses throughout life, finally causing soft tissue swelling (Fig. 17). In both scenarios, it is important to notice the periosteal

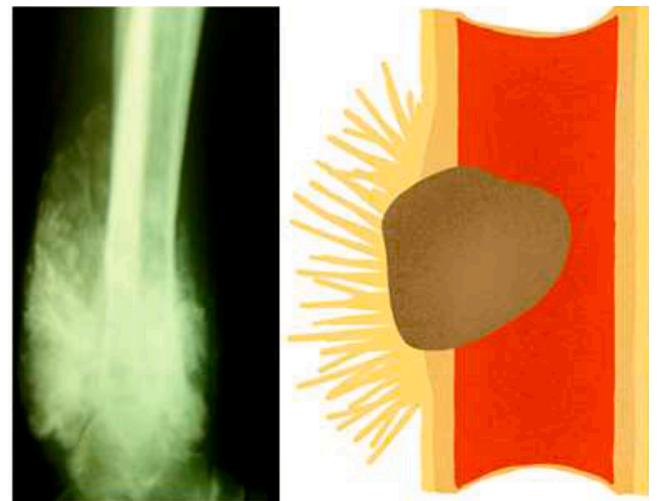


Fig. 10. Male patient diagnosed with osteosarcoma. In the lateral radiograph of the distal tibia, it is possible to see a completely involvement by a new bone layer, with divergent spicules, creating an aspect of *sunburst*.

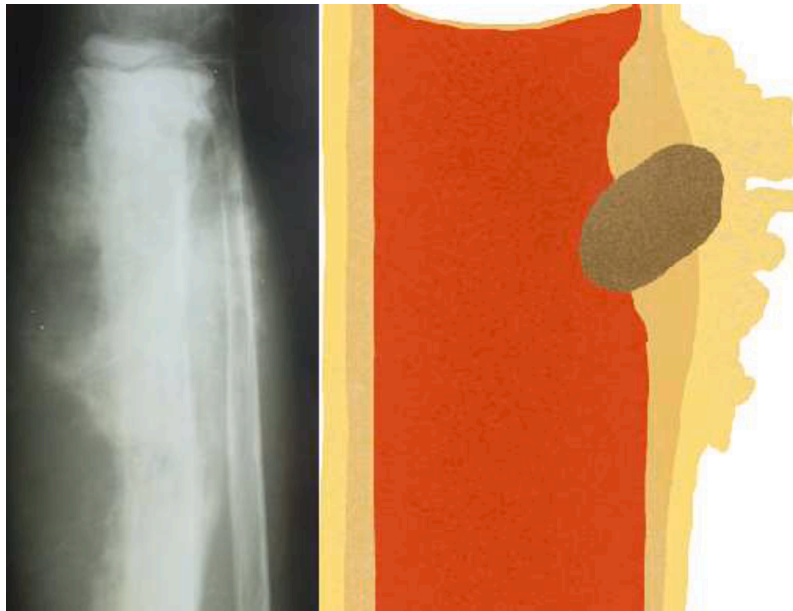


Fig. 11. Patient diagnosed with osteosarcoma. Adjacent to the bone cortex, a new layer of short spicules is created, involving the tibia. Illustration shows the periosteal reaction and its velvet aspect.



Fig. 12. Male patient diagnosed with osteosarcoma of the tibia. In the first lateral plain radiograph of the knee, it is possible to see the buttress periosteal reaction in the posterior aspect of the tibia, characterized by the elevated bone cortex and abrupt interruption of its progression close to the end of the epiphyses, followed by the illustration of the same periosteal reaction.

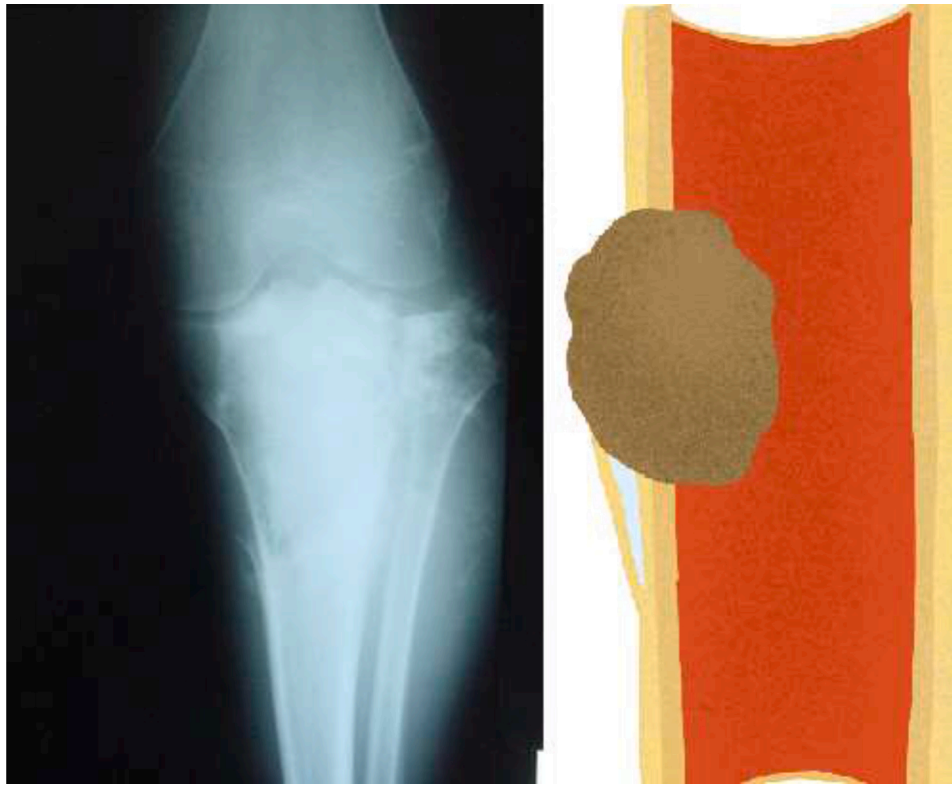


Fig. 13. Female patient with a malignant femoral fibrohistiocytoma. The first image, an anterior-posterior plain radiograph, it is possible to see the elevation of the bone cortex in the medial aspect of the tibia, affected by the soft tissue aggressive lesion, assuming a more triangular shape.

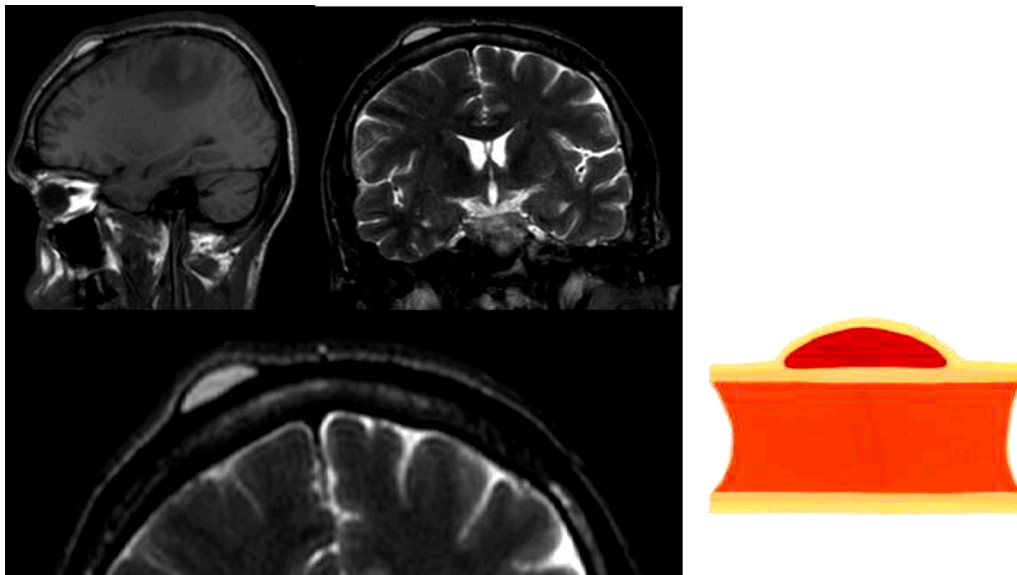


Fig. 14. Male patient suffered a cranium trauma. In the first image, a sagittal T1 magnetic resonance sequence, a small area of periosteal elevation is seen, probably caused by blood, in the frontal bone cortex. The second image, a coronal T2 magnetic resonance sequence, the same area is visualized. In the third, an amplified image of the coronal T2 sequence. The following illustration demonstrates the periosteal elevation caused by a liquid, as may happen in traumas.

alteration in multiple bones, frequently in a bilateral symmetric involvement.

9. Conclusion

This article focused on the essential knowledge every radiologist needs to dominate, including basic anatomy and histology concepts, regarding layers, vascular supply, bone formation and bone resorption.

As seen, a proper analysis of the periosteum and its reactions may suggest different diagnoses or determine aggressiveness. Plain radiograph, computed tomography and magnetic resonance play an important role in determining malignancy, shape, dimension and progression of the periosteal reaction, therefore improvement in radiologist cognition is necessary.

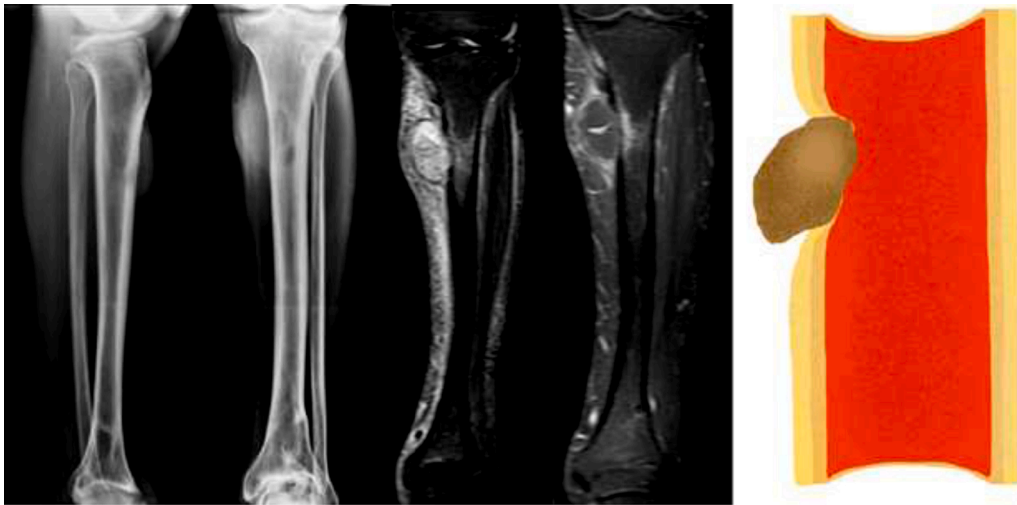


Fig. 15. Male patient diagnosed with fibrosarcoma. In the plain radiographs, it is possible to see a hyperdense area adjacent to the medial superior aspect of the tibia's diaphysis. In the coronal magnetic resonance images, however, the soft tissue lesion may be delimited, while the adjacent bone cortex is excavated, presenting with high signal in T1 sequences.



Fig. 16. Hand-periostitis associated with voriconazole used in a patient after pulmonary transplant. Two first images are before suspension of the medicinal product, and two last are with a month after pause of use. In the first two radiographs, it is possible to see an enlargement of the periosteum in phalanges and in metacarpals, more notably in the second index. The findings are reduced, although still present, in the last two radiographs.

Authorship

All listed authors meet the ICMJE criteria. We attest that all authors contributed significantly to the creation of this manuscript, each having fulfilled criteria as established by the ICMJE. We confirm that the order of authors listed in the manuscript has been approved by all named authors.

Funding

No funding was received for this work.

Intellectual property

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no

impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

Research ethics

We further confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

Declaration of Competing Interest

No conflict of interest exists.



Fig. 17. Male patient, 29 years old, with type 1 diabetes mellitus and multiple joint periosteal bone formation affecting knees, hands, elbows and shoulders. It is important to notice the bilateral symmetric involvement. Patient was later diagnosed with primary hypertrophic osteoarthropathy, also called, paquidermoperiostitis.

Acknowledgements

The authors would like to thank the architect and illustrator Hortênsia Gadelha Maia, who was the creator of all the insightful and careful illustrations seen in this article.

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