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Osteomyelitis Imaging: An Updated Overview for Radiologists

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Abstract:

Background: Osteomyelitis is a complex inflammatory disease of the bone and bone marrow, primarily caused by bacterial infections. It can result from hematogenous spread, direct inoculation, or contiguous spread from nearby infected tissues. The disease manifests in acute, subacute, and chronic forms, each with distinct clinical presentations and complications. Accurate diagnosis and management are critical to prevent severe outcomes such as bone destruction, systemic infection, and chronic pain. Imaging plays a pivotal role in the early detection and assessment of osteomyelitis, guiding both medical and surgical interventions.

Aim: This article aims to provide an updated overview of imaging modalities used in the diagnosis and management of osteomyelitis, highlighting their strengths, limitations, and clinical applications. It emphasizes the importance of integrating advanced imaging techniques with clinical evaluation to improve diagnostic accuracy and patient outcomes.

Methods: The review discusses various imaging techniques, including plain radiography, computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography (US), and nuclear medicine studies such as bone scintigraphy, gallium scanning, and 18F-FDG PET-CT. Each modality's role in detecting early and chronic osteomyelitis, assessing complications, and guiding treatment is evaluated. The article also explores the anatomical and pathophysiological basis of osteomyelitis, focusing on how imaging can visualize bone and soft tissue changes.

Results: Plain radiography, while useful for initial evaluation, often fails to detect early osteomyelitis. MRI is the most sensitive modality for early detection, particularly in identifying bone marrow edema and soft tissue involvement. CT is valuable for assessing bony destruction and chronic changes, while US is beneficial in pediatric cases and for guiding interventions. Nuclear medicine techniques, such as bone scintigraphy and 18F-FDG PET-CT, offer high sensitivity and specificity, especially in complex or multifocal cases. A combination of these imaging modalities, tailored to the clinical context, enhances diagnostic accuracy and guides effective treatment strategies.

Conclusion: Advanced imaging techniques have revolutionized the diagnosis and management of osteomyelitis. While each modality has its strengths and limitations, their integration into a structured diagnostic approach ensures timely and accurate diagnosis, reducing the risk of complications. Collaboration between clinicians and radiologists is essential for optimizing patient care and improving outcomes in osteomyelitis.

Keywords: Osteomyelitis, imaging, MRI, CT, nuclear medicine, bone scintigraphy, 18F-FDG PET-CT, ultrasonography, diagnosis, management.

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Introduction:

Osteomyelitis is a complex inflammatory disease of the bone and bone marrow that often results from an infection. While osteomyelitis can stem from a variety of causes, it is most commonly secondary to bacterial invasion. The infection may be introduced through direct inoculation, hematogenous spread, or contiguous spread from nearby infected soft tissues. The leading causative organisms include *Staphylococcus aureus*, *Streptococcus spp.*, and *Enterobacteriaceae*. In specific patient populations, particularly those with sickle cell disease, other pathogens such as *Salmonella spp.* and *Escherichia coli* may be more prevalent [1]. The pathogenesis of osteomyelitis varies between pediatric and adult populations. In children, the disease predominantly affects the long bones, typically through hematogenous spread, whereas in adults, the condition is more commonly attributed to non-hematogenous factors such as surgical procedures, trauma, or the presence of prosthetic devices. Additionally, individuals with diabetes, especially those experiencing compromised vascular function, are at a significantly higher risk of developing osteomyelitis [2]. Osteomyelitis can manifest in different clinical stages—acute, subacute, and chronic—each with distinct symptoms and implications for treatment. Acute osteomyelitis, which usually presents within two weeks of infection, is characterized by local symptoms such as erythema, edema, and warmth, as well as constitutional signs including fever and malaise. In pediatric patients, non-specific signs such as refusal to bear weight or restricted movement may be present. In contrast, subacute osteomyelitis manifests with mild pain and low-grade fever after the first two weeks. It can lead to septic arthritis if the infection spreads to the joint capsule, and a unique form of subacute osteomyelitis, the Brodie abscess, is characterized by a localized abscess in the metaphysis of long bones, filled with suppurative or granulation tissue [3].

Chronic osteomyelitis arises when the acute infection is inadequately managed or becomes resistant to standard treatments. It is typically associated with persistent symptoms, including pain, edema, and erythema, although fever is less common. The hallmark of chronic osteomyelitis is the presence of necrotic bone (sequestrum), surrounded by reactive bone formation (involucrum) and possible bone loss. In some cases, the infection may extend through cortical bone to form sinus tracts [4]. Chronic recurrent multifocal osteomyelitis (CRMO) is distinct from infectious osteomyelitis and represents an autoinflammatory disorder that primarily affects children. Unlike osteomyelitis, CRMO is not caused by an infection but by a malfunctioning immune response that targets the bone. This condition is characterized by recurrent episodes of bone pain, swelling, and tenderness, often involving multiple skeletal sites such as the long bones, clavicles, and vertebrae. While systemic symptoms such as fever and weight loss are usually absent, diagnosis can be challenging due to the intermittent and nonspecific nature of symptoms. Advanced imaging techniques, particularly magnetic resonance imaging (MRI), are essential for detecting the bone marrow edema and inflammatory patterns typical of CRMO and distinguishing it from other bone pathologies, including metastases [5].

The adult counterpart to CRMO is SAPHO syndrome, which encompasses a combination of synovitis, acne, pustulosis, hyperostosis, and osteitis. Patients with SAPHO syndrome exhibit a higher prevalence of skin manifestations, particularly palmoplantar pustulosis, compared to those with CRMO. The bony lesions in SAPHO syndrome tend to affect the chest wall and pelvis, in contrast to the long bones typically involved in CRMO. The differences in bone involvement are thought to arise from age-related changes in skeletal development, with children's open growth plates increasing susceptibility to metaphyseal lesions. Furthermore, SAPHO syndrome commonly affects the sternoclavicular and sternocostal joints, a feature not

observed in CRMO [6][7]. Accurate diagnosis of osteomyelitis requires a comprehensive approach, combining clinical evaluation, laboratory investigations, and advanced imaging techniques. Imaging modalities such as x-rays, computed tomography (CT), and magnetic resonance imaging (MRI) are invaluable in detecting both early and chronic changes associated with osteomyelitis. In addition, nuclear medicine studies, including bone scintigraphy, gallium scanning, and 18F-fluorodeoxyglucose positron emission tomography-computed tomography (18F-FDG PET-CT), play a crucial role in assessing the extent of infection, guiding therapeutic strategies, and evaluating disease complications [8].

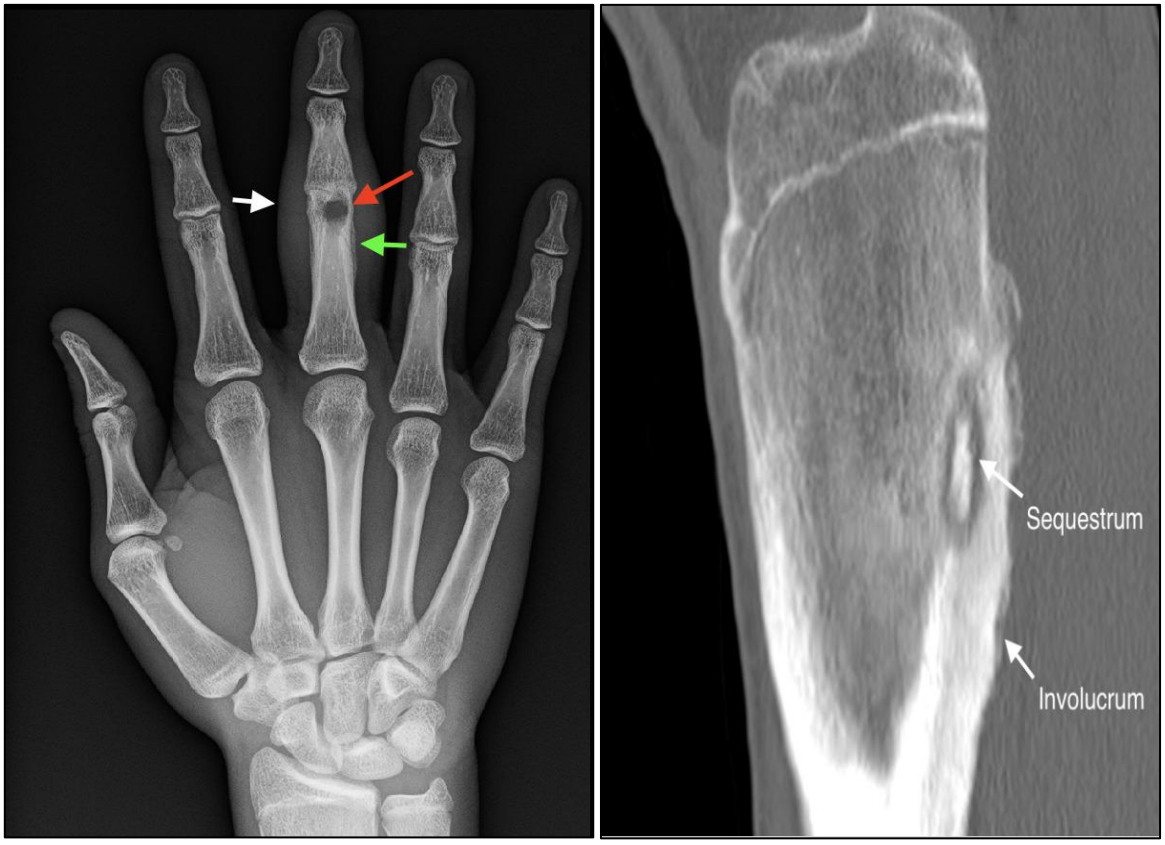

Figure 1: Acute Osteomyelitis.

Pathogenesis of Osteomyelitis

Osteomyelitis occurs when microorganisms, typically bacteria, invade the bone tissue, leading to inflammation. The pathogenesis varies depending on the mode of infection. Hematogenous spread, which is more common in pediatric patients, involves bacteria being carried to the bone via the bloodstream from a distant site of infection. The infection generally affects the metaphysis of long bones, as this region has a rich blood supply with slower blood flow, making it more susceptible to bacterial colonization. On the other hand, non-hematogenous osteomyelitis typically arises from direct inoculation during trauma, surgery, or the presence of foreign materials like prosthetic devices, which may serve as a nidus for infection. The inflammatory response in osteomyelitis is characterized by the release of cytokines and other inflammatory mediators that lead to the recruitment of neutrophils and macrophages. This results in localized bone destruction, abscess formation, and the formation of sequestra in chronic cases. The surrounding bone tissue undergoes sclerosis as part of the body's attempt to wall off the infection [9].

Diagnosis and Imaging

Diagnosing osteomyelitis is complex and relies heavily on a combination of clinical features and imaging studies. Radiographic findings may include bone destruction, periosteal elevation, and soft tissue swelling, although these changes may not appear until late in the disease process. MRI is particularly sensitive in detecting early changes in bone marrow and soft tissue involvement, including edema, which is

characteristic of osteomyelitis. MRI also provides superior soft tissue contrast, making it a valuable tool for assessing complications such as abscesses or septic arthritis. CT scans can be useful for evaluating cortical bone involvement and detecting sequestra in chronic cases. Nuclear medicine imaging, including bone scintigraphy, gallium scanning, and 18F-FDG PET-CT, are increasingly employed to assess the extent of infection, identify areas of active disease, and monitor treatment response. Bone scintigraphy is highly sensitive for detecting osteomyelitis but lacks specificity, while 18F-FDG PET-CT offers the advantage of being both sensitive and specific, providing detailed information about metabolic activity and anatomical location of infection [8].

Management of Osteomyelitis

The management of osteomyelitis involves a combination of surgical and medical interventions. Surgical debridement is often required to remove necrotic bone and drain abscesses, particularly in chronic cases. In some situations, the removal of foreign material, such as prosthetic joints or plates, may be necessary. Antibiotic therapy is the cornerstone of treatment, with the choice of antibiotics being guided by the likely causative organisms, the results of culture and sensitivity testing, and patient-specific factors such as underlying comorbidities. In acute osteomyelitis, intravenous antibiotics are typically administered for several weeks, followed by oral antibiotics to complete the treatment course. Chronic osteomyelitis often requires prolonged antibiotic therapy, with frequent monitoring to assess treatment efficacy. In cases of chronic or recurrent infection, adjunctive therapies such as hyperbaric oxygen therapy may be considered [10]. Osteomyelitis remains a challenging clinical condition that requires prompt recognition and treatment to prevent severe complications. Advances in diagnostic imaging and antibiotic therapies have significantly improved the outcomes for patients with this condition. However, ongoing research into its pathogenesis, optimal treatment regimens, and long-term management strategies is necessary to further enhance the care of patients affected by osteomyelitis. By leveraging the full range of diagnostic and therapeutic options, clinicians can improve outcomes and minimize the morbidity associated with this potentially devastating disease.

Anatomy

Bone is a highly specialized and dynamic organ that plays a crucial role in the body's structure, support, and function. It is composed of two distinct types of tissue: cortical bone (compact bone) and trabecular bone (spongy bone), each serving specific functions that contribute to the overall integrity and performance of the skeletal system. Cortical bone forms the outer, dense layer of the bone, offering strength and protection, while trabecular bone, found within the inner portions of the bone, consists of a network of interconnected trabeculae, contributing to the bone's flexibility, weight reduction, and shock absorption capacity [9]. Within the bone lies the medullary cavity, a central space primarily filled with bone marrow. The bone marrow serves as the site of hematopoiesis, where blood cells are produced. It also contains hematopoietic stem cells that are vital for blood cell regeneration. The marrow is crucial to the bone's function in both the immune systems and circulatory systems. In the context of osteomyelitis, bacteria may infiltrate the medullary cavity, leading to infection and inflammation. This can result in the destruction of bone tissue and a compromised marrow environment, thus affecting overall hematopoietic function [10]. The bones are supplied with nutrients and oxygen through an extensive vascular network. This vascular supply is primarily delivered by arteries that penetrate the bone through small openings known as nutrient foramina. These arteries then branch and anastomose within the bone, forming a network that ensures proper nourishment of the bone tissue. In osteomyelitis, the infection can severely disrupt this blood supply, leading to ischemia and necrosis of the bone. This impairment of blood flow is one of the hallmarks of acute osteomyelitis, as it promotes further infection and hinders the healing process. The compromised blood flow also makes it challenging for the body's immune response to reach the affected area, further exacerbating the condition [11]. In addition to the bone itself, various adjacent soft tissues are involved in the pathophysiology of osteomyelitis. The periosteum, a dense fibrous membrane that covers the external surface of the bone, plays a vital role in the inflammatory response. In osteomyelitis, the periosteum becomes inflamed, contributing to the spread of infection and additional complications. As the infection progresses, it can extend into the surrounding muscles, tendons, and ligaments. These soft tissues are often

involved in the inflammatory cascade and can become infected, leading to further complications such as soft tissue abscesses, joint involvement, and septic arthritis [12].

Understanding the anatomical structure and function of bone and its associated tissues is critical for healthcare professionals in diagnosing and managing osteomyelitis effectively. Imaging modalities like plain radiography, computed tomography (CT), and magnetic resonance imaging (MRI) are pivotal in visualizing the bony structural changes, soft tissue involvement, and the extent of infection in osteomyelitis. Radiography can detect early bone changes, while CT and MRI offer more detailed views of the infection's spread and its effect on surrounding tissues. MRI, in particular, is valuable for evaluating bone marrow edema and soft tissue involvement, making it an essential tool for diagnosing acute and chronic osteomyelitis. In many cases, surgical intervention is required to treat osteomyelitis effectively. Procedures such as drainage and debridement are necessary to remove infected tissue and promote healing. In chronic cases, the surgical removal of necrotic bone may be needed to restore function and prevent the infection from spreading further. Alongside surgical intervention, antibiotic therapy plays a crucial role in eradicating the bacterial infection. The choice of antibiotics is typically based on the causative organisms identified through cultures, ensuring targeted and effective treatment to prevent further spread of infection [13]. Thus, a comprehensive understanding of the anatomy of bone and its vasculature, as well as the adjacent soft tissues, is fundamental for both diagnosing and treating osteomyelitis. Through the use of advanced imaging techniques and a multi-disciplinary approach, clinicians can make informed decisions, manage infections effectively, and improve patient outcomes.

Plain Films

Plain radiography, or standard X-ray, remains the primary imaging technique for the initial evaluation of suspected osteomyelitis. Its widespread availability, cost-effectiveness, and ability to detect gross osseous changes make it a crucial first step in diagnosing bone infections. Though it is not always the most sensitive method for detecting early osteomyelitis, it provides valuable insights into the integrity of the bone and can guide further diagnostic decisions. In the early stages of osteomyelitis, radiographic findings are often subtle and primarily involve adjacent soft tissues. Initial signs may include soft tissue swelling, which may or may not be accompanied by displacement or blurring of the normal soft tissue planes. Bone changes, however, tend to become visible only 10 to 14 days after the infection has begun. At this stage, radiographs may reveal decreased bone mineralization, indicative of bone loss or infection, as well as a periosteal reaction, which appears as new bone formation along the periosteal surface. Other potential findings include focal resorption of the inner cortical layer, lytic lesions, and the formation of new bone in response to the infection [14][15]. Additionally, the presence of gas in the soft tissues, which can occur when gas-forming organisms infect the bone, is another suggestive radiographic feature of osteomyelitis. In cases of chronic osteomyelitis, plain radiographs can show more characteristic changes. The bone may appear thickened and irregular, with signs of sclerosis, reflecting ongoing bone remodeling in response to the infection. Periosteal reactions may also be visible, typically presenting as non-aggressive thickening. The hallmark of chronic osteomyelitis is the presence of a sequestrum, which appears on radiographs as a focal sclerotic lesion surrounded by a radiolucent border. This border represents the area of necrotic bone that has become isolated from the healthy bone. Adjacent to the sequestrum, an involucrum—an area of new bone formation—may be visible, forming an irregular cortical thickening. In advanced cases, a cloaca may be identified on radiographs, which represents a lucent gap in the cortical bone through which infected material, such as pus, can drain into surrounding soft tissues, reflecting a more severe, long-standing infection [8]. A unique radiographic feature of subacute osteomyelitis is the Brodie abscess. This type of abscess typically occurs in the metaphysis of long bones, particularly the tibia. On plain radiographs, a Brodie abscess presents as an oval-shaped lesion with decreased density, often appearing as a lucent region within the bone. This lesion is surrounded by a dense rim of reactive sclerosis, which serves as a protective response to the infection. The lesion’s alignment along the longitudinal axis of the bone helps distinguish it from other conditions, making it a key diagnostic feature of subacute osteomyelitis [16].

Although plain radiographs are helpful for identifying many features of osteomyelitis, they are limited in detecting early-stage infection, particularly when bone changes are minimal. In these instances, alternative

imaging modalities such as magnetic resonance imaging (MRI) and bone scintigraphy are more sensitive and offer better resolution for early diagnosis. MRI, in particular, can detect soft tissue changes and bone marrow involvement much earlier than plain radiographs, providing more detailed information on the extent of infection. Bone scintigraphy, another highly sensitive technique, can detect the inflammatory response in bone tissue before structural changes become apparent on radiographs. As a result, the combination of plain radiography with more advanced imaging techniques has become standard practice for diagnosing osteomyelitis and assessing its severity [14]. In addition to diagnosing osteomyelitis, plain radiography can also be useful in ruling out other conditions that may mimic osteomyelitis, such as stress fractures. Stress fractures can sometimes be challenging to detect in the early stages, as they appear as small, linear lucencies with peripheral sclerosis. Plain radiography can identify these fractures, allowing clinicians to differentiate between them and osteomyelitis, which may present with more complex, infection-related changes [15]. In summary, while plain radiography remains a vital tool in the diagnosis of osteomyelitis, its limitations in detecting early-stage infection necessitate the use of more advanced imaging methods such as MRI and bone scintigraphy. Plain films, however, remain invaluable for detecting later-stage signs of osteomyelitis, such as sequestra, involucrum, and Brodie abscesses, and are essential in the initial assessment of patients suspected of having osteomyelitis.

Computed Tomography

Computed tomography (CT) is an important imaging tool for evaluating osteomyelitis, providing detailed, high-resolution cross-sectional images of bone and adjacent structures. The ability of CT to generate multiplanar reconstructions from axial images into coronal and sagittal planes makes it an invaluable resource for detecting subtle bony changes, which can be critical in managing osteomyelitis. Although CT is not typically the first-line imaging modality for diagnosing osteomyelitis, it offers specific advantages, especially in chronic cases where pathophysiologic and morphologic changes are more pronounced [17]. One of the major strengths of CT in osteomyelitis evaluation is its superior resolution for visualizing bone structures. This makes CT particularly effective for detecting intraosseous gas, sequestra, cloacae, and involucrum, all of which are hallmark features of chronic osteomyelitis. In chronic cases, CT can clearly depict sequestra—areas of necrotic bone isolated by an infected environment—surrounded by an involucrum, a layer of new bone formation that tries to encase and contain the infection. Additionally, CT imaging can identify cloacae, which are lucent areas in the cortical bone that provide a drainage pathway for infected material to the soft tissues surrounding the bone. These features are less clearly visible on other imaging modalities, making CT an essential tool for evaluating the extent of chronic osteomyelitis and helping guide treatment decisions, such as the need for surgical debridement or drainage [17]. CT also plays a crucial role in guiding procedures like needle biopsies and joint aspirations, particularly in cases of vertebral osteomyelitis. The ability to precisely target the area of infection is invaluable for obtaining tissue samples or aspirating infected material for microbiological analysis. Contrast-enhanced CT can further enhance the ability to detect sinus tracts—pathways that extend from the infected bone through the soft tissues to the skin—by providing better contrast between the infected tissues and normal structures [14]. Despite its advantages, CT has certain limitations in the assessment of osteomyelitis. While CT excels at visualizing bony changes, it is less effective in detecting soft tissue involvement, such as bone marrow edema or soft tissue swelling, which are early signs of osteomyelitis. Soft tissue changes, critical for early diagnosis and management, are more clearly identified with magnetic resonance imaging (MRI). MRI provides superior contrast resolution, allowing for better delineation of bone marrow edema, abscesses, and fluid collections within soft tissues, which are essential indicators of infection in its initial stages. As a result, MRI remains the imaging modality of choice for early osteomyelitis diagnosis, while CT is reserved for cases where detailed bony evaluation is necessary or when MRI is contraindicated [8].

Another limitation of CT is its reliance on ionizing radiation, which is a significant concern, particularly in pediatric patients or when multiple imaging studies are required. The risk of radiation exposure must be weighed carefully, especially when alternative non-ionizing imaging techniques like MRI or ultrasound could provide sufficient diagnostic information. Additionally, the presence of metals in or near the region of interest can cause beam-hardening artifacts, which degrade the quality of CT images. These artifacts can

obscure important diagnostic details, such as the extent of bone destruction or soft tissue involvement. In cases where metal implants, prostheses, or other foreign materials are present, this limitation can complicate the diagnostic process [8]. Moreover, certain conditions, such as obesity or challenging anatomical locations, may limit the effectiveness of CT, as thick body tissues can hinder the ability to capture clear images. The use of contrast-enhanced CT can sometimes mitigate these issues, but it also introduces additional risks, such as allergic reactions or renal complications, particularly in patients with pre-existing kidney disease. In conclusion, while CT is an excellent tool for visualizing the bony manifestations of osteomyelitis, particularly in chronic cases, its limitations in assessing soft tissue changes and its potential risks due to radiation exposure must be carefully considered. It is most useful when combined with other imaging modalities like MRI and bone scintigraphy, which can offer complementary insights into the soft tissue involvement and early signs of infection. In clinical practice, CT remains an essential imaging modality in specific situations, such as assessing advanced bone destruction, guiding biopsies, or evaluating complex anatomical regions like the spine or pelvis, where other imaging methods might be less effective.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) has become a cornerstone in the diagnosis and evaluation of osteomyelitis, particularly due to its outstanding soft tissue contrast resolution. MRI provides highly detailed, multiplanar imaging of both the affected bone and surrounding soft tissues, allowing for the accurate assessment of both the early and advanced stages of the infection. Over the past two decades, the improvements in MRI technology have significantly advanced our ability to diagnose osteomyelitis more efficiently and with greater accuracy compared to traditional methods [18]. One of the key advantages of MRI in diagnosing osteomyelitis is its ability to detect early inflammatory changes, such as edema and abscess formation, in both bone and surrounding soft tissues. MRI excels in visualizing bone marrow edema, which is one of the earliest indicators of osteomyelitis. This edema can be observed as soon as 1 to 2 days after the onset of infection, significantly earlier than the 10 to 14 days required for these changes to appear on plain radiographs. On MRI, bone marrow normally exhibits high signal intensity on T1-weighted images due to the fat content. However, in osteomyelitis, the bone marrow becomes infiltrated with fluid and pus, leading to a low T1 signal and a high signal on fluid-sensitive sequences such as short tau inversion recovery (STIR) and post-contrast images [8]. This change in signal intensity provides a direct indication of infection, helping to expedite diagnosis and treatment.

MRI is particularly valuable in assessing the extent of bone marrow involvement and identifying soft tissue complications such as cellulitis, abscesses, and other deep tissue infections. The high resolution of MRI also allows for a direct comparison between the affected area and the contralateral extremity, which can help clarify the extent of changes and improve diagnostic accuracy [19]. In chronic osteomyelitis, MRI is essential for evaluating the spread of infection and identifying specific features associated with advanced disease, such as sequestra, sinus tracts, and abscesses. Sequestra, which are necrotic bone fragments, appear as areas of low signal intensity across all MRI sequences, including T1, T2, and STIR. These areas do not enhance following contrast administration. MRI is also highly effective in visualizing abscesses and sinus tracts. Abscesses typically show peripheral enhancement after contrast injection, with the center remaining hypointense due to the presence of pus. This pattern, known as the "penumbra sign," is useful in distinguishing abscesses from phlegmons, which are more solid and homogeneously enhancing masses without a well-defined outer wall. This distinction is important for clinical management, as abscesses usually require surgical drainage, while phlegmons can often be managed with antibiotics [8][20][21]. MRI is also valuable for detecting chronic inflammatory changes like thickened periosteum, which may indicate ongoing infection, and for identifying the presence of cloacae, which are defects in the cortical bone allowing pus to drain from the bone to the surrounding tissues. These cloacae are easily detected with fluid-sensitive MRI sequences, where the pus within the defect appears as a high signal intensity area [8].

Additionally, MRI can be instrumental in diagnosing conditions like Chronic Recurrent Multifocal Osteomyelitis (CRMO), where plain radiographs might be inconclusive. If clinical symptoms and initial imaging suggest CRMO, whole-body MRI can be employed to detect potentially asymptomatic multifocal lesions, making it a more comprehensive tool than traditional bone scintigraphy [7]. Despite its many

benefits, MRI does have certain limitations. One of the primary challenges is the presence of contraindications. MRI is not feasible for patients with certain metallic implants, such as permanent cardiac pacemakers or intracranial aneurysm coils, as these can interfere with the magnetic field. While advances in MRI technology have improved the ability to mitigate metallic artifacts, patients with metallic prostheses may still experience reduced image quality. Additionally, MRI can be costly and may not be readily accessible in all healthcare settings, which can limit its use in certain regions. For pediatric patients or those who are unable to remain still during the procedure, sedation or general anesthesia may be required, which introduces additional risks and considerations [19]. In conclusion, MRI offers unparalleled advantages in the diagnosis and management of osteomyelitis. Its ability to detect early signs of infection, evaluate the spread of disease, and identify complications such as abscesses, sequestra, and cloacae makes it a crucial imaging modality in both acute and chronic osteomyelitis. Despite its limitations, such as contraindications and high costs, the benefits of MRI in providing a detailed and accurate assessment of osteomyelitis often outweigh these challenges. It remains the imaging modality of choice for evaluating the extent of infection, guiding treatment decisions, and monitoring patient progress.

Ultrasonography

Ultrasonography (US) is not typically the primary imaging modality used to diagnose osteomyelitis, especially in adults, due to its limitations in assessing bony structures. The significant difference in acoustic impedance between bone and soft tissue causes a large portion of the ultrasound wave to reflect back at the bone-soft tissue interface, leading to acoustic shadowing. This phenomenon makes it difficult to visualize structures located behind the bone, thus limiting US in evaluating the underlying bone directly [22]. However, despite these limitations, the US can still provide valuable insights into soft tissue changes and complications associated with osteomyelitis. In pediatric patients, ultrasonography has higher sensitivity for diagnosing acute osteomyelitis, especially due to the pronounced periosteal reaction in children. In the immature skeleton, the periosteum is more loosely attached to the underlying bone, making it more visible on ultrasound. The periosteum in children appears thicker and more distinct compared to the barely noticeable hypoechoic band seen in adults [23]. This increased visibility allows US to detect early changes such as periosteal thickening, which is often one of the first signs of osteomyelitis. The initial signs of osteomyelitis on ultrasonography include juxtacortical soft tissue swelling, which appears as increased echogenicity in the subcutaneous fat. This change may result in the loss of distinction between the fat and dermis. Additionally, color Doppler imaging can highlight increased vascular flow in the affected tissues, providing further indication of inflammation [24]. These findings are valuable in early-stage osteomyelitis, where other imaging modalities like plain radiographs might not yet show significant changes.

As the infection progresses, the US may reveal more definitive signs such as periosteal elevation with underlying subperiosteal fluid collections. These fluid collections appear near the echogenic cortex and should raise suspicion for osteomyelitis. Such subperiosteal collections typically develop 4 to 6 days after the onset of symptoms and can evolve into a subperiosteal abscess. US offers a unique advantage in allowing sequential measurements of these abscesses, which can be helpful in monitoring the progression of the disease and guiding treatment, especially in cases where there is poor response to therapy [25][26]. Another significant advantage of ultrasonography is its ability to guide percutaneous interventions such as aspiration or drainage. In cases where a subperiosteal abscess is identified, US can assist in precisely locating and draining the abscess, which is particularly beneficial for children or other patients who may require frequent follow-up imaging. The real-time imaging capabilities of US, along with its portability and lack of ionizing radiation, make it an invaluable tool in certain clinical scenarios, especially for monitoring treatment response and guiding intervention [27]. Despite its usefulness in detecting soft tissue changes and guiding interventions, a normal ultrasonographic examination does not entirely rule out osteomyelitis. Given that US has limitations in evaluating bone changes, further imaging, such as MRI, is recommended if osteomyelitis is still suspected based on clinical presentation or other diagnostic findings [8]. Therefore, while US plays a useful supplementary role, it should be seen as part of a broader diagnostic strategy that includes more definitive imaging techniques like MRI to confirm the diagnosis of osteomyelitis.

Nuclear Medicine in Diagnosing Osteomyelitis

Bone scintigraphy, a cornerstone of nuclear medicine, has been instrumental in the diagnosis of osteomyelitis since 1975. Pioneering studies, including those by Duszynski et al., demonstrated the capability of bone scans to detect osteomyelitis even before radiographic abnormalities were visible, revolutionizing early detection in clinical settings. This early work laid the foundation for further advancements, such as the introduction of blood-pool imaging by Gilday et al., which led to the development of the modern three-phase bone scan. In addition, Deysine et al. explored the use of gallium-67 scans to study chronic and postoperative osteomyelitis, further refining the utility of nuclear medicine in the diagnosis of bone infections [17][28][29][30]. Nuclear imaging techniques remain invaluable in evaluating suspected osteomyelitis, particularly when other imaging methods, such as MRI or CT, are contraindicated or impractical due to factors like metallic interference. Nuclear medicine modalities such as 18F-FDG PET-CT, single-photon emission computed tomography (SPECT), and gamma cameras have gained increasing use in detecting and assessing osteomyelitis. These imaging methods, which rely on radiotracers, can provide precise localization of infection and inflammation within the bone and surrounding tissues. Radiotracers may be used independently or combined with other molecules targeting areas of infection. Some common examples include 99mTc, Indium 111 (111In), and F-18 [18F]. Tracers may be attached to leukocytes, phosphonates, or glucose analogs such as [18F]-fludeoxyglucose ([18F]-FDG), depending on the specific requirements of the clinical scenario [31][32].

Advantages of Nuclear Medicine in Osteomyelitis Diagnosis

Nuclear medicine techniques are highly sensitive in detecting inflammatory processes, particularly in cases of acute infection. In fact, these methods are often more reliable in diagnosing acute infections than chronic conditions. However, nuclear imaging has some limitations, most notably in distinguishing between osteomyelitis and other conditions that may cause similar patterns of bone turnover or soft tissue inflammation. Conditions such as recent trauma, degenerative joint disease, bone tumors, and septic arthritis can mimic osteomyelitis on nuclear imaging, which complicates the interpretation in certain clinical settings [33][34][35][36]. Therefore, while nuclear medicine plays a critical role in diagnosing osteomyelitis, it is essential to integrate these findings with clinical evaluations and other imaging modalities to ensure accurate diagnosis.

Common Nuclear Medicine Techniques for Diagnosing Osteomyelitis

[99mTc]-MDP Bone Scintigraphy

Bone scintigraphy is commonly performed using [99mTc]-methylene diphosphonate ([99mTc]-MDP) as the radiotracer. [99mTc]-MDP binds to hydroxyapatite crystals in the bone, with its uptake being dependent on blood flow and the rate of new bone formation. When osteomyelitis is suspected, a three-phase bone scan is typically conducted to assess the affected area.

The three-phase bone scan includes three stages:

1. **Flow phase (dynamic imaging):** This phase captures real-time blood flow to the bone.

2. **Blood pool or soft tissue phase:** This static imaging phase provides information on blood flow and soft tissue inflammation.

3. **Bone phase:** Conducted 2 to 4 hours after tracer injection, this phase shows the bone's response to infection and inflammation.

Key findings on the three-phase scan that suggest osteomyelitis include focal hyperperfusion, focal hyperemia, and increased bony uptake. The increased perfusion observed in the initial stages reflects enhanced blood flow to the site of infection, while increased bone uptake in the delayed phase indicates ongoing bone involvement in the infection [39]. The three-phase bone scan is highly sensitive and specific in detecting osteomyelitis in bones unaffected by other conditions. However, its specificity may be reduced

when preexisting conditions like degenerative joint disease or orthopedic hardware are present, as these factors may contribute to new bone formation, which complicates interpretation [41].

Gallium 67 Bone Scintigraphy

Gallium-67 scanning, another technique employed in nuclear medicine, uses radioactive gallium that binds to transferrin. In an inflammatory state—such as infection or malignancy—transferrin extravasates from the bloodstream into the inflamed tissues. Once bound to transferrin, gallium-67 accumulates in areas of active inflammation, providing valuable insights into the location of infection or inflammation. Gallium scanning is typically performed 18 to 72 hours after gallium injection, often in conjunction with [99mTc]-MDP bone scintigraphy. While gallium scanning can be useful for detecting inflammation, it does not offer the same level of detail in visualizing bone structures as [99mTc]-MDP bone scintigraphy. Moreover, gallium scans may not effectively distinguish between bony and soft tissue inflammation, making them less specific than other imaging modalities [42]. In patients with osteomyelitis, gallium-67 scanning may reveal abnormal accumulation in the affected areas, a pattern not typically seen with [99mTc]-MDP bone scintigraphy. This can be especially useful in assessing the inflammatory activity of osteomyelitis, although it is not as effective in distinguishing osteomyelitis from other conditions, such as recent trauma or healed osteomyelitis [8][14].

18F-Fluorodeoxyglucose Positron Emission Tomography-Computed Tomography ([18F]-FDG-PET-CT)

The combination of [18F]-fluorodeoxyglucose ([18F]-FDG) with positron emission tomography (PET) has significantly advanced the field of nuclear imaging. [18F]-FDG is a glucose analog that accumulates in areas of high metabolic activity, such as infection sites, where leukocytes gather to fight inflammation. The accumulation of [18F]-FDG at the site of infection allows clinicians to visualize the metabolic activity associated with osteomyelitis. [18F]-FDG-PET is particularly advantageous because it combines the high spatial resolution of PET with the anatomical detail provided by computed tomography (CT). This combination enhances diagnostic accuracy by offering precise localization of infection. Images from both modalities can be superimposed to provide detailed, high-resolution images that help in understanding the full extent of the infection and its impact on surrounding tissues. This imaging technique is particularly useful in differentiating osteomyelitis from adjacent soft tissue infections, offering superior spatial resolution compared to other imaging modalities, such as dynamic contrast-enhanced MRI [44]. Studies have demonstrated the high sensitivity and specificity of [18F]-FDG-PET in detecting both acute and chronic osteomyelitis, with reported values of 84% and 93%, respectively. One of the key benefits of [18F]-FDG-PET is its ability to distinguish osteomyelitis from Charcot arthropathy, a common complication in diabetic patients, with much greater accuracy than other techniques like diffusion-weighted MRI or dynamic contrast-enhanced MRI [45]. Additionally, [18F]-FDG-PET has proven useful in assessing post-traumatic osteomyelitis, where high accuracy in diagnosing fracture-related infections has been demonstrated. It has also shown utility in diagnosing spondylodiscitis, further broadening its scope in the evaluation of bone infections [46][47].

Limitations and Considerations

While nuclear medicine techniques offer numerous benefits in diagnosing osteomyelitis, they are not without limitations. One significant challenge is the potential for false positives, as conditions such as trauma, recent surgery, and degenerative bone diseases may lead to patterns of inflammation that mimic osteomyelitis. Additionally, gallium-67 scanning, although useful, may expose patients to higher radiation doses compared to other radiopharmaceuticals used in bone imaging, which can limit its use in certain populations [43]. Moreover, nuclear medicine imaging does not always provide definitive structural detail of bone and soft tissues, which may require supplementary imaging modalities such as MRI or CT to confirm the diagnosis and fully assess the extent of the infection. These techniques should therefore be viewed as part of a comprehensive diagnostic strategy, integrating clinical evaluation, radiographic findings, and laboratory tests to achieve the most accurate diagnosis. Nuclear medicine plays a vital role in diagnosing osteomyelitis, particularly in cases where other imaging methods are not feasible. Techniques like [99mTc]-

MDP bone scintigraphy, gallium-67 scintigraphy, and [18F]-FDG-PET-CT offer high sensitivity and specificity, helping clinicians identify osteomyelitis early and accurately. These imaging modalities are particularly useful in assessing acute infections, monitoring treatment response, and distinguishing osteomyelitis from other conditions with similar imaging patterns. Despite their limitations, these nuclear medicine techniques continue to be indispensable tools in the comprehensive evaluation of osteomyelitis, offering valuable insights when other diagnostic options are less accessible or feasible.

Clinical Significance of Imaging in Osteomyelitis Diagnosis and Management

Osteomyelitis, an infection of the bone, is a condition that carries significant morbidity and is notoriously difficult to diagnose. Its symptoms can often be subtle or mimic other conditions, leading to delayed diagnoses and potentially severe consequences, such as bone destruction, systemic infection, and chronic pain. Early identification and treatment are crucial to preventing these outcomes, and modern imaging techniques have greatly improved our ability to detect and assess osteomyelitis. By adopting a structured, step-by-step diagnostic approach, clinicians can more effectively identify the condition, thereby facilitating timely intervention and improving patient outcomes.

Initial Diagnostic Imaging: Plain Radiography

The first imaging tool employed in the evaluation of suspected osteomyelitis is usually plain radiography. X-rays are widely available, non-invasive, and useful for detecting gross bony abnormalities. Plain radiography can also assist in ruling out alternative diagnoses, such as stress fractures or bone tumors, which may present similar clinical symptoms. Early findings on radiographs may include soft tissue changes, such as blurring of soft tissue planes, muscle swelling, or the presence of gas in soft tissues, which can be indicative of infection. However, one of the major limitations of plain radiographs in diagnosing osteomyelitis is that they are often unable to detect early bone changes. Bony abnormalities, including lytic lesions, sequestra, or cortical disruption, may not be apparent until 10 to 14 days after the onset of infection. By this time, the infection may already be well established, necessitating further imaging to confirm the diagnosis and assess the extent of the disease. Thus, while plain radiography is a valuable initial step, it is not always sufficient in identifying early-stage osteomyelitis, and additional imaging should be pursued when clinical suspicion remains high despite normal radiographs.

Advanced Imaging Techniques: MRI and Bone Scintigraphy

When osteomyelitis is suspected but not clearly demonstrated on plain radiographs, advanced imaging modalities such as MRI and bone scintigraphy play a critical role in diagnosis. These techniques offer higher sensitivity and can provide more detailed information regarding the presence of infection and the extent of involvement. Bone Scintigraphy involves the use of radiolabeled tracers, such as 99mTc-MDP, that bind to areas of increased bone turnover and inflammation. This imaging technique is particularly useful for identifying multifocal or diffuse osteomyelitis, especially in cases where the infection involves multiple sites. Bone scintigraphy has the added benefit of helping to identify biopsy sites in cases where tissue sampling is necessary for microbiological confirmation. However, while bone scintigraphy can indicate areas of inflammation, it lacks the spatial resolution to localize infection precisely, limiting its role to screening and identifying areas that require further investigation. On the other hand, MRI is highly sensitive and specific in detecting bone, muscle, and soft tissue involvement in osteomyelitis. MRI is particularly useful in detecting bone marrow edema, a hallmark of early osteomyelitis. In addition to bone abnormalities, MRI can reveal periosteal reactions, joint effusions, abscesses, and soft tissue changes, providing a comprehensive view of the affected area. MRI is also the imaging modality of choice for suspected vertebral osteomyelitis, as it can offer detailed visualization of the spinal cord and surrounding structures. Despite its high sensitivity, MRI may not be available in all settings, and in some cases, may be contraindicated, such as in patients with certain implanted devices or metal hardware.

Role of CT and Ultrasound in Osteomyelitis Diagnosis

When MRI is unavailable or contraindicated, other imaging techniques such as CT and ultrasound (US) can be valuable adjuncts in the diagnosis and management of osteomyelitis. CT is particularly beneficial for

evaluating bony destruction and assessing the integrity of cortical bone. It can also help detect complications such as abscess formation, sequestra, or the presence of gas in infected tissues. CT is often used in cases of chronic osteomyelitis or when complications arise, providing high-resolution images of the affected bones and soft tissues. Additionally, CT can be useful in the assessment of the pelvis, spine, and skull, where MRI may be less effective. Ultrasound (US) is another modality that has a role in evaluating soft tissue changes associated with osteomyelitis. For example, the US can help detect abscesses or fluid collections that are often associated with the infection. US is also helpful in guiding aspirations or drainage procedures when there is suspicion of abscess formation. In neonates, where the bones are incompletely ossified, ultrasound can be a particularly useful tool for detecting soft tissue changes and bone involvement. Furthermore, ultrasound is portable, inexpensive, and can be performed at the bedside, making it a practical option for monitoring progress or assessing complications in real time.

Integrating Imaging Results into Clinical Decision-Making

Interpreting radiological findings is a crucial step in managing osteomyelitis. Specific findings, such as periosteal reactions, abscesses, sequestra, or cloacae (channels through which infected bone or pus drains), can provide valuable insights into the stage and severity of the infection. These findings also help guide treatment decisions, including the need for surgical intervention or targeted antibiotic therapy. For instance, the presence of sequestra or abscesses may indicate the need for surgical debridement, while diffuse osteomyelitis may require systemic antibiotics and close monitoring. Collaboration between clinicians and radiologists is essential for ensuring optimal patient care based on imaging results. A structured imaging algorithm, combined with a clear understanding of the significance of radiological findings, allows clinicians to make informed decisions about the best course of action. Moreover, early recognition of osteomyelitis through imaging enables timely treatment, which is crucial in preventing further complications such as bone necrosis, amputation, or systemic infection. The clinical significance of advanced imaging in osteomyelitis lies in its ability to improve diagnostic accuracy, guide treatment decisions, and ultimately enhance patient outcomes. While plain radiography remains an essential first step in evaluating suspected osteomyelitis, modern imaging techniques such as MRI, bone scintigraphy, CT, and US provide invaluable information that helps to confirm the diagnosis, assess the extent of disease, and guide management strategies. A stepwise approach that incorporates these advanced imaging modalities enables early diagnosis, reduces the risk of complications, and ensures the appropriate therapeutic interventions are implemented in a timely manner. Ultimately, a comprehensive understanding of the strengths and limitations of each imaging tool, along with a collaborative approach between clinicians and radiologists, is essential for optimal patient care in osteomyelitis [8] [14] [24].

Conclusion:

Osteomyelitis remains a challenging condition to diagnose and manage due to its varied clinical presentations and potential for severe complications. The advent of advanced imaging techniques has significantly improved the ability to detect and assess the disease, enabling timely and targeted interventions. Plain radiography, while useful as an initial screening tool, often fails to identify early osteomyelitis, necessitating the use of more sensitive modalities such as MRI, CT, and nuclear medicine studies. MRI, with its superior soft tissue contrast and ability to detect bone marrow edema, has become the gold standard for early diagnosis, particularly in acute and subacute cases. CT, on the other hand, excels in visualizing chronic changes, such as sequestra and cortical destruction, making it invaluable in long-standing infections. Nuclear medicine techniques, including bone scintigraphy and 18F-FDG PET-CT, offer high sensitivity and specificity, especially in complex cases where other imaging modalities may be inconclusive. These techniques are particularly useful in assessing multifocal or diffuse osteomyelitis and in monitoring treatment response. Ultrasonography, while limited in evaluating bone directly, plays a complementary role in detecting soft tissue changes and guiding percutaneous interventions, particularly in pediatric patients. The integration of these imaging modalities into a structured diagnostic approach is crucial for accurate diagnosis and effective management. Early detection of osteomyelitis through advanced imaging not only facilitates prompt treatment but also reduces the risk of complications such as bone necrosis, systemic infection, and chronic pain. Collaboration between clinicians and radiologists is essential

to interpret imaging findings accurately and tailor treatment strategies to individual patient needs. In conclusion, the use of advanced imaging techniques has transformed the diagnostic landscape of osteomyelitis, enabling earlier and more precise detection of the disease. By leveraging the strengths of each modality and adopting a multidisciplinary approach, healthcare providers can improve patient outcomes and minimize the morbidity associated with this potentially devastating condition. Future research should focus on optimizing imaging protocols and exploring novel techniques to further enhance diagnostic accuracy and therapeutic efficacy in osteomyelitis.

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تصوير التهاب العظم والنقي: نظرة محدثة لأخصائي الأشعة

الملخص:

الخلفية :التهاب العظم والنقي هو مرض التهابي معقد يصيب العظام ونقي العظم، وينتج بشكل رئيسي عن العدوى البكتيرية. يمكن أن يحدث بسبب الانتشار الدموي، أو التلقيح المباشر، أو الانتشار المتجاور من الأنسجة المصابة المجاورة. يظهر المرض بأشكال حادة، تحت حادة، ومزمنة، ولكل منها خصائص سريرية ومضاعفات مميزة. التشخيص الدقيق والإدارة الفعالة ضروريان لمنع العواقب الخطيرة مثل تدمير العظام، والعدوى الجهازية، والألم المزمن. يلعب التصوير الطبي دورًا رئيسيًا في الكشف المبكر عن التهاب العظم والنقي وتقييمه، مما يساهم في توجيه التدخلات الطبية والجراحية.

الهدف :تهدف هذه المقالة إلى تقديم نظرة محدثة حول وسائل التصوير المستخدمة في تشخيص وإدارة التهاب العظم والنقي، مع تسليط الضوء على مزاياها، وقيودها، وتطبيقاتها السريرية. تؤكد المقالة على أهمية دمج التقنيات التصويرية المتقدمة مع التقييم السريري لتحسين دقة التشخيص ونتائج المرضى.

الطرق :تناقش هذه المراجعة تقنيات التصوير المختلفة، بما في ذلك الأشعة السينية التقليدية، والتصوير المقطعي المحوسب(CT) ، والتصوير بالرنين المغناطيسي (MRI)، والتصوير بالموجات فوق الصوتية(US) ، ودراسات الطب النووي مثل التصوير الومضاني للعظام، ومسح الغاليوم، والتصوير المقطعي بالإصدار البوزيتروني باستخدام .F-FDG PET-CTيتم تقييم دور كل تقنية في الكشف عن التهاب العظم والنقي المبكر والمزمن، وتقييم المضاعفات، وتوجيه العلاج. كما تستكشف المقالة الأساس التشريحي والفيزيولوجي المرضي لالتهاب العظم والنقي، مع التركيز على كيفية تصور التغيرات في العظام والأنسجة الرخوة من خلال التصوير الطبي.

النتائج :على الرغم من أن الأشعة السينية مفيدة في التقييم الأولي، إلا أنها غالبًا لا تكشف عن التهاب العظم والنقي في مراحله المبكرة. يُعد التصوير بالرنين المغناطيسي أكثر التقنيات حساسية للكشف المبكر، خاصة في تحديد وذمة نقي العظم والتورط في الأنسجة الرخوة. يساعد التصوير المقطعي المحوسب في تقييم تدمير العظام والتغيرات المزمنة، بينما يكون التصوير بالموجات فوق الصوتية مفيدًا في حالات الأطفال ولتوجيه التدخلات العلاجية. توفر تقنيات الطب النووي، مثل التصوير الومضاني للعظام والتصوير المقطعي بالإصدار البوزيتروني F-FDG PET-CT، حساسية ونوعية عالية، خاصة في الحالات المعقدة أو متعددة البؤر. يؤدي استخدام مزيج من هذه الوسائل التصويرية، وفقًا للسياق السريري، إلى تعزيز دقة التشخيص وتوجيه استراتيجيات العلاج الفعالة.

الاستنتاج :أحدثت تقنيات التصوير المتقدمة تحولًا في تشخيص وإدارة التهاب العظم والنقي. على الرغم من أن لكل تقنية نقاط قوة وحدود، فإن دمجها في نهج تشخيصي منظم يضمن تشخيصًا دقيقًا وفي الوقت المناسب، مما يقلل من مخاطر المضاعفات. يعد التعاون بين الأطباء وأخصائي الأشعة أمرًا ضروريًا لتحسين رعاية المرضى وتحقيق نتائج أفضل في حالات التهاب العظم والنقي.

الكلمات المفتاحية :التهاب العظم والنقي، التصوير الطبي، التصوير بالرنين المغناطيسي، التصوير المقطعي المحوسب، الطب النووي، التصوير الومضاني للعظام، التصوير المقطعي بالإصدار البوزيتروني F-FDG PET-CT، التصوير بالموجات فوق الصوتية، التشخيص، الإدارة العلاجية.