



RADIOLOGICAL DIAGNOSIS OF THE SKELETAL SYSTEM: APPEARANCE OF BONES IN X-RAY, CT, AND MRI

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ABSTRACT

This paper provides a comprehensive overview of the radiological diagnosis of the skeletal system, focusing on the appearance and diagnostic value of bones in X-ray, Computed Tomography (CT), and Magnetic Resonance Imaging (MRI). Radiological methods are fundamental tools in modern medical diagnostics, enabling visualization of internal structures that are invisible to the naked eye. The study highlights the role of X-ray imaging in detecting fractures and bone deformities, the advantages of CT in producing detailed cross-sectional images of complex bone structures, and the superior capability of MRI in assessing soft tissues, bone marrow, and tumors. Additionally, the paper discusses the development of radiological technologies, particularly digital radiography and multislice CT, which have improved image clarity, reduced radiation exposure, and enhanced diagnostic accuracy. Radiological imaging of the skeletal system remains essential for evaluating bone health, diagnosing injuries and diseases, and assisting in forensic investigations. Overall, radiological techniques such as X-ray, CT, and MRI continue to serve as indispensable, safe, and non-invasive tools that contribute to early diagnosis and effective treatment of skeletal disorders.

Introduction

The radiological examination of the skeletal system is used to assess the condition of the bones through methods such as X-ray, CT (computed tomography), and MRI (magnetic resonance imaging). X-ray examination reveals the general appearance of the bones and detects fractures, while CT provides detailed images of the complex structure of bones, their injuries, and tumors. MRI, on the other hand, is more effective in identifying the condition of soft tissues (ligaments, cartilage, and bone marrow) and detecting tumors.

Radiological Examination of the Human Body

Radiological or X-ray examination is considered one of the key diagnostic tools in modern medicine, as it helps visualize internal organs, their shapes, boundaries, and various pathological changes occurring within the body. This method makes it possible to observe internal structures that cannot be seen by the naked eye. The use of X-rays began after their discovery in 1896. These rays are generated by a special tube that emits energy capable of penetrating materials opaque to visible light. Different body tissues absorb X-rays to varying degrees, allowing physicians to identify structural differences in organs. For example, during a chest X-ray, bones, the heart, and lungs can be examined. Dense tissues such as bones absorb more radiation and therefore appear lighter on the image, whereas air-filled structures like the lungs transmit more rays and appear darker. [Fundamentals of Diagnostic Radiology.2012] The degree of radiation absorption depends on tissue density and composition, which enables detailed visualization of anatomical structures. Radiological examinations may be performed through fluoroscopy, where real-time images are observed on a monitor, or radiography, in which the image is captured on film for further analysis. A normal chest X-ray shows clear, dark lung fields due to air content, while the heart and bones appear as lighter areas. When inflammation occurs, the affected lung tissue becomes denser, resulting in a light patch on the image. Conversely, the presence of air-filled cavities, as seen in tuberculosis, appears as darker areas. In acute lung abscesses, a well-defined dark zone may appear due to fluid accumulation, while in emphysema, the excessive presence of air causes increased darkness of the lung fields. Radiography is also essential in assessing cardiac and vascular conditions. For instance, an enlarged heart or accumulation of fluid in the pericardium can be recognized by an expanded heart shadow on the X-ray. In cases of aortic aneurysm, the dilation of the aorta produces a distinct, pulsating shadow. The digestive system can be studied using contrast-enhanced radiology. Since abdominal organs absorb X-rays differently, a contrast agent such as barium sulfate is administered to improve visibility. This substance coats the inner lining of the gastrointestinal tract, enabling clear imaging of its shape and surface. [A Practical Approach.2015]

Before the procedure, patients are advised to avoid food or undergo cleansing to ensure image clarity. During the test, the patient drinks a suspension containing barium sulfate mixed with water. As the contrast passes through the esophagus and stomach, it outlines the mucosal surface, helping detect abnormalities such as ulcers or tumors. Skeletal X-ray examination is a diagnostic imaging technique that uses X-rays to produce detailed images of bones and joints. This method is primarily applied when there are concerns about bone health, suspected fractures, tumors, or other structural abnormalities within the musculoskeletal system. During the procedure, a low dose of radiation is used to determine bone age, density, and the condition of surrounding tissues. Modern radiographic technology allows for early detection of bone loss, deformities, or hidden fractures that might not be visible during a physical examination. By analyzing the shape, structure, and density of bones, radiologists can gather important diagnostic information about a person's growth, age, or even certain metabolic and degenerative disorders. In addition to diagnosing injuries, skeletal X-ray imaging plays a crucial role in identifying diseases such as osteoporosis, arthritis, and bone infections. In forensic medicine, it helps determine a person's age, cause of death, and physical development at the time of death. Advancements in digital radiography have made the process

faster and more accurate, reducing radiation exposure while enhancing image clarity. The technique is considered safe, as the radiation dose used in skeletal studies is minimal and does not pose significant health risks. Regular calibration of X-ray equipment and adherence to protective standards further ensure patient safety. In conclusion, skeletal radiography remains an essential and reliable diagnostic method. It provides clinicians with valuable insight into the condition of bones and joints, helping ensure timely diagnosis and effective treatment.

What is Computed Tomography (CT)?

Computed Tomography (CT) is a medical imaging technique that uses X-rays and computer algorithms to create cross-sectional images of the body. Developed in the 1970s, CT is considered a revolutionary advancement in medical diagnostics. This technology allows for detailed visualization of internal structures such as organs, bones, soft tissues, and blood vessels. Unlike traditional X-rays, which produce two-dimensional images, CT generates multiple cross-sectional (slice) images. These slices are digitally combined to create a three-dimensional representation of the body. This enables physicians to detect and evaluate diseases and injuries with greater accuracy and detail.

How Does Computed Tomography Work?

CT scanning operates using X-rays in combination with advanced computer processing technologies. The process involves several key stages:

1. Preparation and Scheduling

A CT scan is usually scheduled by a healthcare provider. Before the procedure, the patient may need to follow specific instructions, such as fasting or temporarily avoiding certain medications. These precautions help ensure optimal imaging quality.

2. Clothing and Accessories

Before scanning, the patient is asked to remove all metallic objects, including jewelry, eyeglasses, hearing aids, and clothing with metal fasteners. Metal items can interfere with X-rays and degrade image quality.

3. Positioning and Readiness

The patient lies on the CT table, which moves into the scanner's tunnel-like opening. Positioning depends on the area being examined—for instance, head scans require the patient to lie on their back with the head stabilized, while body scans may involve arms placed above the head. Maintaining stillness during scanning is critical for obtaining clear images.

4. The Scanning Process

During the scan, the patient must remain motionless while the scanner rotates around them, emitting X-rays that capture detailed cross-sectional images. The procedure is painless and typically takes only a few minutes. The resulting data are processed by a computer to reconstruct precise internal views.

5. Use of Contrast Material

In some cases, a contrast agent is administered before or during the scan to enhance visualization of specific tissues or blood vessels. The contrast may cause temporary sensations such as warmth or a metallic taste but is generally safe. It helps radiologists distinguish between different types of tissues more clearly. [Diagnostic Imaging and Interventional Techniques. Springer.2021]

6. Image Review and Diagnosis

Once the scanning is complete, a radiologist analyzes the images and prepares a report. The findings are sent to the referring physician, who interprets them in the context of the patient's condition and develops an appropriate treatment plan.

Types and Advances in Computed Tomography

Computed Tomography (CT) enables the examination of body organs in extremely thin sections—often as fine as 1 millimeter—using X-rays. Introduced to medicine in the 1970s as a non-invasive diagnostic method, CT technology has continuously evolved. Modern advancements have led to Multislice (or Multispiral) CT (MSCT) scanners, which provide faster and higher-resolution imaging. Compared to Magnetic Resonance Imaging (MRI), MSCT scans require less time—typically 7–8 minutes per organ—making them especially valuable in urgent cases such as cranio-cerebral injuries. MSCT can generate high-quality three-dimensional images of any organ, including blood vessels. In cases of intracranial hemorrhage (such as post-traumatic bleeding or hemorrhagic stroke), MSCT offers higher diagnostic accuracy in the early stages than MRI. It also provides excellent visualization of bone tissue pathologies.

For enhanced vascular imaging, Multislice CT Angiography (MSCTA) can be performed by injecting a contrast agent into a peripheral vein, typically in the arm. MSCTA delivers diagnostic precision comparable to modern angiographic methods such as Magnetic Resonance Angiography (MRA), allowing for highly detailed assessment of blood vessel conditions.

Summary. Computed Tomography has transformed modern medicine by providing rapid, accurate, and non-invasive diagnostic imaging. With advancements like Multislice CT and CT angiography, clinicians can detect and evaluate complex pathologies—including trauma, vascular disorders, and bone diseases—with unprecedented clarity and speed.

Interaction Between MRI Radio Waves and Static Magnetic Fields

Magnetic Resonance Imaging (MRI) operates on the principle of the interaction between radiofrequency (RF) waves and the atomic nuclei exposed to a strong static magnetic field. Not all atomic nuclei respond to magnetic fields—only those that possess a net magnetic moment, i.e., nuclei with an odd number of protons or neutrons. Among these, the hydrogen nucleus (^1H) plays the most significant role in MRI because hydrogen is the most abundant element in biological tissues—approximately 85% of the human body consists of water, each molecule of which contains two hydrogen atoms. Therefore, MRI primarily utilizes hydrogen protons as the source of nuclear magnetic resonance (NMR) signals. The hydrogen nucleus (a single proton) acts as a small spinning charged particle that produces a magnetic dipole moment, similar to a tiny magnet rotating around its own axis.

Nuclear Spin and Precession

The spin of the proton causes it to behave like a rotating magnetic dipole. When placed in an external magnetic field (B_0), the magnetic moment of the proton aligns either parallel or antiparallel to the direction of this field. Because of quantum mechanical constraints, the parallel alignment (lower energy state) is slightly more populated than the antiparallel alignment (higher energy state). This small difference in population forms the basis of the measurable MRI signal.

The rotation of the magnetic dipole around its own axis creates a secondary motion known as precession. Precession is analogous to the wobbling motion of a spinning top in the presence of gravity. The frequency of this precession depends directly on the strength of the external magnetic field and is described by the Larmor equation:

$$\omega_0 = \gamma B_0$$

where

- the Larmor angular frequency (rad/s)
- the gyromagnetic ratio (constant for each nucleus type)
- the magnetic field strength (Tesla)

Radiofrequency Excitation and Resonance

When an alternating electromagnetic field (RF pulse) is applied perpendicular to the static magnetic field, it exerts a torque on the precessing nuclear spins. If the RF pulse oscillates at the same frequency as the nuclei's precession frequency (the Larmor frequency), resonance occurs, allowing efficient energy transfer from the RF field to the nuclei. This process tips the net magnetization vector away from the longitudinal axis toward the transverse plane, where it can induce a measurable signal in a receiver coil. After the RF excitation, the nuclei gradually return to their equilibrium state—a process described by relaxation mechanisms (T_1 and T_2 relaxation), which are the foundation for MRI contrast formation. [Greenspan, A., & Norman, A. 2015]

2. T_1 and T_2 Relaxation

After the excitation pulse tips the net magnetization vector away from its equilibrium position, the system gradually returns to equilibrium through two distinct but simultaneous processes: T_1 (longitudinal) relaxation and T_2 (transverse) relaxation. These processes determine how the MRI signal decays over time and are crucial for tissue contrast differentiation.

T_1 Relaxation (Spin-Lattice Relaxation)

T_1 relaxation refers to the recovery of longitudinal magnetization along the direction of the static magnetic field (B_0). During excitation, the RF pulse transfers energy to the nuclear spins, displacing them from equilibrium. As the excited protons lose energy to their surrounding molecular environment (the "lattice"), they gradually realign with B_0 . This energy exchange is characterized by the T_1 relaxation time, defined as the time required for approximately 63% of the longitudinal magnetization to recover to its equilibrium value. T_1 relaxation times vary significantly across tissues depending on molecular mobility and composition. Fat, for instance, has a short T_1 (quick relaxation), while fluids such as cerebrospinal fluid (CSF) exhibit long T_1 times. In imaging, T_1 -weighted sequences provide excellent anatomical detail, with fat appearing bright and fluids appearing dark. [Resnick, D., & Kransdorf, M. J. 2018]

Conclusion

Radiological examination of the skeletal system remains one of the most essential and reliable methods in modern diagnostic medicine. Through techniques such as X-ray, Computed Tomography (CT), and Magnetic Resonance Imaging (MRI), physicians can obtain detailed insights into the structure, density, and health of bones and surrounding tissues. Each imaging modality serves a specific diagnostic purpose: X-rays are most effective for

identifying fractures and general bone abnormalities; CT provides highly detailed cross-sectional and three-dimensional images of complex bone structures, injuries, and tumors; while MRI offers superior visualization of soft tissues, bone marrow, ligaments, and cartilage. Advancements in digital radiography and multislice CT have significantly enhanced image resolution, reduced radiation exposure, and shortened examination times—making radiological diagnosis safer and more accurate. Furthermore, radiological imaging contributes not only to clinical diagnostics but also to preventive medicine and forensic investigations, where bone health, age estimation, and cause of death can be evaluated with precision. In conclusion, the continuous evolution of radiological technologies has transformed the field of medical diagnostics. The integration of X-ray, CT, and MRI techniques provides a comprehensive approach to understanding skeletal and soft tissue pathologies, ensuring early detection, effective treatment planning, and improved patient outcomes.

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