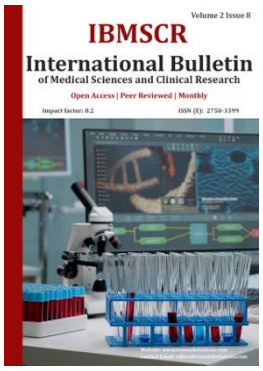

INTRODUCTION TO DIAGNOSTIC IMAGING AND TYPES OF IMAGING EQUIPMENT: A COMPARATIVE ANALYSIS OF X-RAY, CT/MSCT, MRI, AND ULTRASOUND

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Abstract. Diagnostic imaging (radiological diagnostics) is one of the key pillars of clinical medicine, providing objective evidence for early disease detection, differential diagnosis, selection of treatment tactics, and outcome monitoring. This article presents a comparative overview of the main imaging modalities—radiography and fluoroscopy, computed tomography (CT) and multislice CT (MSCT), magnetic resonance imaging (MRI), and ultrasound (US)—with emphasis on their physical and technical principles, equipment architecture, diagnostic capabilities, limitations, and safety considerations. The paper argues that modality choice must be guided by the clarity of the clinical question, the patient's risk profile (age, pregnancy, renal function, implants), and available resources; for examinations using ionizing radiation, the ALARA principle remains the central criterion.

Keywords: diagnostic imaging, radiography, fluoroscopy, CT, MSCT, MRI, ultrasound, ionizing radiation, dose, ALARA, image quality.

Introduction

In contemporary clinical practice, many symptoms and syndromes (pain, dyspnea, neurological deficits, palpable swelling) cannot be fully explained by physical examination and laboratory findings alone. Imaging diagnostics therefore implements the principle of "proving by visualization," providing clinicians with information on anatomy, lesion localization and extent, and, in some cases, functional status (blood flow, perfusion, motion).

In practice, the term "diagnostic imaging" is used in two senses. First, it may refer specifically to methods that use ionizing radiation (radiography, fluoroscopy, CT/MSCT). Second, it may be used more broadly for all medical imaging modalities, including MRI and ultrasound. Today radiology has evolved into a digital ecosystem: images are stored in DICOM format, transmitted through PACS/RIS, and interpreted increasingly with the support of teleradiology and artificial intelligence. This development expands selection criteria beyond image acquisition to include standardized storage, post-processing, and rapid sharing within the clinical team.

Appropriate selection of imaging methods directly influences clinical outcomes. For example, plain radiography is often sufficient for suspected fractures; in polytrauma, MSCT can provide a rapid "map" for detecting internal bleeding or occult injuries; diffusion MRI reveals early changes in acute cerebral ischemia; and in acute abdominal presentations, ultrasound is frequently the first-line tool for biliary or gynecological emergencies. Thus, modalities do not simply compete; rather, they complement one another when matched to the clinical question.

Every examination has a "cost" in terms of potential risk. X-ray and CT may increase stochastic risk as a function of ionizing radiation dose; iodinated contrast agents may cause

allergic reactions or contrast-associated nephropathy; MRI may be limited by ferromagnetic implants, electronic devices (e.g., certain pacemakers), claustrophobia, or motion artifacts. Although ultrasound does not involve radiation, its results can depend strongly on operator skill, and gas or bone may limit acoustic penetration, reducing image quality and field of view.

For these reasons, radiological practice relies on three core principles: (1) justification—an examination must provide a clinically meaningful benefit; (2) optimization—the required information should be obtained with the lowest reasonable dose and minimal adverse effects; and (3) appropriateness of modality selection—choosing the method that best answers the clinical question. The aim of this article is to systematize the physical and technical foundations that support such decisions.

Materials and Methods. This work is a narrative, analytical review designed to compare imaging modalities using a consistent set of criteria. The analysis considered: (1) physical principle (type of energy and signal detection), (2) key hardware blocks (generator, detector, reconstruction and processing), (3) image quality metrics (spatial resolution, contrast resolution, noise), (4) clinical applications (indications), (5) safety constraints (radiation, contrast, implants), and (6) practical factors (speed, availability, cost).

From a dosimetric perspective, the concept of "effective dose" (mSv) was used as an orienting measure for X-ray/CT examinations; however, it was emphasized that in real practice dose varies substantially with scanner model, protocol parameters (kV, mAs, pitch, slice thickness), patient habitus, and reconstruction algorithms. Results were summarized in a comparative table, and the discussion section developed practical selection logic and risk–benefit management principles.

III. Results. Comparative assessment indicates that no single modality is "best for all cases." Optimal choice means selecting the method that provides the needed information for the clinical question with the lowest acceptable risk.

1) Radiography (X-ray). The "core" of an X-ray unit is the X-ray tube: electrons emitted from the cathode are accelerated by high voltage (kV) toward the anode, producing X-ray photons. The generator controls kV and mAs (tube current-time product); the collimator limits the beam; and an anti-scatter grid reduces scattered radiation to improve contrast. In modern digital radiography, detectors (CR phosphor plates or DR flat-panel detectors) convert the signal into digital data; post-processing (window/level adjustment) broadens diagnostic visualization. Radiography is fast, relatively inexpensive, and widely available, making it a first-line test for musculoskeletal trauma, chest screening, pneumonia, pneumothorax, and suspected bowel obstruction. Its main limitations are superimposition of structures in projection images and relatively low soft-tissue contrast.

2) Fluoroscopy. Fluoroscopy provides real-time imaging and is used for contrast studies of the gastrointestinal tract, urologic procedures, angiography, and as guidance during interventions. Because fluoroscopy can deliver higher dose than single radiographs, practical dose-reduction measures are essential: pulsed operation, strict collimation, minimizing exposure time, increasing distance, and using protective shielding.

3) CT and MSCT. In CT, the X-ray tube rotates around the patient while detectors record multiple projections; computer algorithms reconstruct cross-sectional images. Spiral (helical) scanning, pitch control, and iterative reconstruction help reduce dose while maintaining image quality. MSCT uses multiple detector rows, enabling acquisition of many slices per rotation—

improving speed, reducing slice thickness, and supporting isotropic voxels and advanced 3D reconstructions (MPR, MIP, volume rendering). CT/MSCT has high diagnostic value in emergency trauma, internal hemorrhage, pulmonary embolism, aortic dissection, complex fractures, and lung parenchymal disease. Limitations include relatively higher ionizing radiation dose, risks of iodinated contrast (allergy and nephrotoxicity), and metal-induced artifacts.

4) MRI. MRI operates without ionizing radiation. A strong static magnetic field (commonly 1.5T or 3T), gradient coils, and radiofrequency pulses generate signals from hydrogen protons. Different sequences—T1/T2 weighting, proton density, diffusion (DWI), perfusion, and MR angiography—depict pathology with multiple contrast mechanisms. MRI excels in imaging the brain and spinal cord, soft tissues, joints, tumors, focal liver lesions, and myocardial pathology. Constraints include longer examination time, claustrophobia, motion artifacts, the presence of ferromagnetic or MRI-incompatible implants (certain prostheses or clips), and careful consideration of contrast use in severe renal impairment.

5) Ultrasound (US). Ultrasound uses piezoelectric transducers to transmit and receive sound waves; the returning echoes depend on differences in acoustic impedance between tissues. Higher transducer frequency improves resolution but reduces penetration depth; therefore, higher frequencies are used for superficial structures and lower frequencies for abdominal imaging. Doppler techniques (color and spectral) assess flow direction and velocity, and elastography may provide additional information on tissue stiffness. Ultrasound is radiation-free, portable, relatively inexpensive, provides real-time imaging, and can be repeated frequently. Limitations include operator dependence, acoustic barriers from gas and bone, and reduced quality in obesity.

Table 1. Comparative map of imaging modalities.

Modality	Physical principle	Ionizing radiation	Strengths	Limitations	Typical clinical tasks
Radiography	X-ray photons + detector	Yes	Fast, low cost, widely available; effective for bone and chest imaging	Superimposition; limited soft-tissue contrast	Fracture, chest screening, pneumonia/pneumothorax, bowel obstruction
Fluoroscopy	Real-time X-ray imaging (pulsed/continuous)	Yes	Guidance for procedures and contrast studies; dynamic assessment	Dose may be higher; time/operator dependent	GI contrast studies, urologic procedures, interventions and angiography
CT/MSCT	Rotating X-ray tube + multi-row detectors; reconstruction	Yes	Cross-sectional imaging; high spatial resolution; very fast in emergencies; 3D reconstructions	Dose; iodinated contrast risks; metal artifacts	Trauma, internal bleeding, pulmonary embolism, aortic dissection, complex fractures, lung parenchyma
MRI	Strong magnetic field + RF pulses; relaxation signal	No	Excellent soft-tissue contrast; DWI/perfusion;	Longer time; claustrophobia; implant restrictions; motion artifacts	Brain/spine, joints, tumors, focal liver lesions, myocardium

			multiparametric assessment		
Ultrasound	Sound waves; acoustic impedance; Doppler	No	Safe, portable, real-time; Doppler for hemodynamics	Operator dependent; gas/bone barriers; reduced quality in obesity	Abdomen, gynecology, thyroid, soft tissues, vascular screening

IV. Discussion

IV. Discussion. The findings support a stepwise selection approach in clinical practice. First, the clinical question must be explicitly defined (e.g., “Is there a fracture?”, “Is internal bleeding likely?”, “Is cerebral ischemia present at an early stage?”). Second, the patient’s risk profile must be considered: minimizing ionizing radiation in children and pregnant patients; limiting contrast use in renal impairment; and verifying MRI safety in the presence of implants. Third, resources and time constraints should be integrated: a rapid modality is prioritized in emergencies, whereas the most informative method can be chosen in scheduled settings.

Practical algorithm examples include: (1) suspected fracture—radiography first; CT for complex joints or comminuted fractures; (2) polytrauma—MSCT trauma protocol in clinically stable patients; (3) acute stroke—CT initially to rapidly exclude hemorrhage, followed by DWI MRI when feasible to detect early ischemia; (4) acute abdomen—ultrasound for biliary or gynecological causes (and sometimes appendicitis), with CT for unclear cases or suspected complications; (5) vascular disease—Doppler ultrasound as screening, then CT angiography or MR angiography depending on the question.

From the perspective of radiation safety, the ALARA principle is implemented through three primary controls: reducing time, increasing distance, and using shielding (lead aprons, barriers), as well as strict collimation and protocol optimization. Although patient examinations do not have fixed dose limits (because diagnostic benefit is the purpose), diagnostic reference levels, avoiding unjustified repeat scans, and careful review of prior imaging are practical quality indicators. In CT, pediatric protocols, automatic exposure control, iterative reconstruction, and limiting scan range to the minimum necessary region can substantially reduce dose.

Equipment performance depends not only on physical capabilities but also on quality assurance (QA). In X-ray and CT, detector calibration, early artifact detection, and phantom-based monitoring of Hounsfield unit stability are essential. In MRI, checks of field homogeneity and RF noise control are critical. In ultrasound, transducer condition and standardized Doppler settings reduce variability. In this sense, the “technical culture” of radiology services is directly linked to clinical outcomes.

Future trends include low-dose CT enabled by improved detectors and reconstruction, point-of-care ultrasound with portable probes, multiparametric MRI protocols, and automated image analysis using AI systems. Nevertheless, the core principle remains unchanged: an examination must answer a clinical question, the benefit must outweigh the risk, and the result must improve clinical decision-making.

Conclusion

Diagnostic imaging equipment is based on diverse physical principles, and diagnostic value depends on the clinical task. Radiography and fluoroscopy are fast and economical but

require justification and optimization due to ionizing radiation. CT/MSCT provides high spatial resolution and speed in emergency diagnostics, yet dose and iodinated contrast risks must be managed rigorously. MRI enables deep soft-tissue evaluation without ionizing radiation, but is limited by implant restrictions, scan time, and artifacts. Ultrasound is radiation-free and real-time with Doppler capabilities, making it a first-line choice in many settings; however, operator dependence and acoustic barriers must be considered. Overall, optimal imaging is a decision grounded in the clinical question, patient risk profile, and available resources, supported by ALARA and robust quality control.

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