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Radiographers' Journal

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Editorial

Shankar K. Bhagat
Editor-in-chief

As we step into the vibrant monsoon month of June, the Radiographers Journal once again brings together a bouquet of insightful, pioneering, and thought-provoking articles from across the medical imaging and paramedical sciences landscape. This edition represents a powerful confluence of innovation, research, and clinical application that mirrors the dynamism and complexity of modern radiological practice.

Our lead article, "Exploring Workforce Limitations and Capacity-Building Needs in Allied Health and Paramedical Sciences in the Indian Context," is a timely reflection on the growing need to address manpower challenges in India's healthcare delivery system. It highlights the structural gaps in training, policy support, and institutional infrastructure that must be bridged to build a resilient and skilled paramedical workforce.

From human resource challenges, we move into safety with "The Evolution and Future of Radiation Protection in Medical Imaging," which traces the progress of radiation safety protocols and forecasts a future where advanced technology, AI, and robust regulatory mechanisms create a safer environment for both patients and healthcare professionals.

Technological innovation takes center stage with "Blockchain for Radiology Data Management," presenting a revolutionary perspective on how decentralized data management can offer heightened security, streamlined interoperability, and a truly patient-centric data ecosystem in radiology.

Improving efficiency is critical in high-demand settings, and "Improving Turnaround Time Efficiency in Radiology and Hybrid Operating Rooms" focuses on optimizing workflow, enhancing inter-departmental coordination, and leveraging automation to reduce patient wait times and improve outcomes.

Next, the cutting-edge ZAP-X Technology is introduced—a paradigm shift in non-invasive radiosurgery. This compact gyroscopic radiosurgery system provides an exciting frontier in neuro-oncology with reduced shielding requirements and precision targeting, signaling a move towards patient-friendly and cost-effective treatments.

In vascular imaging, the article "Non-Nephrotoxic Contrast Agent in Digital Subtraction Angiography: The Role of Carbon Dioxide" explores an essential alternative contrast medium for patients with renal concerns, widening diagnostic access without compromising safety.

The realm of contrast media is further expanded in "MRI Contrast Agents Based on Protein-Targeted Gadolinium," where molecular-level specificity is enabling highly targeted imaging in neurological and oncological applications. This, coupled with "High-Resolution Hip Joint Imaging in the Era of Deep Learning," demonstrates how AI is refining musculoskeletal imaging, achieving sharper insights with lower scan times.

We also delve into thoracic oncology with "MRI in Lung Cancer," examining the modality's emerging role in early detection, staging, and treatment monitoring—especially valuable in cases where radiation exposure is a concern.

In the same oncological stream, "Radiogenomics: Integrating Imaging and Genomics for Precision Oncology" bridges radiology and molecular biology, shedding light on how imaging biomarkers can predict tumor behavior and tailor treatment strategies for individual patients.

Complementing this is "Theronostic Imaging Agents," which offers a look into radiopharmaceuticals that serve both diagnostic and therapeutic functions—a promising domain in personalized cancer care.

Finally, our concluding study, "A Comprehensive Study of Hematuria Evaluation Using CT Urography," serves as a clinical guide to a commonly encountered but often complex diagnostic problem, highlighting CTU's diagnostic superiority in hematuria workup.

We extend our heartfelt thanks to all the contributors whose scholarly articles and clinical insights have enriched this edition. Your dedication to advancing the profession continues to inspire and educate.

We are equally grateful for the feedback we consistently receive from our readers. Your suggestions, appreciation, and constructive criticism help us maintain relevance and excellence. We encourage continued engagement—your voice shapes the direction and impact of this journal.

Wishing you an insightful read!

Warm regards,
Editor-in-Chief
Radiographers Journal

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MAHE 2025
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in association with

Society of Indian Radiographers
Karnataka Medical Radiographers and Allied Technologists Association
Karnataka State Government Radiology Imaging Officers Central Association

HOST: *Department of Radiodiagnosis and Imaging, Kasturba Medical College, Mangalore*

THEME: ***Advancing Frontiers: Ushering in a New Era of Medical Imaging***

31st October - 2nd November 2025 / **TMA Pai Convention Centre, Mangalore**

WELCOME Message

Namaskara from Mangaluru,

We are delighted to extend a warm welcome for the 23rd National Conference of Society of Indian Radiographers – IMAGINE 2025, in association with Karnataka Medical Radiographers and Allied Technologist Association and Karnataka State Government Radiology Imaging Officers Central Association, hosted by the Department of Radiodiagnosis and Imaging, Kasturba Medical College, Mangalore (unit of Manipal Academy of Higher Education).

IMAGINE 2025 brings together leading researchers, clinical experts, industry pioneers, and aspiring professionals to explore the latest innovations, share groundbreaking research, and foster collaboration in the dynamic field of medical imaging.

The theme, ***"Advancing Frontiers: Ushering in a New Era of Medical Imaging,"*** the conference will spotlight cutting-edge technologies, transformative ideas, and emerging trends shaping the future of healthcare. It's an opportunity to engage in thought-provoking discussions, attend insightful keynote sessions, and participate in interactive workshops.

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Exploring Workforce Limitations and Capacity-Building Needs in Allied Health and Paramedical Sciences in the Indian Context

Wilson Hrangkhawl, Lecturer (Medical Imaging Technology), Sikkim Manipal Institute of Medical College, Sikkim Manipal University.

Introduction

When we step into a hospital ward be it in Delhi or a clinic in rural Uttar Pradesh, and you will witness a quiet symphony of healthcare orchestrated not just by physicians, but by allied health and paramedical professionals' radiographers obtaining critical images, emergency medical technicians (EMTs) racing against time, the lab tech rushing to draw samples and delivering reports, an optometrist conducting a refraction test, a dialysis tech in the dialysis unit assisting a senior physician. These professionals are the unsung architects of India's healthcare framework, bridging gaps that doctors and nurses alone cannot fill, and most often go unnoticed. As India marches toward universal health coverage by 2025, propelled by initiatives like Ayushman Bharat, the spotlight intensifies on Paramedical Sciences (PS) and Allied Health Sciences (AHS). Yet, beneath their growing prominence there lies a pressing question: Are these professionals equipped with the skills and education to meet the nation's needs, and are India's institutions nurturing or neglecting this vital workforce? This review synthesizes contemporary evidence to evaluate the state of AHS and PS in India, focusing on few interwoven threads: the proficiency of practitioners, the quality of their educational foundation, and the justice or injustice institutions render to healthcare.

The Rising Tide of Demand and the Skill Divide

India's healthcare demands are rising at a breathtaking pace. Rise in aging population, steep surge in chronic conditions, 77 million diabetics alone, as per the International Diabetes Federation (1) and expanded public health programs have intensified the need for AHS and PS professionals. A 2021 Planning Commission report estimated a shortfall of six lakh paramedical workers (2), a deficit likely deepened by 2025 due to rapid expansion of private healthcare and the continued neglect of rural healthcare demands. "Yet, the actual numbers tells only half of the story; in Healthcare professions skills paint the fuller picture. As highlighted in a 2023 Times of India report (4), private hospitals are in high demand for paramedics trained in modern technology and emergency protocols; however, the existing education system leaves many graduates unprepared, contributing to a significant skills divide. According to Lancet Regional Health survey 2024, 55% of paramedics struggle with advanced diagnostics, and 30% lack basic emergency skills. (5) Personal anecdotes echo this: a clinic manager in Pune confided that new hires often require weeks of retraining to operate basic equipment like ECG machines. The demand is undeniable, but a skill divide persists, rooted in the uneven terrain of education.

Educational Landscape: Peaks of Excellence, Valleys of Decline

Education shapes the backbone of any profession, and for AHS and PS in India, it's a tale of stark contrasts. Premier institutions like Manipal University, AIIMS, and CMC Vellore, TATA Memorial Centre, Mumbai to name some and many Government and private intuitions stand as beacons, melding cutting-edge labs with hospital-based training (6,7,8). The Indian Journal of Public Health (2023) celebrated a 15% enrollment surge since 2020, attributing it to such programs' robust infrastructure (9). Graduates from these hubs emerge as exemplary labels capable of interpreting scans, managing trauma, and engaging patients with empathy, as noted in a Prehospital Emergency Care study on critical paramedic skills (10). However, this excellence is the exception, not the norm. Beyond urban centers, education quality plummets. A 2024 Health Education Research study found that only 40% of paramedical graduates felt job ready, citing outdated curriculums and scant practical exposure (11). In smaller towns, students contend with dilapidated equipment one microscope for dozens, as a lab tech graduate recounted and faculty stretched thin by low pay and poor resources. The limited emphasis on practical experience in paramedical education is a major concern. According to the Journal of Medical Education (2024), just 25% of programs mandate hospital internships (12), unlike the intensive clinical training characteristic of nursing and medical education. As a result, and as a 2022 Times of India exposé pointed out (13), many graduates are inadequately prepared, possessing credentials that don't necessarily translate into real-world competence.

The Erosion of Educational Standards

The decline in paramedical education quality is no subtle shift it's a slow hemorrhage threatening healthcare's vitality. Regulatory efforts, like the 2021 National Commission for Allied and Healthcare Professions Act, aimed to standardize training (14), yet implementation lags. In a report by Mint 2024 report highlighted the potential for growth but expressed concerns over "institutional inertia," highlighting that many states have yet to set up oversight councils. (15). Unregulated institutes proliferate, often churn out graduates with diplomas of dubious value, offering degrees that lack proper accreditation, rigorous academic standards, thereby undermining the integrity of higher education. Funding disparities exacerbate from the slide of government resources favor medical colleges, leaving paramedical schools and colleges underfunded and understaffed (16).

Faculty quality also compounds the crisis, underpaid instructors and educators, often juggling multiple jobs, struggle to keep pace with rapid evolution and growing innovations like AI-driven diagnostics, leaving students untrained in the tools they will encounter in practice. A paramedic from Gujarat shared a telling story lamenting trained on obsolete X-ray machines, he resorted to YouTube tutorials upon joining a modern facility. Such gaps are not mere inconveniences they translate into misdiagnoses, often delayed care, and compromised patientcare and safety, as evidenced by the Journal of Rural Health (2023), which linked rural skill deficits to urban-centric training biases. (17)

Skills in Action: Proficiency Amid Pressure

On the ground, the skill spectrum of India's AHS and PS workforce is a mosaic. Elite graduates like those from AIIMS's (18) excel in high stakes and skillful tasks like intubation, defibrillation, and rapid assessment, aligning with global benchmarks (10). Yet, the broader workforce falters. The Lancet survey (2024) paints a sobering picture, over half lack proficiency in advanced techniques, and a third falter in emergencies (5).

in a nation where trauma and acute conditions dominate, this skill and professional gap is a ticking clock.

Burnout amplifies the challenge all the more. The Indian Journal of Occupational Health (2023) reported a 45% burnout rate among paramedics, driven by grueling shifts and meager pay ₹25,000 rural versus ₹30,000 urban (19,20). Exhausted workers can't refine their craft, and many eye overseas roles offering ₹1 lakh monthly (21). Skills stagnate or erode under such strain, a human toll that reverberates through healthcare delivery.

Institutions: Pillars or Pitfalls?

India's educational institutions wield profound influence over AHS and PS, yet their impact is a double-edged sword. Exemplary centers like Manipal, CMC, AIIMS, Tata Memorial Centre, many Government and Private institutions do justice to healthcare, producing professionals who elevate patient outcomes Rad. tech and lab techs detecting diseases early (6,7,8). A 2024 The Hindu feature lauded Chennai's AI-integrated training as a gold standard (22), showcasing how innovation can sharpen skills and strengthen systems.

Conversely, countless institutions perpetrate injustice. Unregulated colleges often cash-driven, charging ₹2-5 lakhs for subpar courses flood the market with underprepared graduates, as a Healthcare Executive report (2022) decried (23). Lacking hospital affiliations or practical focus, these programs yield workers who falter in crises, clogging rural healthcare with errors rather than easing its burden (17). Private players like Apollo Hospitals train in-house talent, bolstering urban care but little is done for rural needs (24). Government efforts, such as the National Skill Development Corporation's programs (2025), plug some gaps (25), yet fail to address systemic flaws. The verdict? While pockets of excellence shine, too many institutions betray healthcare's promise.

Technological Lifelines and Human Resilience

Amid these challenges, technology offers hope. Telemedicine empowers rural paramedics to consult urban specialists, narrowing skill divides (26). AI accelerates diagnostics radiographers, cut analysis time by 30%, as per the Journal of Medical Imaging (2024) (27) Amrita Vishwa Vidyapeetham integrated innovative simulation tools into its curriculum and teaching learning to enhance learning outcomes in Radiology education. These advances are not universal, but they signal a significant path forward.

Charting the Future: A Call to Action

India's AHS and PS sectors stand at the edge of possibility and opportunity. Many Institutions have increased their intakes and applicants spiked very rapid since 2022 and as policy inches ahead with the 2021 Act (14). Yet, transformative action needs to be taken up with urgency like recognition of the profession first and foremost, rural and urban centric training, affordable education, Standardized Curriculum, rigorous Faculty Training and Development, Clinical Exposure and Practical Training, Soft Skills and Communication Training, Capacity Building in Rural and Underserved Areas, Fostering a Culture of Patient Safety and Ethics, Interdisciplinary Collaboration and Research Promotion, Continuing Medical Education (CME), Strengthening Regulatory Frameworks, Accreditation and Quality Assurance, stringent regulation of institutes, regulations framework on intake and outgoing screening for professionals, Licensing and Skill Assessment Frameworks.

Conclusion:

Allied health and paramedical sciences beat at the heart of India's healthcare dreams, their professionals creating a canvas of care amidst growing demand and technological advances. But this review uncovers a sector under strain from skill deficits, a dilapidated educational framework, and institutional inequalities that swing between brilliance and exploitation. It's a deeply human story of late-night Rad techs and lab techs, odds defying EMTs, and a system ready to uplift or allow them to plummet. To get a strong healthcare future, India has to invest in these professionals' abilities, remake their training, and expect institutional responsibility. It is only then that the heartbeat of progress will be strong and steady.

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The Evolution and Future of Radiation Protection in Medical Imaging: Benefits and Risks

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Abstract
A dynamic interaction between clinical necessity, patient safety, and technological innovation is shown in the evolution of radiation shielding in medical imaging. Growing diagnostic capabilities, from the discovery of X-rays to contemporary hybrid imaging methods like PET/CT and SPECT/CT, have sparked worries about cumulative radiation exposure. The historical evolution of radiation protection principles—justification, optimization, and dose limitation—as well as their use in clinical settings are examined in this review. New technologies that promise to reduce exposure while preserving diagnostic accuracy include dose-tracking software and artificial intelligence. International norms and regulatory frameworks are constantly evolving to accommodate new methods and evidence. The future of radiation protection depends on further research into low-dose imaging alternatives, improved training for medical professionals, and customized imaging techniques. In the end, the foundation of patient-centered care in medical imaging continues to be striking a sustainable balance between radiation risk and diagnostic utility.

Introduction
Globally, the use of radiation in medicinal applications is still growing. According to recent UNSCEAR estimates, around 4 billion X-ray exams are performed annually worldwide. Medical professionals must execute all of these operations, which entails the risk of occupational radiation exposure. Does the rising need for X-ray imaging affect medical personnel's radiation protection? One could consider the growing utilization to be merely a workload problem with no unique difficulties. However, there has also been a shift in the kinds of X-ray imaging treatments that are being carried out and by whom. These methods necessitate that medical professionals be in close proximity to the patient, which makes it difficult to guarantee that they are properly protected from radiation.

Although X-rays and radioactive materials were originally handled recklessly, growing understanding of the risks posed by radiation in the 20th century prompted the deployment of several preventive measures globally, culminating in the creation of radiation safety laws. Despite being the first casualties, radiologists were also instrumental in the advancement of radiology, and their sacrifices will never be forgotten. Many people died of cancer or had their limbs amputated as a result of radiation harm. It was previously trendy to use radioactive materials in daily life, but as time went on, the negative health impacts were discovered. Awareness of preventative actions has grown as a result of research into the causes of these consequences. A significant shift in perceptions of radiation was brought about by the dropping of atomic bombs during World War II. The impacts of natural cosmic radiation, environmental radioactive materials like radon and radium, and the possible health risks of non-ionizing radiation are all widely known. Around the world, radiation protection rules and regulations have been passed, monitoring equipment has been built, and protective measures have been established and put into place.

Regulations are become increasingly more stringent in the twenty-first century. The acceptable ionizing radiation intensity limits are continuously being lowered. Regulations for the management of non-ionizing radiation are now part of the radiation protection concept.

Historical Context and Current Landscape
It is impossible to predict what further innovations Edison would have created if he had pursued his x-ray study. However, he gave up after his longtime friend and helper, Clarence Dally, suffered a serious x-ray burn that ultimately necessitated the amputation of both arms. Dally is regarded as the first x-ray fatality in American history, having passed away in 1904.

Rollins used x-rays to scan teeth and discovered that the diagnostic quality of radiographs was enhanced by limiting the x-ray beam with a sheet of lead with a hole in the middle, a diaphragm, and the insertion of an aluminum or leather filter.

The widespread use of collimation and filtration techniques came relatively slowly after this initial application. Later, it was realized that these devices lessen the risk that comes with x-rays.

The use of x-rays was a revolutionary tool in the hands of a few physicists, but two discoveries that happened at the same time turned it into a useful, widespread medical specialty. H.C. Snook introduced an interrupterless transformer, a high-voltage power supply alternative, replacing the static machines and induction coils that were then in use in 1907. The Snook transformer's capabilities vastly outstripped those of the Crookes tube, despite the fact that it was far superior to these other devices. The widespread use of the Snook transformer did not occur until the Coolidge tube was introduced.

The Coolidge tube and Snook transformer matching marked the beginning of modern radiography; only then were acceptable kVp and mA values achievable. Since then, not many advancements have impacted medical imaging so significantly.

The stationary grid, or "Glitterblende," was created in 1913 by German inventor Gustav Bucky. Two months later, he sought for a second patent for a moving grid. A moving grid was also created in 1915 by H. Potter, an American who was most likely ignorant of Bucky's invention due to World War I. Bucky's contribution was acknowledged by Potter, who is credited with creating the Potter-Bucky grid in 1921. Bell Telephone Laboratories exhibited the light amplifier tube in 1946. By 1950, this apparatus had evolved into an image intensifier tube for fluoroscopy. Solid-state image receptors are replacing image-intensified fluoroscopy nowadays.

Medical imaging has advanced significantly every ten years. Both the gamma camera and diagnostic ultrasonography first arrived in the 1960s. The 1970s saw the development of x-ray CT and Positron Emission Tomography. Since magnetic resonance imaging (MRI) gained acceptance in the 1980s, screen-film radiography and image-intensified fluoroscopy are being quickly replaced by digital radiography and digital fluoroscopy.

In the US, the first x-ray-related death happened in 1904. Unfortunately, in the early years, radiation damage happened quite frequently. These wounds typically manifested as anemia, hair loss, and occasionally serious skin damage. Because of the low energy of radiation that was then accessible, extensive exposure durations were required to acquire good photographs, which led to injuries to doctors and, more frequently, patients.

As the biological effects of x-rays were studied and documented scientifically by 1910, these acute injuries started to be controlled The number of reports of superficial tissue damage declined with the invention of the Coolidge tube and the Snook transformer.

Years later, it was shown that radiologists were far more likely than the general population to suffer from blood illnesses including leukemia and anemia. These observations led to the development of protective gear and clothing, including aprons and lead gloves, which radiologists now use. Workers who performed X-rays were regularly monitored for any side effects of their work-related exposure and given radiation monitoring equipment then Establishing and improving the principles of radiation protection is mainly the responsibility of the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP). Contributions to the area are acknowledged, especially from the ICRP, Rolf Maximillian Sievert often referred to as the "father of radiation protection" have made important contributions. Reducing the negative consequences of radiation exposure on people and the environment is the goal of radiation protection. Preventing deterministic consequences and bringing the danger of stochastic effects down to a manageable level are two examples of this.

This focus on radiation safety in radiology has shown to be successful.

Challenges and Emerging Technologies

Dose optimization and justification: Justification decisions must take into account economic, sociological, and environmental factors in addition to radiation protection. The ideas of "good" and "harm," which are frequently stated as "benefits" and "risks," are arbitrary and differ from person to person. Therefore, using the justification principle necessitates making judgment calls that are rarely simple.

Actions intended to lessen radiation exposure are also justified, in addition to the introduction of new radiation sources. Remediation of contaminated soil and lowering radon exposure in buildings are two examples. The decision-making process must take into account the costs of each of these activities as well as their effects on society and the environment.

justification and optimization are closely related since one of the factors influencing decisions is the degree to which radiation safety and protection may be maximized. regarding justification. Making the best decisions feasible under the circumstances at hand is the goal of optimization. Similar to justification, optimization must consider factors other than the necessity of lowering radiation doses.

The utilization of justifying concepts and When dealing with radiation sources, optimization is fairly well established. When discussing circumstances involving exposure from radon, non-medical human imaging, and radionuclides in food and drinking water, this is less true.

In order to control these exposures, national officials are not always clear about what actions, if any, are appropriate and how much exposure should be minimized if it is determined that actions are justified.

New imaging modalities: While new medical imaging technologies promise improvements in treatment precision and diagnostic accuracy, they also pose special radiation protection challenges. Higher radiation doses are naturally delivered by some modalities, such as CT scans, than by traditional X-rays, while other modalities, such as interventional radiology treatments, need extended exposure to scatter radiation. A multifaceted strategy is required to solve these issues, which includes using shielding equipment, improving imaging processes, and raising medical workers' awareness of radiation safety procedures.

CT Scan: Compared to routine X-rays, CT scans are known to include higher radiation dosages, which raises the possibility of radiation-induced malignancies and other health consequences.

Interventional Radiology: Long-term radiation exposure for patients and personnel can result from procedures like angiography, which employ fluoroscopy to guide catheters and other instruments. Despite its benefits in spine surgery, isocentric three-dimensional C-arms and O-arms can nevertheless result in high radiation exposure, especially for personnel.

Intraoperative MRI: Despite avoiding ionizing radiation, intraoperative MRI may still provide safety risks because of the use of contrast agents and magnetic fields.

Future Directions

technological developments, improved education and training, and a more international and cooperative approach to applying the principles of radiological safety are the main themes of the future of radiation protection in radiology. Optimizing the utilization of new imaging technology, incorporating patient-specific data, and encouraging a safety and awareness culture among medical staff are important areas.

Technological Development:

New Imaging Methods: creation and application of lower-dose imaging modalities, such as CT scans, with enhanced detector technology and picture reconstruction driven by artificial intelligence.

AI-Powered Dose Optimization: This technique reduces radiation exposure while preserving image quality by using AI to evaluate patient-specific traits and modify imaging parameters.

Better Shielding and Filtration: To lower scatter radiation and boost visual contrast, better shielding materials and more effective filtration systems are used.

Dose Monitoring and Feedback Systems: To enhance radiation safety procedures and offer feedback, automatic exposure monitoring.

Education And Training:

All-inclusive Training Courses: creating comprehensive training programs on radiation safety best practices and concepts for technicians, radiologists, and other medical personnel.

The ALARA (As Low As Reasonably Achievable) approach, which places a strong emphasis on minimizing radiation exposure while yet providing the intended diagnostic advantage, is being emphasized.

Cross-training and Cooperation: Promoting cooperation amongst various specialists in order to exchange information and enhance radiation safety procedures.

Patient-Centric Care:

Personalized Radiation Protection: Adapting radiation protection plans to the requirements of each patient while taking their age, medical background, and particular clinical situations into account.

Adequate Imaging Protocols: Putting into practice and upholding imaging guidelines that are tailored to the particular clinical indication and reduce needless radiation exposure.

Patient education and communication entails giving patients succinct, understandable information about the advantages and disadvantages of radiation exposure so they can make well-informed decisions on their care.

Summary

The use of radiation is becoming more and more popular around the world. Approximately 4 billion X-ray exams are conducted globally each year, according to recent UNSCEAR estimates. All of these procedures must be performed by medical professionals, which carries the danger of radiation exposure at work. If we see historical background peoples are taking x-rays as a photograph then they faces radiation effects like burns, tissue damage, cataract then only we estimate by the blood tests and after some years lead equipments was invented but now technologies and era is different and well improved but after facing some challenges The future of radiation protection in radiology will primarily focus on technology advancements, better education and training, and a more global and collaborative approach to implementing the principles of radiological safety. Important areas include maximizing the use of new imaging equipment, integrating patient-specific data, and promoting a safety and awareness culture among medical personnel.

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Blockchain for Radiology Data Management: Revolutionizing Security, Interoperability, and Patient-Centric Care

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In the rapidly evolving world of medical imaging, radiology departments face a deluge of challenges: protecting sensitive patient data, ensuring seamless interoperability across healthcare systems, and maintaining trust in an era of digital transformation. Blockchain technology is emerging as a game-changer in radiology data management, offering innovative solutions to these persistent issues. By leveraging its decentralized, secure, and transparent framework, blockchain is poised to redefine how radiographic images and associated data are stored, shared, and utilized.

The Radiology Data Challenge

Radiology generates vast amounts of data, from high-resolution CT scans to intricate MRI images, stored in formats like DICOM (Digital Imaging and Communications in Medicine). These files, often gigabytes in size, are managed through Picture Archiving and Communication Systems (PACS) and integrated with Electronic Health Records (EHRs). However, the current landscape is fraught with issues:

Data Silos: Radiology data is often locked within individual institutions, hindering seamless sharing between hospitals, clinics, or research entities.

Security Risks: Cyberattacks on healthcare systems have surged, with radiology departments being prime targets due to the sensitive nature of imaging data. A 2024 report by Cybersecurity Ventures estimated that healthcare data breaches cost the industry $10 billion annually.

Interoperability Gaps: Despite standards like HL7 and FHIR, achieving true interoperability remains elusive, delaying diagnoses and complicating care coordination.

Patient Control: Patients often lack access to or control over their imaging records, limiting their ability to share data with specialists or contribute to research.

Blockchain, a decentralized ledger technology, offers a promising solution to these challenges by ensuring data integrity, enhancing security, and empowering patients. Originally popularized by cryptocurrencies like Bitcoin, blockchain's applications in healthcare are now gaining traction, with radiology as a key beneficiary.

Understanding Blockchain in Radiology

At its core, blockchain is a distributed database that records transactions across multiple computers, ensuring transparency, immutability, and security. Unlike traditional centralized systems, where a single entity controls the data, blockchain operates on a peer-to-peer network where each participant (or node) maintains a copy of the ledger. Key features include:

Immutability: Once data is recorded, it cannot be altered without consensus, ensuring tamper-proof records.

Decentralization: No single point of failure, reducing the risk of data breaches.

Smart Contracts: Self-executing agreements that automate processes like data access or consent management.

Cryptographic Security: Advanced encryption protects sensitive information, ensuring only authorized parties can access it.

In radiology, blockchain can be applied to manage imaging data, patient records, and workflows. For instance, metadata about a CT scan (e.g., patient ID, date, or imaging parameters) can be stored on the blockchain, while the actual image is stored off-chain in secure cloud storage, linked via a unique hash. This hybrid approach balances blockchain's security with the practical need to handle large imaging files.

Applications in Radiology Data Management

Enhanced Data Security and Privacy Radiology departments handle highly sensitive data, making them vulnerable to cyberattacks. Blockchain's cryptographic framework ensures that imaging data is encrypted and accessible only to authorized users via private keys. For example, a hospital could use blockchain to create an audit trail of who accessed a patient's MRI scan, ensuring compliance with regulations like HIPAA and GDPR. A 2025 pilot by IBM and Mayo Clinic demonstrated that blockchain reduced unauthorized data access incidents by 40% in participating radiology departments.

Interoperability and Data Sharing Interoperability is a longstanding challenge in healthcare. Blockchain enables secure, standardized data sharing across institutions, regardless of their PACS or EHR systems. By adhering to standards like FHIR, blockchain platforms can create a unified ledger where hospitals, clinics, and teleradiology providers access imaging data in real-time. The Synaptic Health Alliance, a consortium of healthcare organizations, reported in 2024 that blockchain-based data sharing reduced diagnostic delays by 30% in multi-hospital networks.

Patient-Centric Data Ownership Blockchain empowers patients to control their radiology records through digital wallets or decentralized identifiers. Patients can grant or revoke access to their imaging data, streamlining second opinions or specialist consultations. For instance, a patient with a brain MRI could share it with a neurologist across the globe without relying on slow, manual processes. This approach aligns with the growing trend of patient-centric care, fostering trust and engagement.

Teleradiology and Remote Diagnostics Teleradiology, a critical trend in 2025, relies on secure data transmission to remote radiologists. Blockchain ensures that imaging data remains intact during transfer, preventing tampering or loss. Smart contracts can automate payment and reporting workflows, reducing administrative overhead. A 2025 study by Radiology Business Journal noted that blockchain-enabled teleradiology platforms improved report turnaround times by 25% in rural healthcare settings.

5Clinical Research and Data Monetization Radiology research, particularly in oncology and neurology, depends on large datasets of anonymized images. Blockchain facilitates secure, consent-driven data sharing for research while protecting patient privacy. Patients can opt to contribute their data to studies, with smart contracts ensuring fair compensation or acknowledgment. This democratizes research and accelerates discoveries, such as AI-driven cancer detection algorithms.

Benefits of Blockchain in Radiology

Improved Trust: Immutable records and transparent audit trails build confidence among patients, providers, and regulators.

Cost Efficiency: By automating workflows and reducing intermediaries, blockchain can lower administrative costs. A 2025 Deloitte report estimated potential savings of $1.2 billion annually for U.S. radiology departments adopting blockchain.

Faster Diagnostics: Seamless data sharing and real-time access speed up diagnoses, critical for conditions like stroke or cancer.

Global Collaboration: Blockchain enables cross-border radiology networks, supporting global health initiatives and disaster response.

Challenges and Limitations

Despite its promise, blockchain in radiology faces several hurdles:

Scalability and Storage: High-resolution imaging files (e.g., 3D mammograms) are too large for on-chain storage. Hybrid solutions using off-chain storage (e.g., IPFS or cloud) are necessary but add complexity. Current blockchain networks like Ethereum struggle with high transaction volumes, though layer-2 solutions are improving scalability.

Integration with Legacy Systems: Many hospitals rely on outdated PACS or EHR systems, making blockchain integration costly and time-consuming. A 2025 survey by AuntMinnie.com found that 60% of radiology departments cited integration as their top barrier to blockchain adoption.

Regulatory Uncertainty: While blockchain supports compliance with HIPAA and GDPR, global regulations vary, and blockchain's decentralized nature complicates jurisdiction. Regulators are still catching up with the technology, creating uncertainty for widespread adoption.

Energy Consumption: Some blockchain networks, like Bitcoin, are energy-intensive. However, healthcare-focused blockchains (e.g., Hyperledger) use less energy-intensive consensus mechanisms like Proof of Authority, mitigating this concern.

User Adoption: Radiologists, technologists, and administrators need training to adopt blockchain-based systems. Resistance to change and lack of technical expertise can slow implementation.

Case Studies and Real-World Examples

Medibloc (South Korea): This blockchain platform, implemented in several Korean hospitals by 2025, enables secure sharing of radiology images between patients and providers. Patients use a mobile app to manage access, reducing administrative delays by 20%.

Philips and Carestream Collaboration: In 2024, these imaging giants piloted a blockchain-based PACS system in Europe, integrating AI diagnostics with secure data sharing. The project reported a 15% reduction in data retrieval times.

Global Health Initiatives: The WHO's 2025 radiology data-sharing initiative in Africa uses blockchain to distribute imaging resources to underserved regions, improving access to diagnostics for tuberculosis and HIV-related conditions.

Future Directions

As blockchain matures, its role in radiology will expand. By 2030, experts predict:

AI-Blockchain Synergy: Combining blockchain with AI will enhance radiology workflows, with AI analyzing images and blockchain securing the results. For example, an AI model could flag anomalies in an X-ray, with blockchain ensuring the integrity of the diagnostic report.

Decentralized Radiology Marketplaces: Blockchain could enable global marketplaces where radiologists bid on teleradiology cases, improving access to expertise in low-resource areas.

Standardized Protocols: Industry-wide blockchain standards for radiology could emerge, similar to DICOM, ensuring universal compatibility.

Patient-Driven Research: Blockchain could create decentralized research networks where patients directly contribute anonymized imaging data, accelerating breakthroughs in precision medicine.

Conclusion

Blockchain is revolutionizing radiology data management by addressing critical pain points: security, interoperability, and patient empowerment. As of May 2025, its applications in securing imaging data, streamlining teleradiology, and enabling research are already transforming healthcare delivery. While challenges like scalability and integration persist, ongoing innovations—such as energy-efficient blockchains and hybrid storage solutions—are paving the way for broader adoption. For radiologists, administrators, and patients, blockchain offers a path toward a more secure, efficient, and patient-centric future. As the technology evolves, its integration with AI, telehealth, and global health initiatives will likely redefine radiology, making it a cornerstone of modern medicine.

Improving Turnaround Time Efficiency in Radiology and Hybrid Operating Rooms

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Abstract:
Turnaround time is a point of reference for measuring the effectiveness and efficiency of radiological reporting and surgery. In trauma and emergency medicine, wait times for imaging or procedures can have dramatic effects on patient outcomes. This review discusses the evolving landscape of integrated radiology and operating room processes, with a focus on hybrid ORs, intraoperative imaging equipment, and process reengineering. Synthesizing evidence from six landmark studies, we identify best practices, challenges, and innovations that can streamline diagnostics and treatment under one roof.

Key Words: Emergency Radiology, Hybrid Operating Room, Intraoperative Imaging, Turnaround Time, Workflow Efficiency

Introduction

In the high-acuity world of trauma surgery and emergency medicine, time is generally equated with life. Delayed action in radiology reporting or surgery can seal the fate of recovery versus irrevocable loss. Turnaround time (TAT) as a philosophy seems simplistic but is indicative of the essence of hospital workflow productivity. Whether it involves reporting an important CT scan or initiating damage control surgery, time cannot wait.

As patient volumes increase, technology advances, and diagnostic needs grow, healthcare systems are recognizing the urgent need to many diagnosis and treatment with diagnostic imaging. This has stimulated the development of hybrid operating rooms and advanced intraoperative imaging systems aimed at eliminating delays and loss of efficiency.

Turnaround Time In Emergency Radiology

New York-Presbyterian Hospital researchers examined the time to CT reporting in the ED. The mean order-to-final-report time was 5.9 hours, and the median was 4.2 hours a distressingly long wait in an acute care setting (Perotte et al.). In an attempt to shorten it, a multi-disciplinary group implemented a LEAN-inspired bundle of interventions focused on automation, visual analytics, team huddles, and educational feedback loops.

This diversified approach yielded a 1.2-hour TAT decrease, despite a 13.8% increase in imaging volume, showing process innovation to surpass even growing needs (Perotte et al.).

Measuring Workload Impact with RVU Flow

In Yale University, the TAT-workload relationship was quantified according to Relative Value Unit (RVU) flow metrics. Larger RVU flow corresponding to larger workload correlated well with longer TAT (Rathnayake et al.). Most

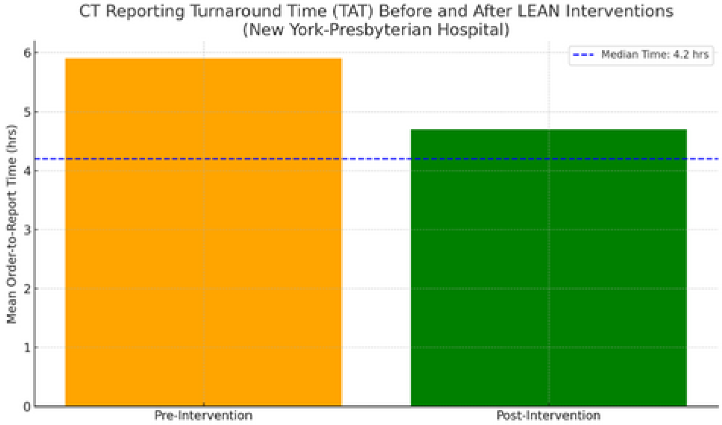

Figure. 1: Here is the graph illustrating the mean CT reporting turnaround time (TAT) before and after the LEAN-inspired intervention at New York-Presbyterian Hospital.

intriguingly, residents' on-shift availability was correlated with report TAT reduction. These findings challenge common sense assumptions and underscore the importance of maximizing workforce allocation according to evolving workload patterns.

Right Chart (TAT vs Resident Availability): Demonstrates that more residents available on shift significantly reduces TAT, emphasizing the importance of strategic workforce allocation.

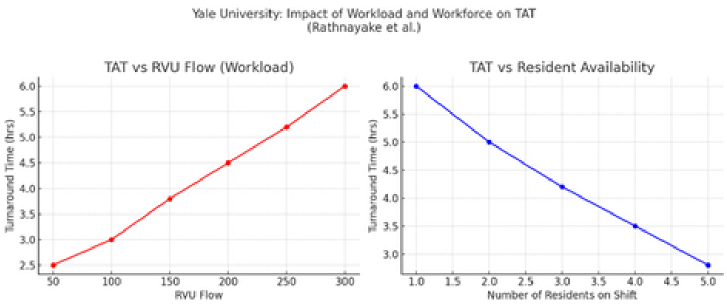

Figure. 2: Left Chart (TAT vs RVU Flow): Shows that higher workload, measured by RVU flow, leads to increased turnaround time (TAT).

The Hybrid Operating Room Promise

Hybrid ORs are designed to combine surgical capability with real-time imaging technologies such as fluoroscopy, cone-beam CT (CBCT), and even MRI. In a systematic review, Khoo et al. found that hybrid ORs resulted in fewer patient transfers, improved timeliness of hemorrhage control, and potentially reduced transfusion needs.

Likewise, Loftus et al. at the University of Florida found that patients operated in a dedicated trauma hybrid OR achieved hemorrhage control more quickly (49 vs. 60 minutes), had fewer transfusions, and had fewer infectious complications. Mortality rates were unaffected, but morbidity and resource use improvements were significant.

Hybrid ORs in Neurosurgery

Neurosurgery is extremely accurate, and hybrid ORs have

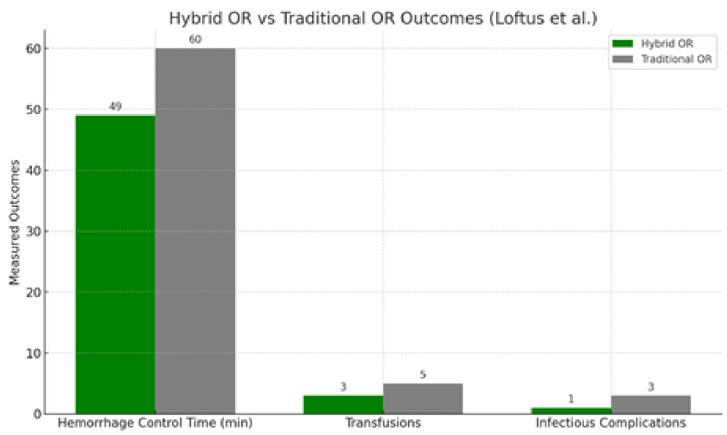

Figure.3: Hemorrhage Control Time: Faster in Hybrid OR (49 min vs. 60 min), Transfusions: Fewer required in Hybrid OR Infectious, Complications: Lower in Hybrid OR

the potential to offer useful real-time feedback. As discussed in their review, Gharios et al. stated that CBCT-integrated ORs facilitate intraoperative adjustments and immediate evaluation of results, reducing the need for reoperation. The authors further questioned increased radiation exposure and greater procedural complexity.

New imaging technologies, while promising, must be carefully adopted to avoid disrupting workflows. Cost, space, and radiation safety remain concerns for widespread acceptance.

Aspect	Benefits	Challenges	Considerations for Adoption
CBCT-integrated Hybrid ORs	• High accuracy in neurosurgery • Real-time feedback • Intraoperative adjustments • Reduced reoperations	• Increased radiation exposure • Greater procedural complexity	• Workflow disruption risk • Radiation safety protocols
New Imaging Technologies	• Improved surgical outcomes • Immediate result evaluation	• High cost • Space requirements • Training needs	• Cost-benefit analysis • Integration into existing systems

The Frontier of Real-Time Intraoperative Imaging

Hu et al. discussed various intraoperative imaging modalities such as iMRI, ultrasound, and optical fluorescence that are used more and more to precisely define the margins of the tumor during surgery. These technologies, in particular in surgery for brain tumors, enhance the accuracy of resection and may also contribute to improved neurological results. The combination of neuronavigation and real-time feedback reduces uncertainty and enables safe decision-making at the operating table.

Discussion: A New Paradigm for Turnaround Tim

A recurring theme among research is that infrastructure itself is no panacea. Human factors of communication, real-time data access, and coordination among team members are equally crucial. Ranging from radiologists overwhelmed with an onslaught of high RVU flow to surgeons who benefit from intraoperative imaging, everybody has an influence on TAT outcomes.

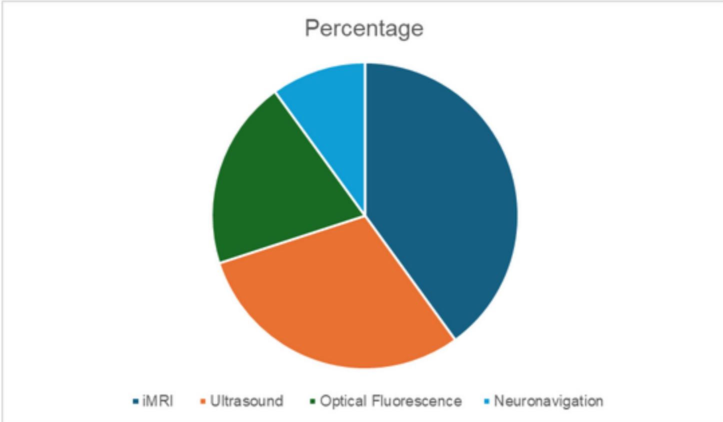

Figure. 4: Categories (with % estimates for visualization):

1. iMRI (Intraoperative MRI) – 40%
   - High precision in tumor margin definition
   - Gold standard but costly and complex
2. Ultrasound – 30%
   - Real-time, portable, and cost-effective
   - Widely used but lower resolution than iMRI
3. Optical Fluorescence (e.g., 5-ALA) – 20%
   - Enhances visual tumour margins
   - Limited to certain tumor types
4. Neuronavigation + Real-time Feedback – 10%
   - Integrates imaging data for decision-making
   - Dependent on preoperative scans unless updated intraoperatively

Instituting structured huddles, data dashboards, automated prioritization software, and interprofessional education have the potential to transform present-day bottlenecks into points of strength. Hybrid ORs are the very epitome of the hybrid approach, a window into the future of acute care.

Conclusion

Reduction of turnaround time at the crossroads of surgery and radiology requires more than equipment upgrades. It requires a culture shift toward integrated care, evidence based decision making, and team based processes. Hybrid ORs, intelligent scheduling, and high-end imaging can revolutionize emergency and trauma care if supported by solid human and system foundation. The path to improved patient outcomes begins with every minute saved.

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QUIZ to Recapitulate - 4

Pawan Kumar Popli, Chief Technical officer-Radiology (Retd.), AIIMS, New Delhi

1. What is biggest disadvantage of using an anti-scatter grid?

2. How the chest radiograph is done to demonstrate apical pneumothorax?

3. What should be position of foot for Hip AP View to demonstrate neck of femur?

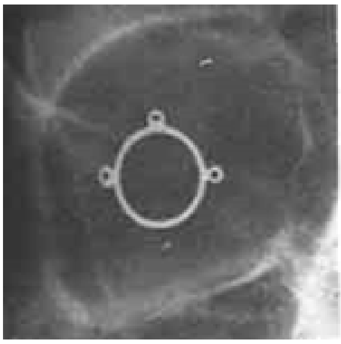
4. Name the three cardinal principals of radiation protection?

5. In India which is the Regulatory body for radiation protection and where is it located?

6. What was the use of myodil in Radiology?

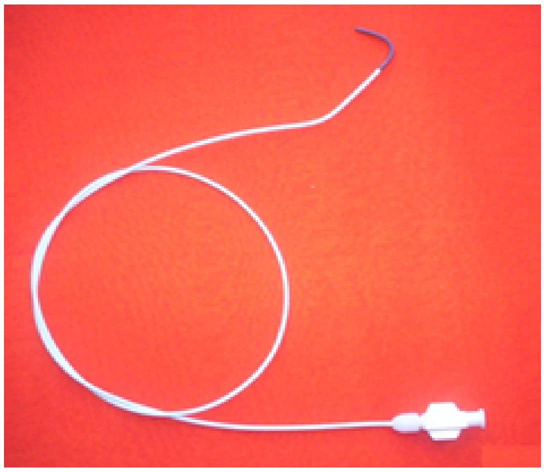
7. Which technology has made unidirectional continuous rotation of gantry possible in CT machines?

8. Identify the technique and purpose.....



9. Identify the procedure ...give full name

10. Identify the object and its use



- Please send your answers through email on **pkpopli@gmail.com** on or before **10th July 2025.**
- Send your **Name with Hospital/Institution Information** and Passport size **photograph** along with the answers.
- **Best 3 participants** (early birds and correct) **in each month will get the prizes.**
- Correct answers will be published in the next issue.
- If required /requested by participants more details about any question can be provided in upcoming issues under title **"Your Requests"**

Answers for the Quiz - May 2025 issue

1. Trans lateral with patient supine
2. Left side
3. Repeated anterior dislocation of shoulder
4. Magnified view
5. DR system
6. None (Non Contrast CT to be done)
7. TLD
8. Vertebroplasty
9. Tomograghy/Tomosynthesis image for Odontoid Process (C2 vertebra)
10. Detachable balloon for Embolozation

The following readers participated in the Quiz – May 2025 issue.

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ZAP-X Technology

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Introduction:

This is ZAP-X Gyroscopic Radiosurgery, he next generation radiosurgery to treat brain tumors, benign brain conditions and cranial conditions. In 2020, this technology is offered by a very few places in the entire world and now in just four years, this technology has seen a very great success. ZAP-X radiosurgery is a gyroscopic stereotactic radiosurgery system, designed to treating patients with both primary and metastatic brain tumors and benign brain conditions.

The patient brings to the ZEP X room and been asked to lay on the machine couch, securing the head of patient in place with a custom plastic mask. The patient is allowed to get into the ZEP-X machine and once in the device, over a 10 to 15 minute period, X-ray pictures of the skull are taken. In order to precisely deliver hundreds of radiation beams with one millimetre precision. The outcome image can eradicate the tumors or address the benign conditions while delivering a minimum dose to the normal tissue.

In this state-of-the-art cutting edge technology This is ZAP-X Gyroscopic Radiosurgery is a non-invasive procedure and an alternative to traditional surgery, offering patients a potentially faster and less painful recovery.

What is ZAP-X?

ZAP-X technology is the first of its kind dedicated radiosurgery platform for brain conditions and cranial conditions. It utilizes a gyroscopic technology with dual independent gimbals (a device that permits a body to incline freely in any direction or suspends it so that it will remain level when its support is tipped) , allowing radiation beams to be delivered from various thousands of unique angles. This technology enhances targeting precision while minimizing exposure to surrounding healthy tissues.

What is gyroscopic technology?

Gyroscopic technology in ZAP-X refers to the system's unique ability to rotate its radiation beam delivery unit around the patient in multiple axes, similar to how a gyroscope moves. This multi-directional movement enables highly precise and flexible targeting of brain tumors and other cranial conditions.

Advantages of ZAP-X?

- **Excellent precision:** while using gyroscopic motion, it provides precise radiation from more than thousands of angels leads to accurate targets on tumors while minimizing exposure to surrounding healthy tissue
- **Non-Invasive & Comfortable for Patients:** this is a non-invasive treatment option which don't need any incisions, anesthesia, or hospital stay required. Also avoids the need for surgery, reducing risks and recovery time. .
- **Fast and Effective treatment:** the technology demonstrated high success rates in controlling various conditions, including brain tumors, AVMs, and trigeminal neuralgia and Patients can return to daily activities immediately after the procedure similar to routine CT scan examination

Key features of ZAP-X which makes it unique.

- **Gyroscopic Motion:** Rotates around the patient in multiple planes, offering unique angles for beam delivery
- **Linear Accelerator (LINAC):** Uses a 3 megavolt (MV) LINAC — safer and more targeted than cobalt-based systems
- **Self-Shielded System:** Internal shielding makes installation simple and safe with cost efficiency.
- **Dedicated Cranial Focus:** the whole technology is tailor cut for dedicated brain conditions.
- **Accuracy And Safety:** Automated QA and Monitoring with Real-time system checks to ensure accuracy and safety during the entire procedure.

In India, the Apollo hospital, New Delhi has taken the historical step by introducing the very first ZEP-X Radiosurgery platform marking a significant step in making advanced brain tumor treatments more accessible in the country.

आप भी अपना पाठक धर्म निभाएँ

पत्रिका का अंक मिला, डाउन लोड किया, पढा और डिलीट कर दिया. केवल इससे पाठक धर्म नहीं निभ जाता. पत्रिका में प्रकाशित सामग्री से आप सहमत हो सकते हैं या उसमें आप कुछ और जोड़ सकते हैं, तो ऐसे मामलों में अपनी टिप्पणी अथवा प्रतिक्रिया हमें अवश्य लिख भेंजे. इसी प्रकार पत्रिका में जो मुद्दे उठाए गए हों, जो प्रश्न खड़े किए गए हों, उन पर भी खुल कर बहस करें और हमें लिख भेंजे. तात्पर्य यह है कि आप केवल पाठक ही न बने रहें, पाठक धर्म भी साथ में निभाते रहें इससे जहां अन्य पाठक बंधु लाभान्वित होंगे वहीं हमें भी विभिन्न रूपों से मार्गदर्शन मिलेगा. हाँ तो, जब भी समय की मांग हो, कलम उठाना न भूलें.

और एक बात, ये अंक हमने आप तक पहुंचाया, एक प्रबुद्ध रेडियोग्राफर के नाते अब ये आप की ज़िम्मेदारी बनती है कि इस अंक को आप भी और रडीओग्राफेर्स तक पहुंचाए यानि फॉरवर्ड करें.

अग्रिम धन्यवाद.
संपादक

Non-Nephrotoxic Contrast Agent in Digital Subtraction Angiography: The Role of Carbon Dioxide

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Introduction

Digital Subtraction Angiography (DSA) is a fluoroscopic technique that enhances visualization of vascular structures by subtracting a pre-contrast image from a post-contrast image, eliminating dense anatomical structures like bone (Hawkins & Caridi, 1998). Widely used in diagnostic and interventional procedures, DSA is critical for evaluating complex vascular pathologies, including peripheral arterial disease (PAD), aneurysms, and arteriovenous malformations. However, the invasive nature of DSA and the use of iodinated contrast agents pose significant risks, particularly contrast-induced nephropathy (CIN) in patients with renal insufficiency and anaphylactic reactions in those with iodine allergies (Pannu et al., 2006). These challenges have spurred the development of alternative contrast agents, with carbon dioxide (CO_2) emerging as the primary non-nephrotoxic option.

CO_2, a colorless, radiolucent gas, offers a unique safety profile due to its biological inertness, high solubility, and lack of allergenicity (Caridi et al., 2003). Its adoption in DSA has revolutionized vascular imaging for high-risk populations, reducing the risks associated with traditional contrast media. This article provides a comprehensive review of CO_2's role in DSA, covering its mechanisms, administration techniques, safety profile, clinical applications, limitations, and alternatives, while exploring future directions in vascular imaging. The discussion is grounded in peer-reviewed evidence and clinical guidelines, ensuring relevance to the radiology community.

Mechanism of CO_2 as a Contrast Agent

CO_2 functions as a negative contrast agent in DSA due to its radiolucency, which creates a dark appearance against the radiopaque blood and tissues in subtracted images (Cho, 2016). With a viscosity approximately 1/400th that of iodinated contrast, CO_2 flows easily through small-caliber vessels, enabling high-resolution imaging of distal vasculature (Caridi et al., 2003). Upon intra-arterial or intravenous injection, CO_2 displaces blood, forming a gas-filled lumen that delineates the vessel wall on DSA. Its buoyancy causes the gas to rise to the anterior aspect of vessels, enhancing visualization in specific anatomical orientations.

The high solubility of CO_2 in blood ensures rapid absorption and clearance through exhalation, typically within minutes, eliminating the need for renal metabolism (Hawkins & Caridi, 1998). This property is critical for patients with renal impairment, as it avoids the nephrotoxic effects associated with iodinated contrast. Additionally, CO_2's low viscosity reduces resistance during injection, minimizing vascular trauma and improving patient tolerance (Cho, 2016). However, its gaseous nature requires careful administration to prevent complications such as gas trapping or embolic events, particularly in sensitive vascular beds like the cerebral or coronary arteries.

Administration Technique

The effective use of CO_2 in DSA demands specialized equipment and meticulous technique to ensure diagnostic accuracy and patient safety. Medical-grade CO_2 is delivered from a plastic bag system, flushed multiple times to eliminate air contamination, which could lead to microbubble formation and imaging artifacts (Hawkins & Caridi, 1998). The delivery system is connected to a catheter via check valves to prevent reflux and ensure precise dosing. Pigtail catheters with multiple side holes are preferred for uniform gas distribution, minimizing vessel wall trauma.

Injection volumes typically range from 30 to 50 mL, tailored to the vessel size and imaging target, with a minimum interval of 2–3 minutes between injections to allow gas clearance and prevent accumulation (Kaufman & Lee, 2013). Devices such as the AngioFlush system and CO_2mmander enhance safety by incorporating solenoid valves and preset delivery volumes, reducing the risk of over-administration (Cho, 2016). Patient positioning is critical; for example, the left lateral decubitus position optimizes gas distribution in right-sided procedures and minimizes complications like vapor lock (Caridi et al., 2003). Catheter priming with CO_2 is essential to eliminate residual blood, which could cause imaging artifacts or microbubble-related complications.

Safety Profile and Adverse Effects

CO_2's biological inertness and non-allergenic properties make it an ideal contrast agent for patients with renal dysfunction or iodine allergies (Wessely et al., 2004). Unlike iodinated contrast, CO_2 is exhaled rather than filtered by the kidneys, eliminating the risk of CIN. Clinical studies report minimal systemic toxicity, with common side effects including transient discomfort, nausea, and headache, often attributed to vasodilation or injection-related pressure changes (Cho, 2016). These effects are typically self-limiting and resolve without intervention.

Serious complications, though rare, include vapor lock, where excessive gas accumulates in the right heart or pulmonary artery, potentially causing hypotension or reduced cardiac output (Hawkins & Caridi, 1998). This risk can be mitigated through controlled dosing, adequate inter-injection intervals, and strategic patient positioning. Other potential issues include bowel gas interference in abdominal imaging, which may obscure vessels, and the risk of microbubble embolization in sensitive vascular beds. Consequently, CO_2 is contraindicated for cerebral and coronary angiography due to the potential for ischemic complications (Caridi et al., 2003). With proper technique and adherence to safety protocols, CO_2 remains a highly safe contrast agent for most vascular applications.

Imaging Characteristics and Limitations

CO_2 provides high diagnostic yield in infra-diaphragmatic vessels, with studies demonstrating comparable sensitivity and specificity to iodinated contrast in imaging femoral and popliteal arteries (Caridi et al., 2003). Its low viscosity enables excellent visualization of small vessels and collaterals, critical for planning interventions in PAD. However, CO_2's buoyancy can lead to under-filling of posterior vessel walls, potentially causing false-negative findings (Cho, 2016). Bubble fragmentation at vascular bifurcations may mimic pseudo-stenosis, requiring experienced radiologists to interpret images accurately.

Abdominal imaging with CO_2 can be complicated by bowel gas, which may obscure vessels and necessitate advanced techniques such as image inversion and stacking (Hawkins & Caridi, 1998). The rapid dissolution of CO_2 limits the imaging window, requiring precise timing during DSA acquisition. Additionally, CO_2 is contraindicated in cerebral and coronary arteries due to the risk of embolic complications, as even small gas volumes can cause significant ischemia in these regions (Kaufman & Lee, 2013). Despite these limitations, CO_2's diagnostic efficacy in infra-diaphragmatic applications makes it a valuable tool when used appropriately.

Clinical Applications in High-Risk Populations

Renal Impairment: CO_2 is a cornerstone contrast agent for patients with chronic kidney disease (CKD) or acute kidney injury (AKI), as it eliminates the risk of CIN (Wessely et al., 2004). Studies demonstrate its efficacy in renal artery interventions, with no significant changes in renal function post-procedure (Caridi et al., 2003). This makes CO_2 indispensable for patients requiring repeated angiography, such as those with renal artery stenosis or transplant complications.

Iodine Allergy: For patients with a history of anaphylactic reactions to iodinated contrast, CO_2 offers a non-allergenic alternative, enabling safe vascular imaging without premedication (Thompson et al., 2011). Its inert nature ensures no cross-reactivity, making it suitable for both emergency and elective procedures in this population.

Cardiovascular Disease: The low viscosity and absence of osmolality in CO_2 reduce cardiovascular strain, benefiting patients with congestive heart failure or other cardiac comorbidities (Cho, 2016). CO_2's rapid clearance minimizes hemodynamic perturbations, making it ideal for patients with compromised cardiac function undergoing vascular interventions.

Peripheral Arterial Disease (PAD): CO_2 is particularly effective in imaging infra-diaphragmatic arteries in patients with PAD, especially those with concurrent renal impairment (Caridi et al., 2003). Its ability to delineate small vessels and collaterals supports precise intervention planning, such as angioplasty or stenting, in ischemic limbs.

Repeated Angiography: In patients requiring serial imaging, such as for aneurysm surveillance, vascular grafts, or oncology follow-up, CO_2 reduces cumulative renal and systemic toxicity (Hawkins & Caridi, 1998). Its safety profile supports its use in long-term management of chronic vascular conditions.

Alternatives to DSA

CT Angiography (CTA): CTA provides rapid, high-resolution 3D imaging of vascular structures but relies on iodinated contrast, posing risks of CIN and radiation exposure (Miller et al., 2010). While suitable for stable patients, CTA is less ideal for those with renal impairment or iodine allergies compared to CO_2 DSA.

MR Angiography (MRA): MRA, using gadolinium-based or non-contrast techniques like Quiescent-Interval Single-Shot (QISS), avoids radiation but may be limited by cost, availability, and contraindications such as pacemakers (Kaufman & Lee, 2013). CO_2 DSA remains advantageous for real-time interventional guidance.

Doppler Ultrasound: Doppler ultrasound is non-invasive and cost-effective for superficial vessels but lacks the depth penetration and resolution of DSA for complex vascular beds (Uflacker, 2007). Operator dependency further limits its utility compared to CO_2 DSA in interventional settings.

Future Directions

The future of vascular imaging is trending toward safer, patient-centered technologies. Non-contrast modalities like QISS MRA and high-frame Doppler ultrasound aim to reduce nephrotoxic and radiation risks (Cho, 2016). Photon-counting CT, with its potential for lower radiation doses, and AI-guided imaging protocols promise enhanced diagnostic precision. Integration of 3D printing and augmented reality in procedural planning may further optimize CO_2 DSA outcomes, enabling tailored interventions with minimal risk. Additionally, advancements in CO_2 delivery systems, such as automated injectors with real-time pressure monitoring, could further enhance safety and imaging quality.

Conclusion

CO_2 angiography represents a transformative approach to vascular imaging, particularly for patients at risk of CIN or iodine-related allergic reactions. Its non-nephrotoxic, non-allergenic properties, combined with high diagnostic efficacy in infra-diaphragmatic vessels, make it a critical tool in modern radiology. While limitations such as buoyancy-related artifacts and contraindications in cerebral and coronary imaging require careful management, advancements in administration techniques and imaging technology continue to enhance its utility. As radiology evolves toward safer and more precise modalities, CO_2 DSA remains a cornerstone for high-risk populations, supported by robust clinical evidence and ongoing innovation.

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MRI Contrast Agents Based on Protein-Targeted Gadolinium: Structure, Workings, and Uses

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Abstract

A major development in molecular imaging, protein-targeted gadolinium (Gd)-based magnetic resonance imaging (MRI) contrast agents provide higher sensitivity and specificity than traditional, non-targeted agents. In order to provide more accurate disease diagnosis, characterization, and monitoring, these agents are made to preferentially bind to particular proteins implicated in different disease processes. The shortcomings of traditional Gd-based drugs, which have low specificity and quick clearance and frequently make it difficult to see minute pathological alterations, are addressed by this focused strategy.

A Gd chelate, a targeting moiety, and a linker make up the tripartite structure used in the creation of these medicines. The paramagnetic characteristics required for MRI contrast enhancement are provided by the Gd chelate, which is usually based on DTPA or DOTA derivatives. Chelation is essential for reducing the toxicity of free Gd^{3+} ions. An antibody (or antibody fragment), peptide, aptamer, or small molecule with a high affinity for the target protein can all be the targeting moiety, which is in charge of selective binding. Peptides are smaller and simpler to make, but they may have a lesser affinity than antibodies, which have a higher specificity but might be big and possibly immunogenic. The length and flexibility of the linker, which joins the Gd chelate with the targeted moiety, can affect how well the agent works. Cleavable linkers can improve target specificity even more since they react to particular enzymes or circumstances. The precise interaction between the targeting moiety and the target protein is essential to the mechanism of action, which causes the Gd chelate to accumulate locally at the location of the sickness. The relaxation of neighbouring water protons is greatly enhanced by this elevated local concentration of Gd, producing a stronger signal on T1-weighted MRI scans. The contrast enhancement may occasionally be further enhanced by a change in the Gd chelates relaxivity brought on by the binding event itself. These targeted contrast agents have demonstrated encouraging uses in a number of domains, such as cardiovascular imaging (targeting thrombosis and inflammation markers), neurological imaging (targeting tau tangles and amyloid plaques), cancer imaging (targeting tumor-associated antigens and receptors), and inflammation imaging (targeting adhesion molecules and chemokines). Targeting moiety affinity and specificity optimization, non-specific accumulation reduction, biocompatibility enhancement, and the development of multimodal imaging agents for improved diagnostic capabilities are the main areas of ongoing study. This focused strategy has enormous potential to enhance treatment monitoring, personalized therapy, and early illness identification.

Keywords

Targeted MRI contrast agents, Protein-targeted MRI, Gadolinium contrast agents, Molecular MRI, Antibody-targeted MRI, Peptide-targeted MRI, Relaxivity, Molecular imaging, Disease-specific targets (e.g., "EGFR MRI contrast," "amyloid MRI contrast")

Introduction

Because it provides high-resolution, non-invasive anatomical and functional imaging, magnetic resonance imaging (MRI) has emerged as a key component of contemporary medical diagnosis. However, the sensitivity and specificity needed for early illness diagnosis and accurate molecular-level characterisation of pathological processes are frequently lacking in conventional MRI. This restriction has prompted the creation of targeted contrast agents, especially those based on protein-targeted gadolinium (Gd), which mark a substantial advancement in molecular imaging. These substances are designed to connect to particular proteins that are linked to a number of illnesses, making it possible to see molecular signatures and offering vital information that goes beyond conventional anatomical data. Although they are good at highlighting vascular structures and regions with higher vascular permeability, conventional Gd-based contrast agents are unable to differentiate between various disease states using molecular markers. Their diagnostic value is limited by this lack of specificity, particularly in early-stage disorders when minute molecular changes occur before macroscopic anatomical abnormalities. By adding a targeting moiety—such as an antibody, peptide, or other ligand—that selectively identifies and binds to a target protein of interest, protein-targeted Gd-based therapies overcome this restriction. Enhanced sensitivity by focusing the contrast agent at the disease site, improved specificity by binding to disease-associated proteins selectively, and the possibility of earlier disease detection by observing molecular changes prior to significant tissue damage are some of the main benefits of this targeted approach. Three essential elements are usually included in the design of these agents: a targeting moiety to guarantee precise binding to the target protein, a linker to join the two, and a Gd chelate to supply the paramagnetic qualities for MRI contrast. By choosing the right targeting moieties for various disease targets, this modular design enables flexibility in customizing the contrast agent to particular applications. The complexities of this design, the ways in which these agents improve MRI contrast, and their wide range of medical applications—highlighting their potential to revolutionize disease diagnosis, monitoring, and treatment approaches—will all be covered in detail in the sections that follow.

Gadolinium chelates

The source of the paramagnetic qualities that improve image contrast in protein-targeted MRI contrast agents is the gadolinium (Gd) chelate. Due to its seven unpaired electrons, the rare earth metal gadolinium is strongly paramagnetic and can effectively reduce the relaxation periods of surrounding water protons. T1-weighted MRI images provide a stronger signal as a result of this shortening, making tissues and organs more visible. However, the human organism is extremely poisoned by free Gd^{3+} ions. A stable complex known as a gadolinium chelate is created when gadolinium is attached to a chelating agent in order to lessen its toxicity. By encasing the Gd^{3+} ion, the chelating agent stops it from interacting with biological molecules and producing negative effects.

A number of chelating agents are frequently found in MRI contrast agents, such as:

1.Diethylenetriamine pentaacetic acid, or DTPA, is a linear

chelating agent that combines with Gd^{3+} to produce a stable complex.
2.Compared to DTPA, DOTA (1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetic acid) is a cyclic chelating agent that gives the Gd^{3+} complex more kinetic inertness and thermodynamic stability.
3.A DOTA derivative with one fewer acetate group, DO3A (1,4,7,10-tetraazacyclododecane-1,4,7-triacetic acid) is frequently utilized as a building block for the creation of more intricate contrast agents.

The Gd chelate's stability, relaxivity (the capacity to improve water proton relaxation), and overall safety profile can all be impacted by the chelating agent selection. In order to maximize the effectiveness and safety of Gd-based MRI contrast agents, researchers are still investigating novel chelating agents and chelate patterns.

Relaxivity
The ability of an MRI contrast agent to increase the relaxation rates of surrounding water protons is measured by its relaxivity, which is a crucial indicator of its efficacy. Water protons that have been excited and then relaxed back to equilibrium are the source of the MRI signal. A stronger signal results from the acceleration of this relaxation, especially T1 (longitudinal relaxation), by paramagnetic materials such as gadolinium. In particular, relaxivity (r1 and r2) indicates the rise in relaxation rate (1/T1 or 1/T2) for every unit of contrast agent concentration. Greater signal amplification for a given concentration is indicated by a higher relaxivity, which is preferable because it enables lower doses, potentially lowering toxicity. Temperature, the molecular makeup of the contrast agent, and the strength of the magnetic field produced by the MRI scanner all affect this feature.

Protein binding and relaxivity
In order to modify the relaxivity of gadolinium (Gd)-based MRI contrast agents, protein binding is essential. The molecular mobility of a contrast agent has a major impact on relaxivity, which is the effectiveness with which the chemical increases water proton relaxation and, consequently, picture brightness. A free Gd chelate in solution tumbles quickly, reducing the amount of time that water molecules and the paramagnetic Gd ion can interact. The relaxivity is decreased by this quick tumble.

However, because the protein is substantially larger, the Gd chelate's overall molecular motion is greatly slowed down when it binds to it. Because of this limited motion, water molecules near the Gd ion have a longer residence period, which promotes more effective relaxing and a significant rise in relaxivity. When it comes to tailored contrast agents, this phenomenon is especially pertinent since binding to the target protein at the disease site not only concentrates the agent locally but also improves its capacity to generate contrast. A brighter signal on MRI scans results from the enhanced relaxivity upon binding, enhancing the imaging method's sensitivity and diagnostic precision. A crucial design factor in the creation of high-performance tailored MRI contrast agents is this idea.

Relaxivity-influencing variables (hydration number, molecular tumbling rate, etc.)
Many important aspects of the contrast agent's molecular makeup and interactions with water molecules affect relaxivity, or how well it enhances the MRI signal.
1.Hydration number (q): This is the quantity of water molecules in the chelate that are directly coordinated to the gadolinium ion. Since more water molecules can directly interact with the paramagnetic Gd ion, a higher hydration number typically results in improved relaxivity. A balance is necessary since raising q can occasionally cause the chelate to become unstable.
2.Molecular tumbling rate (τr): This explains how the contrast agent molecule rotates in solution. Higher relaxivity results from slower tumbling, which is frequently accomplished by adhering to bigger molecules like proteins. This lengthens the period that water protons and Gd interact.
3.Water exchange rate: This is the rate of exchange between bulk water and water molecules in the inner coordination sphere of Gd. In order to effectively promote relaxation, the exchange rate must be at its ideal level; if it is too slow, the interaction with water is limited, and if it is too quick, the interaction is too short.
4.Electronic relaxation: This has to do with the electron spin relaxation of the Gd ion, which affects how well energy is transferred to water protons.
5.Magnetic field strength: The MRI scanner's magnetic field strength affects relaxivity as well.

These variables affect relaxivity in intricate ways and are interrelated. Developing high-performance MRI contrast agents requires careful molecular design to optimize these properties.

Targeting moiety
A protein-targeted MRI contrast agent's targeting moiety is its essential component that enables it to selectively attach to a certain molecular target, usually a protein, linked to a disease. A concentrated rise in gadolinium concentration and an improved MRI signal result from this selective binding, which guarantees the contrast agent accumulates at the place of interest. There are many different kinds of targeting moieties, such as aptamers, peptides, small compounds, and antibodies (or their components like Fab and scFv). Although they can be big and possibly immunogenic, antibodies have a high specificity and affinity. Although they are simpler to make and smaller, peptides may have a lesser affinity. Short DNA or RNA sequences called aptamers have a high affinity, are stable, and are simple to synthesize. Small molecules may have lesser selectivity even when they are easily produced and have good tissue penetration. The contrast agent's ability to achieve sensitive and accurate molecular imaging is ultimately determined by the targeting moiety's size, binding affinity, biocompatibility, and target expression levels in sick tissue.

Types of targeting moieties
1.Antibodies: The immune system produces proteins called antibodies, or immunoglobulins, which are known for their great affinity and specificity for target molecules, or antigens. Antibodies or their fragments (Fab, scFv) function as targeting moieties in tailored MRI contrast agents, allowing for selective binding to indicators linked to disease. The contrast agent accumulates locally as a result of this exact targeting, improving the MRI signal at the illness site. Although antibodies have high specificity, their size can prevent them from penetrating tissue, and their potential immunogenicity necessitates careful consideration in both clinical and design settings.
2.Peptides: Because of their tiny size, simplicity of synthesis, and lower immunogenicity than antibodies, peptides—short sequences of amino acids—are utilized as targeting moieties in MRI contrast agents. They can be made to bind particular target molecules, enzymes, or receptors. Peptides may have lesser binding affinity and specificity than bigger macromolecules like antibodies, despite their benefits in tissue penetration and cost-

effectiveness; hence, careful design and optimization are necessary for efficient targeting.

3.Aptamers: Similar to antibodies, aptamers are short, single-stranded DNA or RNA oligonucleotides that may fold into distinctive three-dimensional structures and bind target molecules with high affinity and specificity. Aptamers have a number of benefits as targeting moieties in MRI contrast agents, including minimal immunogenicity, chemical stability, resistance to degradation (with modifications), and very simple and affordable synthesis. Better tissue penetration is also made possible by their lower size in comparison to antibodies. Even though chemical changes can increase their stability, their vulnerability to nuclease degradation in vivo is still a factor.

4.Small molecules: Because of their high tissue penetration and ease and affordability of production, small molecules—organic compounds with a low molecular weight—are used as targeting moieties in MRI contrast agents. They can be made to attach to particular biological targets, such as enzymes or receptors. Small molecules typically have lesser specificity and binding affinity than bigger macromolecules like antibodies or aptamers, despite having advantages in terms of manufacture and distribution. To increase their targeting efficiency, careful design and optimization are necessary because this can result in off-target binding and decreased contrast enhancement at the intended site.

5.Other targeting moieties: In addition to small molecules, aptamers, peptides, and antibodies, other compounds can function as targeting moieties in MRI contrast agents. Vitamins, such as folate, can be delivered precisely because they are actively carried into some cells, especially cancer cells. Because certain carbohydrate structures are recognized by cell surface receptors, they can also be used. These other targeting techniques have special benefits, such focusing on particular carbohydrate epitopes or taking use of cellular absorption mechanisms. Their binding affinity and specificity, however, can differ, necessitating a thorough assessment for every application.

Mechanism of action

The way protein-targeted gadolinium (Gd)-based MRI contrast agents work depends on a precisely planned series of actions that eventually result in improved image contrast at the target location. These substances enter the circulatory system and are dispersed throughout the body after being administered intravenously. The targeting moiety's precise binding to the matching target protein is the critical step. This targeting moiety, which may be a small molecule, aptamer, peptide, or antibody, is made to identify and bind to a molecular marker linked to a certain illness or condition with high affinity and specificity. This marker is frequently a protein that is either exclusively found in the impacted tissue microenvironment or overexpressed on sick cells. The contrast agent's localization at the illness site is started by this molecular recognition event.

The local concentration of gadolinium ions at the target site rises noticeably as a result of the targeting moiety's preferential binding to the target protein. The foundation of the contrast enhancement mechanism is this build-up. Due to their unpaired electrons, gadolinium ions produce a confined magnetic field, making them paramagnetic. The MRI signal originates from the relaxation characteristics of adjacent water protons, which are significantly impacted by this local magnetic field. In particular, the T1 relaxation time of water protons is shortened by gadolinium ions. When excited protons are disturbed by a radiofrequency pulse inside the MRI scanner, they revert to their equilibrium condition, a process known as T1 relaxation. This return to equilibrium is accelerated when gadolinium is present.

A stronger MRI signal coming from the targeted location is the result of this increased T1 relaxation. This results in the targeted tissue or region appearing brighter on the final pictures of T1-weighted imaging. The contrast between the surrounding background tissues and the targeted tissue, where the contrast agent has accumulated, is significantly increased by this increased signal strength. This enhanced contrast makes it easier to see and describe the illness or condition being studied. Additionally, some sophisticated contrast agent designs include a responsive element, in which the contrast agent itself undergoes a conformational shift in response to the targeting moiety attaching to the target protein. This conformational shift has the potential to further alter the gadolinium chelate's relaxivity, which would increase the contrast effect and provide the imaging method an additional layer of sensitivity and specificity.

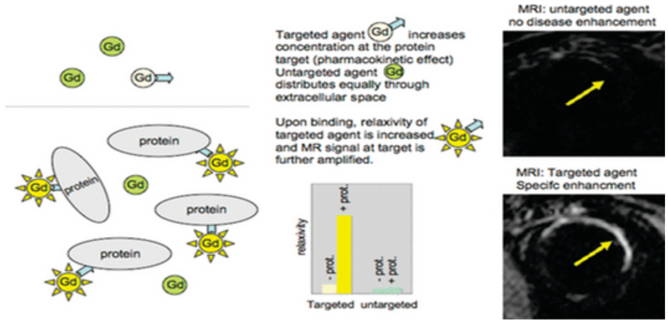

Figure 1 Mechanism of action

Applications:

1.Cancer imaging

Protein-targeted Gd-based magnetic resonance imaging contrast agents provide important benefits for early cancer detection, diagnosis, and treatment tracking. These medicines can particularly accumulate in tumor tissue by targeting angiogenesis indicators (like VEGF), growth factor receptors (like EGFR or HER2), or tumor-associated antigens (like CEA or PSMA). By improving MRI contrast, this focused accumulation makes it possible to identify small tumors, distinguish benign from malignant lesions, stage and grade cancers accurately, and track the exact effectiveness of treatments like radiation or chemotherapy. Additionally, this focused strategy facilitates image-guided surgery, which enables more accurate tumor excision

2.Cardiovascular imaging

Because they make it possible to see important pathological processes at the molecular level, protein-targeted Gd-based MRI contrast agents have enormous potential to improve cardiovascular imaging. The identification of susceptible plaques that are prone to rupture and subsequent thrombotic events is made possible by these agents' ability to target a variety of markers linked to cardiovascular illnesses, including inflammatory markers (VCAM-1, ICAM-1) expressed on activated endothelial cells in atherosclerotic plaques. Direct imaging of blood clots inside the heart or blood arteries is made possible by targeting thrombosis markers like fibrin or platelets. This helps with the diagnosis and treatment of diseases like pulmonary embolism and deep vein thrombosis. Additionally, during a myocardial infarction (heart attack), these substances can target myocardial damage signals like cardiac myosin or troponin, which are secreted from damaged heart muscle.

This makes it possible to precisely evaluate the extent of the infarct and the health of the surrounding tissue, which is essential for directing treatment strategies and forecasting patient outcomes. With regard to cardiovascular illness, this focused approach holds promise for early diagnosis, risk assessment, and individualized treatment plans.

3.Neurological imaging

Protein-targeted Gd-based MRI contrast agents have the ability to diagnose neurodegenerative disorders early and accurately in neurological imaging. These agents can visualize the molecular alterations linked to Alzheimer's disease and other tauopathies by focusing on important pathological hallmarks such as neurofibrillary tangles, which are aggregation of tau protein, and amyloid plaques, which are made of amyloid-beta peptide. Compared to traditional MRI, which usually only identifies structural alterations at a later stage, this enables earlier detection. Additionally, by analyzing changes in the amyloid and tau burden over time, these agents can be used to follow the development of the illness and assess the efficacy of therapeutic measures meant to lessen these pathological hallmarks. This focused strategy provides a potent instrument for improving our comprehension and treatment of neurodegenerative diseases.

4.Inflammation imaging

Gd-based MRI contrast agents that target proteins have great promise for identifying and detecting inflammation in a range of illnesses. These medicines can identify inflammation locations with great specificity by targeting particular markers implicated in the inflammatory process, such as adhesion molecules (integrins, selectins) that mediate leukocyte trafficking or signaling molecules like chemokines and cytokines. This makes it possible to image inflammatory diseases such as multiple sclerosis, rheumatoid arthritis, and inflammatory bowel disease, facilitating early diagnosis, evaluation of disease activity, and tracking of the effectiveness of anti-inflammatory treatments. Compared to traditional imaging methods, which frequently lack the sensitivity and specificity to identify modest inflammatory changes at an early stage, this tailored approach offers a considerable benefit.

5.Infectious disease imaging

By focusing on certain proteins found on the surface of pathogens such as bacteria, viruses, or fungus, protein-targeted Gd-based MRI contrast agents have the potential to enhance the imaging of infectious diseases. Compared to traditional imaging techniques, this tailored approach enables the identification and localization of infections with enhanced sensitivity and specificity. This can help with timely and effective treatment techniques,

6.Gene therapy monitoring

By measuring the expression of therapeutic genes given to target cells, protein-targeted Gd-based MRI contrast agents can be extremely useful in gene therapy monitoring. Researchers can see the degree of gene expression in vivo and the success of gene transfer by using contrast agents that target the proteins encoded by these therapeutic genes. This makes it possible to evaluate the effectiveness of gene delivery, monitor treatment efficacy non-invasively, and optimize gene therapy regimens. This method helps create more efficient and focused gene therapies by offering insightful information on the spatiotemporal dynamics of gene expression.

Conclusion

An important development in molecular imaging is the use of protein-targeted gadolinium (Gd)-based MRI contrast agents, which have higher sensitivity and specificity than traditional agents. Because of their ability to bind selectively to particular proteins linked to disease, these agents allow for accurate monitoring, characterisation, and detection. The targeting moiety, the linker, and the Gd chelate are the three main parts of the design. The paramagnetic characteristics for enhancing MRI signals are provided by the Gd chelate, usually utilizing DTPA or DOTA. The chelating agent maximizes relaxivity while minimizing Gd^{3+} toxicity. Target specificity is determined by the targeting moiety, which might be tiny molecules, aptamers, peptides, or antibodies. Each has special benefits in terms of synthesis ease, size, and affinity. The linker affects flexibility, stability, and biodistribution by joining the targeted moiety and chelate.Local Gd build-up results from the mechanism's reliance on precise binding between the targeting moiety and the target protein. A stronger signal on T1-weighted imaging is the result of this rise in local Gd concentration, which also improves water proton relaxation. This targeted accumulation enhances contrast and makes it possible to see minute molecule changes, sometimes in conjunction with relaxivity modulation upon binding. These substances can be used to treat neurological disorders (targeting tau tangles and amyloid plaques), cardiovascular disease (targeting thrombosis, inflammation, and myocardial damage markers), cancer (targeting tumor antigens, receptors, and angiogenesis markers), and inflammation (targeting adhesion molecules, chemokines). Optimizing targeting, reducing non-specific accumulation, enhancing biocompatibility, and creating multimodal agents are the main areas of ongoing research that could transform illness diagnostics and individualized care.

High-Resolution Hip Joint Imaging in the Era of Deep Learning

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Introduction

Because of its improved soft tissue contrast, absence of ionising radiation, and capacity to produce high-resolution imaging, magnetic resonance imaging (MRI) has shown itself to be a significant tool in the diagnosis and treatment of orthopaedic challenges. Attempts are being made to shorten scan times without sacrificing image quality and resolution due to dwindling reimbursement and growing demands for higher patient throughput. This is particularly crucial for people who are claustrophobic or in discomfort and cannot endure extensive scan times. In these situations, quicker scan times might be crucial for patient care.

Numerous standard procedures have been tested with quicker MRI sequences in recent years, with positive outcomes for the accelerated scans. Additionally, new artificial intelligence (AI) approaches helped to improve imaging resolution and scan duration. Deep learning (DL) reconstruction scans were in fact thought to have higher image quality, and there was no difference in diagnostic confidence or competence.

To preserve diagnostic accuracy, the comparatively thin hip cartilage need higher in-plane and through-plane (slice) resolution, which lengthens scan times. To enable a hip MRI protocol, employ DL reconstruction, reduced echo spacing, and reduced specific absorption rate (SAR) while optimising radiofrequency (RF) pulses for a 15-minute scan duration that preserves spatial resolution and signal-to-noise ratio (SNR).

Hip MRI procedure expedited with illustrations

Five crucial acquisitions using a prototype turbo spin-echo (TSE) sequence are included in the recommended protocol. The acquisition parameters for implementation on a MAGNETOM Vida 3T scanner with an XT gradient system are listed in detail in Table 1. A broad field-of-view axial TSE sequence of the pelvis and bilateral hips is obtained with moderate weighting after a 3-plane rapid localiser.

A bilateral hip coronal TSE short tau inversion recovery (STIR) sequence is then obtained after a coronal unilateral TSE sequence targeted at the afflicted hip. To evaluate the hip joint, unilateral intermediate-weighted sagittal and oblique axial TSE scans are acquired.

An 18-channel phased-array coil is used anteriorly and an in-table spine matrix coil is used posteriorly in this contrast-free acquisition strategy. Every acquisition makes use of Deep DL-enhanced image reconstruction methods include Resolve Boost and Deep Resolve Sharp.

High-resolution diagnostic scans are produced by this approach, as seen in **(Fig 1),** which displays excellent images from every sequence obtained.

An overview of the pelvic and hip structures is given by the broad field-of-view sequences, which also enable the identification of probable intrapelvic pathology that could manifest as groin discomfort and comparison to the contralateral side for symmetry of the osseous structures

Acquisition	Axial TSE	Coronal TSE	Coronal IR	Sagittal TSE	Oblique axial TSE
Coverage	Bilateral	Unilateral	Bilateral	Unilateral	Unilateral
Field of view, mm	380	190	380	190	190
TR/TE, ms	5600 / 30	3500–4800 / 35	3500–5500 / 24	4000 / 35	4000 / 34
TI,ms	**TI,ms**	-	240	-	-
Phase encoding direction	R > L	H > F	H > F	H > F	L > R
Slice thickness, mm	5.5 / 0	3 / 0	5.5 / 0	2.5 / 0	3 / 0
Slices	50	32	36	26	28
Fat suppression	-	-	STIR	-	-
Scan time, min:sec	2:00	3:20	2:15	2:40	2:15

Table 1 MAGNETOM Vida 3T acquisition parameters of the suggested hip protocol using an XT gradient system.
TSE: Turbo Spin Echo; **TR:** Repetition Time; **TE:** Echo Time; **TI:** Inversion Time; **iPAT:** Integrated Parallel Acquisition Technique; **DRB:** Deep Resolve Boost; **DRS:** Deep Resolve Sharp; **STIR:** Short Tau Inversion Recovery.

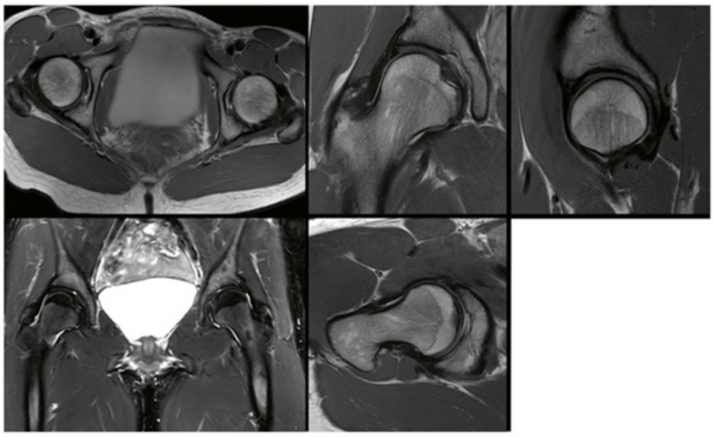

Figure 1. Example MR images of all five sequences obtained utilizing the method described.

and hip muscles. Joint effusions, bursitis, cysts, marrow or soft tissue oedema, and other sites of fluid or oedema are highlighted by inversion recovery weighing. Intermediate-weighted sequences with a smaller field of view enable high-resolution anatomic assessment of the hip's symptoms. . Hip abductors, superior acetabular labrum, and superior joint cartilage are all best evaluated in the coronal plane. The rectus femoris, iliopsoas tendons, anterior and posterior cartilage, and labrum can all be seen more clearly in the oblique axial plane, which also allows for an evaluation of the neck-head offset. An additional view of the anterior and posterior joints is offered by the sagittal plane, the best plane for assessing the anterior labrum is cartilage.

Figure 2 shows a modest quantity of joint fluid together with hyperintense bursitis caused by low-signal calcium hydroxyapatite deposition in the coronal STIR and intermediate-weighted TSE images. **Figure 3** displays multiplanar intermediate-weighted TSE images of a single individual with multifocal labral and chondral diseases. An oblique axial intermediate-weighted TSE sequence showing a labral tear and related paralabral cyst is shown in **Figure 4**.

Figure 2 The right hip's coronal STIR (2A) and intermediate-weighted TSE (2B) images, taken at 1:30 and 2:22 minutes, respectively, reveal a low signal focus of calcium hydroxyapatite deposition along the gluteus medius insertion (arrows) with concurrent thickening of the greater trochanteric bursa (arrowheads), which indicates bursitis and calcific tendinosis. An asterisk indicates that there is a tiny quantity of fluid in the joint.

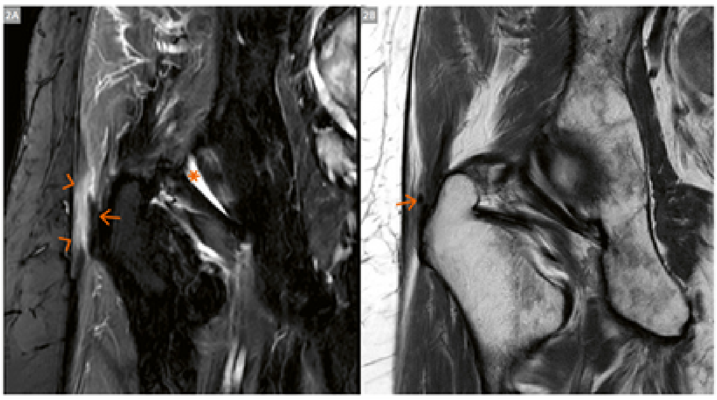

Figure 3 Using intermediate-weighted TSE sequences with acquisition periods of 2:22, 2:28, and 3:22 minutes, respectively, coronal (3A), sagittal (3B), and oblique axial (3C) show regions of full thickness cartilage loss (arrowheads) over the acetabulum and femoral head. Arrows show an anterior labral tear, a high-grade chondral fissure, and a subchondral cyst in 3A, 3B, and 3C, respectively.

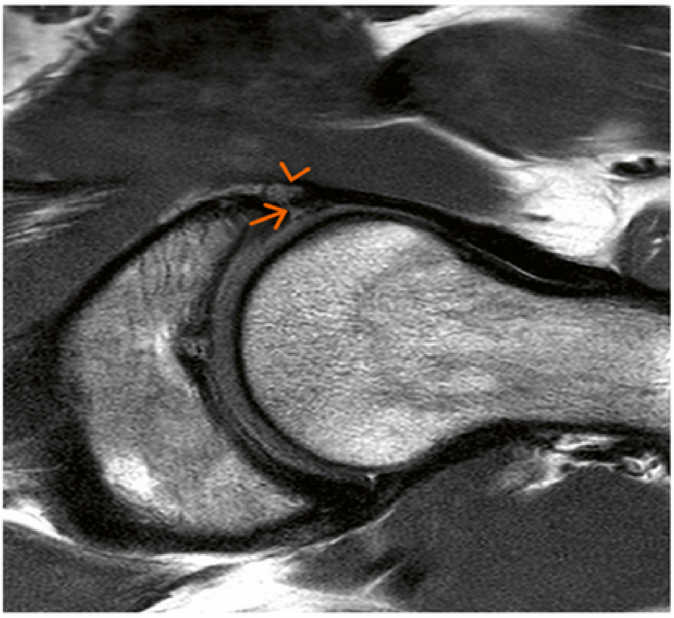

Figure 4 With a collection period of 2:05 minutes, an oblique axial intermediate-weighted TSE sequence of left hip reveals a tiny paralabral cyst (arrowhead) resulting from an anterior labral rupture (arrow).

Conclusion and directions for the future

The creation of novel MRI protocols targeted at enhancing clinical results and throughput has been made easier by developments in deep learning techniques. We can continue to enhance our procedures as this technology develops, enabling us to accommodate growing patient numbers while preserving high diagnostic quality.

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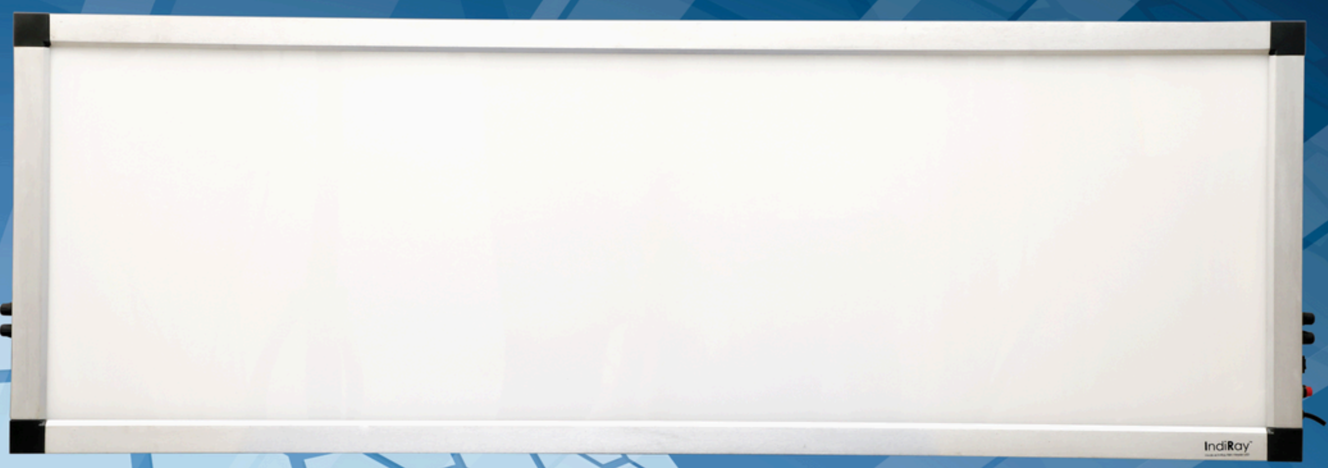

MRI in Lung Cancer

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Abstract

In comparison to low-dose CT (LDCT), recent investigations using lung MRI (MRI) have demonstrated high sensitivity (Sn) and specificity (Sp) for lung nodule detection and characterization. Magnetic resonance imaging (MRI) has not been widely used for early lung cancer detection, staging, and treatment, despite being an essential tool in oncologic care for many diseases. MRI has better soft tissue contrast than computed tomography (CT), which is advantageous for many organs. However, the physical characteristics of the lungs and mediastinum pose particular challenges for lung MRI.

Keywords

Lung cancer, Cancer screening, Magnetic Resonance Imaging, Lung nodules, Lung MRI, Diffusion magnetic resonance imaging, Advancements, Functional lung MRI.

Introduction

Because of its iOne of the biggest health issues in the US and around the world is lung cancer . In Europe and North America, there are roughly 1.3 million new cases of lung cancer and 1.2 million lung cancer deaths annually (2017) [4–6] It is anticipated that there will be 609,820 cancer-related fatalities and 1,958,310 new cancer cases in the US in 2023 . Prior research has shown that tobacco smoke , Second hand smoke, industrial chemicals , environmental pollution , and genetic factors might result in lung cancer. The survival rate for lung cancer remains significantly lower than that of certain other common malignancies, like breast cancer [7]. The five-year survival rate is greatly increased when lung cancer is detected early and treated appropriately [8] Radiation and chemotherapy treatments are frequently used for small cell lung cancer (SCLS) [9], but surgical procedures are typically employed for NSCLS (non-small cell lung cancer) [10].

Male lung cancer mortality is highest in Eastern Europe, while female lung cancer mortality is highest in Northern Europe and America [11]. Lung cancer cases are predicted to rise in several developing nations in the coming years, including China and India [12].CT has long been regarded as the gold standard for lung screening because it provides details about tumor characteristics like size, morphology, and growth. A 3D CT scan provided evaluation of the mediastinum invasion, diaphragm, and chest wall in addition to the tumor's staging. CT-generated radiation also raised the risk for cancer . LDCT was used for lung imaging to overcome this restriction, and it resulted in a 20% reduction in death rate from lung cancer [13]. But LDCT still has a significant proportion of false positives (up to 96.4 percent) [14]. The use of 18F-fluorodeoxyglucose PET/CT in oncological imaging resulted in incorrect findings [15,16]. Recently, magnetic induction tomography (MIT) has been suggested for early detection of lung cancer with the benefits of high sensitivity and low cost .

Diagnostic performance of lung MRI in detection of small malignant lesions

In a lung cancer screening program, the ability of lung MRI to identify tiny lesions with high or intermediate signal intensity against the black backdrop of healthy lung tissue would be needed. These could be ground glass opacities in, in-situ adenocarcinoma and small-solid nodules or tiny solid nodules.

The sensitivity of MRI for lung nodules of 4–8 mm in diameter varies from 60 to 90% in experimental trials, and it approaches 100% for lesions larger than 8 mm in diameter (Fig 1).The ideal threshold size for lung nodule detection with MRI utilizing 3D gradient echo or T2-weighted fast spin echo imaging is 3–4 mm which depends on the pulse sequence and the signal intensity of the lesions, under ideal circumstances (breath hold or proper gating/triggering) .In this regard, ultra-short echo time (UTE) imaging in particular seems highly promising. The lengthy acquisition durations in the lung make diffusion weighting challenging because they permit respiratory and cardiac movements to deteriorate the image. DWI detection rates are less than T2-weighted detection rates . Unlike contrast-avid vascular lesions, which will exhibit high signal intensity on T1-weighted images, calcified nodules are difficult to identify with MRI due to their low signal intensity. The intravenous infusion of a paramagnetic contrast material may be beneficial to increase detection rates if malignant lesions exhibit strong vascularization and intense amplification. Intravenous contrast material injection is dubious when used in primary MRI screening, by LDCT.

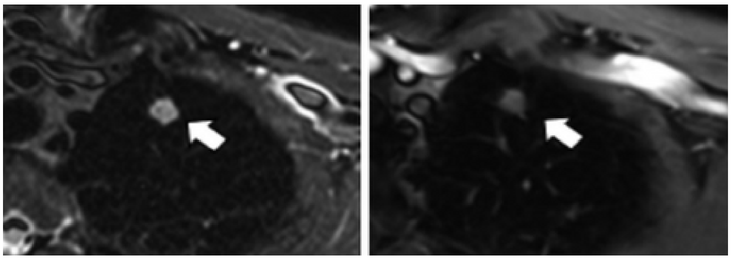

Fig 1. 10 mm solid nodule in the left upper lobe in a 58-year-old man. The nodule (arrows) was clearly visible using all magnetic resonance imaging (MRI) sequences and classified as Lung-RADS 4X because of a spiculated margin.(A) MRI T2 short inversion time inversion recovery, and (B) MRI contrast-enhanced fat-saturated T1-weighted images.

Barriers to lung MRI

The physical characteristics of the lungs and mediastinum present particular challenges when using diagnostic MRI, even though in other body sites MRI offers superior soft tissue contrast that is not possible with computed tomography (CT) (Fig 2).

Advances in MRI technology

Despite the previously mentioned obstacles, MRI has benefits over the current CT and PET/CT regimen, among which is the ability to eliminate the radioactive contrast agent required in PET/CT's . MRI is now more clinically relevant in assessing lung cancer due to advancements in its technology. Turbo spin echo (TSE), for instance, is a quick MRI sequence that can detect malignant nodules at a rate comparable to MDCT and is resistant to variations in susceptibility between lung and air tissues [17].The influence of respiratory and cardiac motion artifact is lessened by a Half Fourier single-shot TSE (HASTE) sequence, which further optimizes scan timings by utilizing specific "mirror-image" characteristics of the raw MR data (k-space) [18]. While TSE (turbo STIR) for fat signal suppression is commonly utilized in short-tau inversion recovery (STIR)

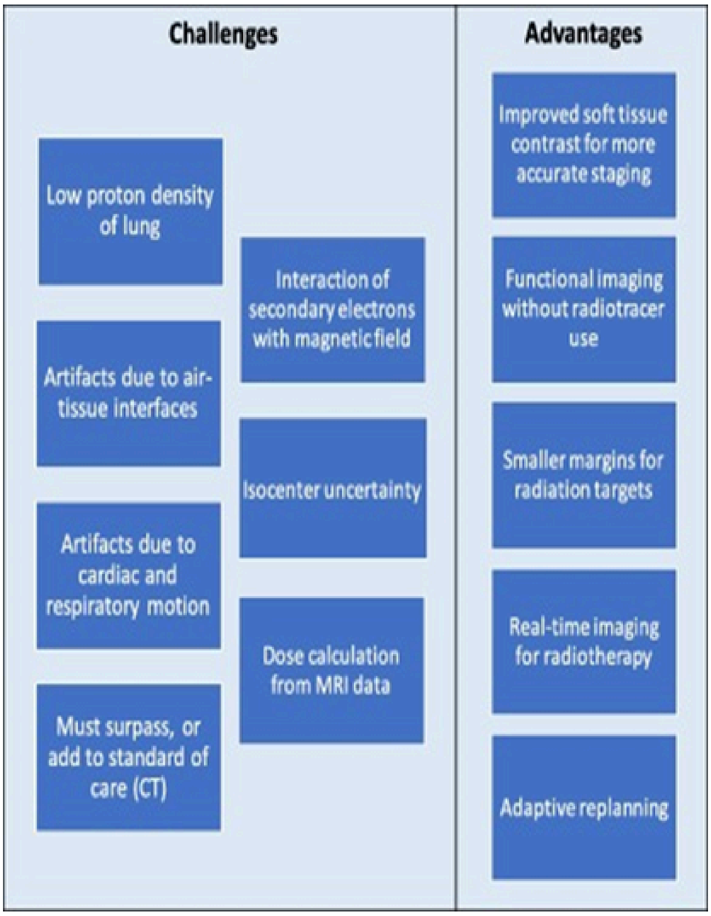

Fig.2 Overview of challenges and advantages for the use of lung MRI in early lung cancer diagnosis and radiotherapy. CT = computed tomography; PET = positronemission tomography; MRI = magnetic resonance imaging.

sequences to improve the delineation of soft tissue and local tumour spread . It can be used to improve contrast for pulmonary lesions without excessively extending breath hold times . These sequences are still vulnerable to flow artifact from substantial blood flow across the lungs, yet, can also be lessened by using black-blood sequences utilizing a double recovery sequence, particularly when there is insufficient cardiac gating [19]. Several groups have demonstrated the viability of volumetric interpolated breath-hold examinations (VIBE),a radio-frequency spoiled 3D gradient recall echo (GRE) sequences. Its use might miss tiny lesions but has shown fewer motion artifacts [20] .

Lung functional imaging

The lung is being studied using functional MRI sequences that are derived from data in other disease sites. Diffusion weighted imaging (DWI), for instance, can separate hypercellular regions (tumors) from regions of increased diffusivity by detecting restricted diffusion of water as signal attenuation. An apparent diffusion coefficient (ADC) is used in DWI to quantify diffusion[21]. Compared to CT or PET/CT, which are frequently challenging clinical scenarios, DWI has been demonstrated to more accurately define gross tumor sizes within atelectatic lung in lung cancer[22]. DWI can also reveal details about intratumor vasculature, involvement of lymph nodes, and effusions that CT cannot (Fig. 3). Nevertheless, DWI may experience geometric distortions, primarily due to variations in the sensitivity of the lungs' tissue and air interfaces, necessitating further technological fixes[23]. In addition to DWI, dynamic contrast-enhanced MRI (DCE) further clarifies tumor vascularity patterns by providing functional information in the form of blood flow and vascular permeability.

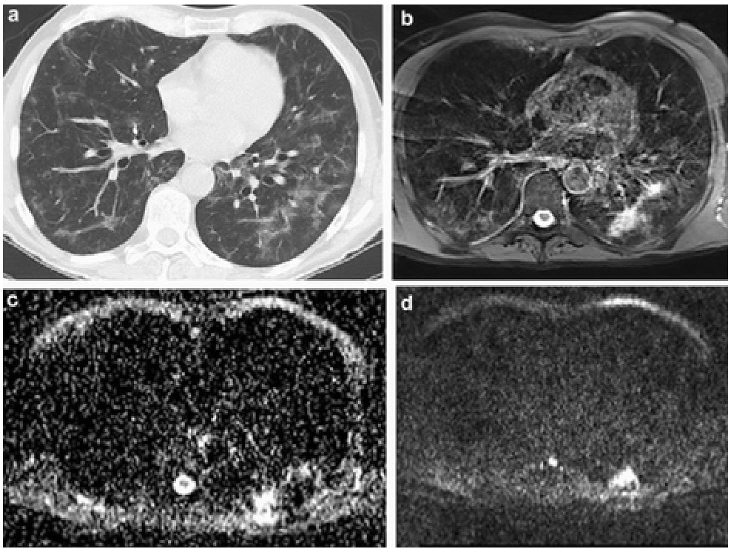

Fig.3 Ground-glass opacities with positive DWI. 58-year-old male. a End-inspiratory axial CT, b Free-breathing PD-weighted axial image, c Apparent Diffusion Coefficient Map, and d) DWI free breathing (b = 1000 s/mm2). Note an area of GGO on the left lower lobe that shows restricted diffusion on DWI and hyperintensity on ADC map, corresponding to an area of acute inflammation.

Particularly when considering respiratory and cardiac motion, both DWI and DCE have inadequate spatial resolution; however, this uncertainty is lessened by respiratory/cardiac gating and faster temporal acquisition.

Conclusion

Since MRI is becoming more widely used in functional evaluation, response to therapy, and treatment recommendations for a number of malignancies, such as prostate and brain , its application in lung cancer has fallen behind due to innate obstacles brought about by the physical characteristics of the lung. However, the use of functional MRI and novel MR sequences is making lung MRI useful for early lung stage detection, staging, and surveillance of early stage lung cancer. The identification of subcentimeter nodules is still a significant drawback of lung MRI in comparison to MDCT.

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Radiogenomics an Integrating Imaging and Genomics for Precision Oncology

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Abstract

Radiogenomics is a rapidly evolving field that connects medical imaging with molecular biology to identify correlations between radiological features and tumor genomics. This integration provides a noninvasive method to characterize tumors, predict therapeutic response, and guide personalized treatment. Radiogenomics leverages artificial intelligence and machine learning to interpret complex imaging-genomic relationships, addressing the limitations of conventional biopsies, such as sampling bias and inability to capture tumor heterogeneity. Despite challenges including standardization and high computational demands, radiogenomics has the potential to revolutionize precision oncology (Gillies et al., 2016; Lambin et al., 2017).

Keywords: Radiogenomics, Radiomics, Genomics, Artificial Intelligence, Precision Oncology, Imaging Biomarkers

Introduction

Cancer exhibits extensive genetic and phenotypic variability, which limits the effectiveness of one-size-fits-all treatment approaches. Radiogenomic a discipline combining imaging and genomic data offers a promising alternative. By associating radiographic features from Magnetic Resonance Imaging, Computed Tomography, Positron Emission Tomography scans with genetic alterations such as mutations and gene expression profiles, clinicians can gain deep insights into tumor behavior without invasive tissue sampling (Rutman & Kuo, 2019). This integration is vital in the era of precision medicine, where treatment decisions depend on patient-specific biological data.

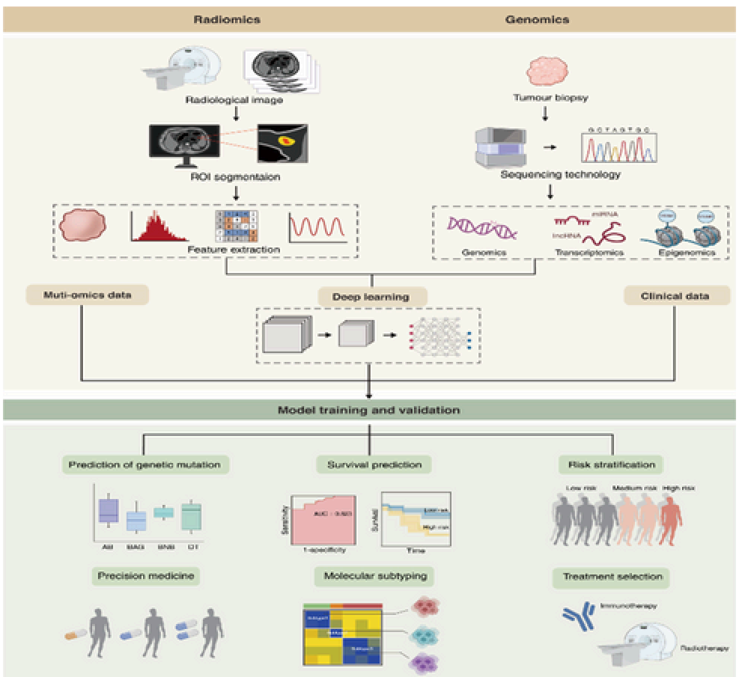

Fig1. Description to Radiogenomics

Methods of Radiogenomics

Radiogenomics involves several sequential steps:
For Image Acquisition & Preprocessing high-resolution scans are acquired and standardized using techniques like denoising and segmentation to ensure data consistency as depticed in the article (Aerts et al., 2014).

The Feature Extraction of Radiomic analysis, quantifies features such as shape and texture. Deep learning models, including convolutional neural networks, automate this process and enhance precision.

In Genomic Profiling The tumour samples undergo Deoxyribonucleic acid/ Ribonucleic acid sequencing and epigenetic analysis, revealing mutations and expression patterns (Kumar et al., 2012).

Data Integration & Modelling in Machine learning algorithms like support vector machines and random forests integrate radiomic and genomic features to predict outcomes such as treatment response and survival (Gillies et al., 2016).

Workflow Analysis

Radiogenomics enables the identification of specific imaging traits that correspond to genetic alterations. For instance, Magnetic resonance imaging derived texture features in glioblastoma are predictive of IDH- Isocitrate dehydrogenase Gene mutation status (Kumar et al., 2012). Similarly, radiomic features in Computed tomography scans can suggest the presence of EGFR- Epidermal Growth Factor Receptor mutations in non-small cell lung cancer, aiding in targeted therapy decisions (Aerts et al., 2014). AI tools further support this analysis by extracting hidden data patterns, allowing real-time

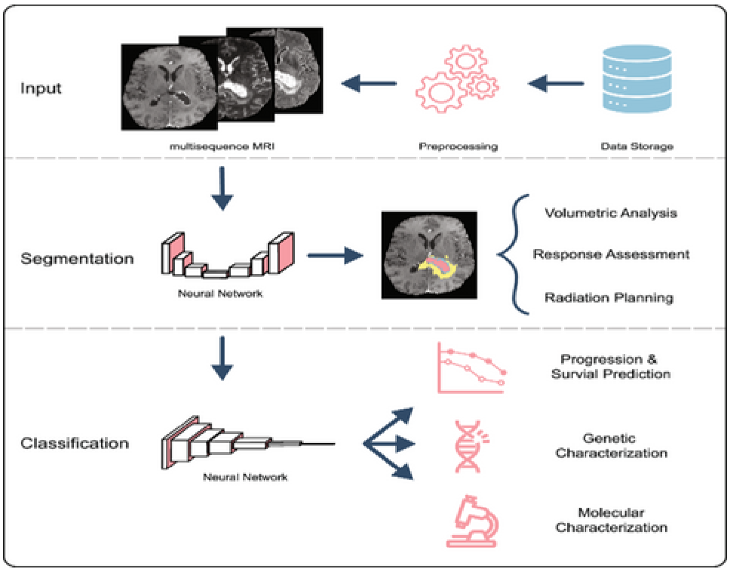

Fig 2. Image acquisition and pre-processing

monitoring of tumor evolution during therapy (Lambin et al., 2017).

Advantages

- Noninvasive Profiling eliminates risks associated with tissue biopsies (Rutman & Kuo, 2019).

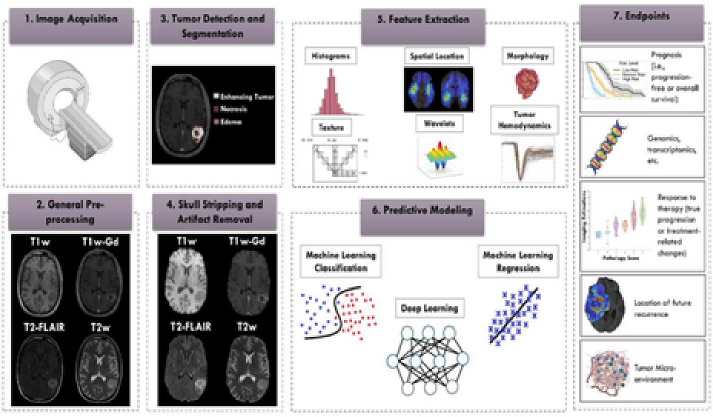

Fig 3. Radiomic feature extraction

- Captures Tumor Heterogeneity evaluates the entire tumor volume rather than a localized sample (Gillies et al., 2016).
- Dynamic Monitoring enables repeated assessments over time to track treatment effects.
- Supports Personalized Treatment enhances decision-making by integrating patient-specific tumor biology (Pinker et al., 2018).
- AI-Enhanced Interpretation Improves prediction accuracy and feature detection (Aerts et al., 2014).

Disadvantages

- Variation in imaging protocols can affect reproducibility that is lack of standardization (Gillies et al., 2016).
- Computational Complexity Requires robust computational tools and infrastructure (Lambin et al., 2017).
- Limited Clinical Implementation Many models remain experimental and need further clinical validation (Rutman & Kuo, 2019).
- Use of large datasets raises data security and consent concerns causing ethical and privacy issues.

Applications in Clinical Practice and Research

In glioblastoma, for example, specific MRI features such as contrast enhancement patterns, necrosis, and peritumoral oedema have been correlated with IDH mutation status and MGMT promoter methylation. These molecular subtypes are crucial for prognostication and guiding therapeutic decisions, as IDH-mutant tumours generally exhibit a more favourable prognosis and different therapeutic sensitivities compared to wild-type tumours (Kumar et al., 2012).

In lung cancer, particularly non-small cell lung cancer (NSCLC), radiomic analysis of CT scans has enabled the identification of driver mutations like EGFR and ALK, which are essential targets for tyrosine kinase inhibitors. This noninvasive approach supports mutation screening when tissue availability is limited or biopsy is not feasible (Aerts et al., 2014).

In breast cancer, radiogenomic models have linked imaging characteristics such as mass margins, enhancement kinetics, and texture with molecular markers like HER2 expression and hormone receptor status. These insights not only support subtype classification but also assist in tailoring treatment regimens and monitoring response to endocrine or targeted therapy (Pinker et al., 2018). Beyond diagnosis and stratification, radiogenomics is also contributing to drug development and clinical trial design by enabling imaging biomarkers that can act as surrogate endpoints, improve patient selection, and reduce trial costs. As datasets expand and validation efforts improve, radiogenomics will play an increasingly central role in early detection, therapy planning, resistance monitoring, and longitudinal surveillance in oncology.

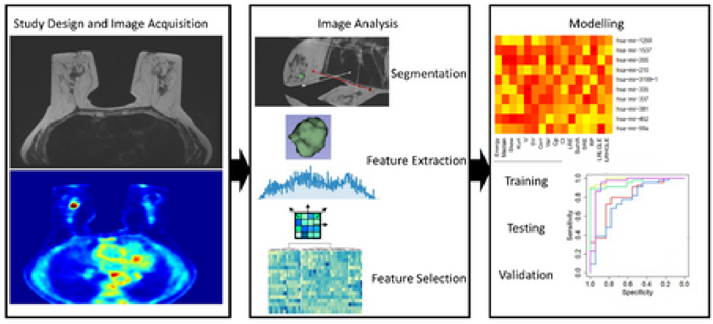

Fig 4. Genomic Data Acquisition process

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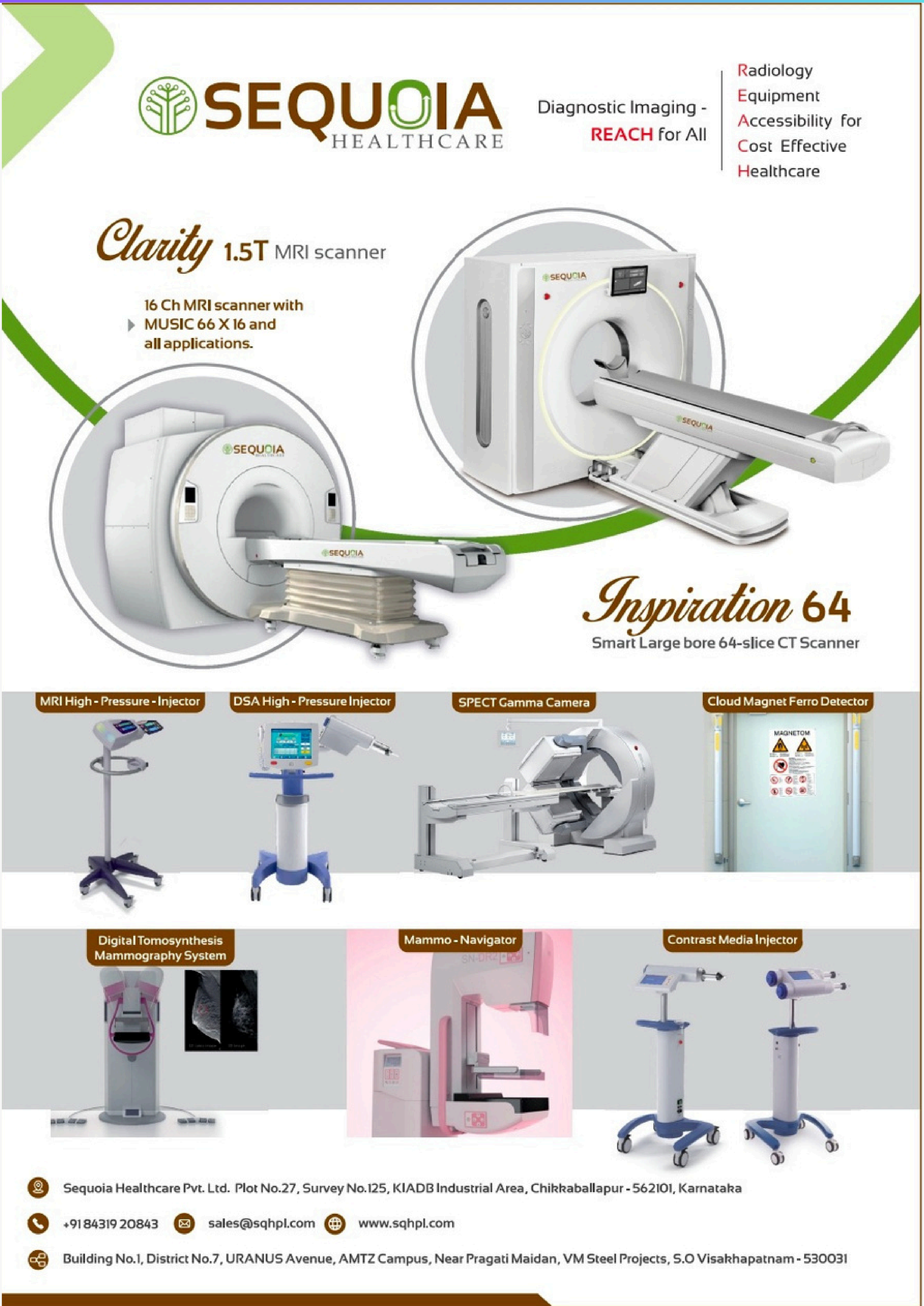
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Theronostic Imaging Agents: Expanding Theranostic Radiopharmaceuticals for Tumor Diagnosis and Therapy

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Abstract
Theranostics is a rapidly expanding field and is a portmanteau of Therapeutics and Diagnostics. In a broader definition, theranostics is considered a diagnostic methodology for personalized therapeutic interventions. In a narrower and recently more frequently used definition, theranostics employs molecular targeting vectors and often nanoplatform technologies into which both diagnostic and therapeutic functionalities are incorporated.

This chapter provides the reader with an outline of different theranostic approaches that have been investigated for the diagnosis and treatment of disease, with a particular focus on approaches for the treatment of cancer. We will discuss different imaging modalities and their associated contrast generating methodologies, e.g., T1 and T2 contrast agents mangentic resonance imaging, gold nanoparticles CT and optical imaging, and nuclear agents PET/SPECT, as well as their function as delivery vehicles for the targeted treatment of disease in vivo using a range of strategies including chemotherapy, photothermal therapy, and immunotherapy. The benefit of theranostic agents over traditional therapies is also discussed as well as our thoughts on the future direction of the field.

Keywords: Molecular Imaging, Molecular Imaging Cancer, Molecular Imaging Clinical Translation, Molecular Imaging Target Development, PET/CT, SPECT/CT, Radionuclide Therapy, Dosimetry, Oncology, Radiobiology

Introduction

Imagine a day when physicians can both visualize a tumor and treat it with a single agent. That is the promise of theranostics a pioneering approach that integrates diagnostic imaging with targeted therapy in one molecular platform. By homing in on specific molecular signatures, theranostics enables:

- Personalized treatment tailored to the individual patient
- Real-time monitoring of treatment response
- Minimized side effects through precise tumor targeting

Already transforming care in neuroendocrine tumors, prostate cancer, and thyroid cancer, theranostics continues to expand into new areas of oncology.

Working and uses of Theranostic Agents

Radioiodine (I-123/I-131): Thyroid Cancer

- I-123 enables imaging and staging of differentiated thyroid cancer (DTC).
- I-131 delivers therapeutic radiation to eliminate residual cancer tissue.
- Effective only in tumors expressing the sodium-iodide symporter (NIS).

2. Somatostatin Receptor: Neuroendocrine Tumors

- 68Ga-DOTATATE PET imaging identifies tumors expressing SSTR.
- 177Lu-DOTATATE (Lutathera®) delivers targeted radiotherapy.
- Proven to improve progression-free survival in the NETTER-1 trial.

3. Prostate-Specific Membrane Antigen: Prostate Cancer

- 68Ga-PSMA-11 PET/CT detects metastatic lesions with high sensitivity.
- 177Lu-PSMA-617 (Pluvicto®) is FDA-approved, demonstrating survival benefits in the VISION trial.
- Investigational use in earlier stages is underway.

4. Fibroblast Activation Protein Inhibitors: Emerging Pan-Cancer Target

- Target cancer-associated fibroblasts (CAFs), common across tumor types.
- 68Ga/177Lu-FAPI agents show promise where PSMA/SSTR targeting is ineffective.
- Active trials in breast, pancreatic, and soft-tissue cancers.

5. Emerging Isotopic Platforms

- 64Cu/67Cu: Longer half-lives allow wider clinical use.
- Alpha emitters (e.g., 225Ac, 213Bi): Potent cell-killing capacity with limited off-target damage.
- 89Zr/90Y: Applied in antibody-based theranostics.

Mechanism of Action

A typical theranostic system includes:
A targeting vector (peptide, small molecule, or antibody) that binds to tumor-specific receptors
A diagnostic radionuclide (e.g., 68Ga, 18F) for PET or SPECT imaging
A therapeutic radionuclide (e.g., 177Lu, 131I) that delivers cytotoxic radiation

Workflow:

1. Diagnostic imaging determines target expression.
2. Patient selection ensures only suitable candidates receive therapy.
3. Therapeutic administration targets the tumor precisely.
4. Follow-up imaging assesses therapeutic efficacy and tumor response.

Clinical Applications

Cancer Type	Diagnostic Agent	Therapeutic Agent	Clinical Evidence
Thyroid Cancer	I-123	I-131	Clinical standard
Neuroendocrine Tumors	68Ga-DOTATATE	177Lu-DOTATATE	NETTER-1 trial
Prostate Cancer	68Ga-PSMA-11	177Lu-PSMA-617	VISION trial
Glioblastoma	68Ga-DOTA-TOC	177Lu/90Y-DOTATATE	Phase II clinical studies
Breast Cancer	68Ga-FAPI	177Lu-FAPI	Early-phase clinical trials


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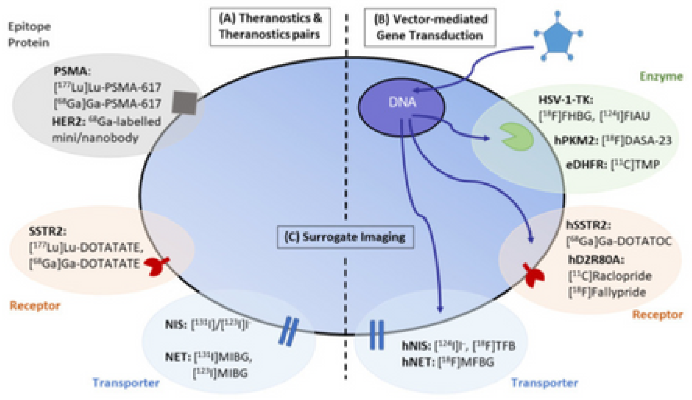

Figure: 1. showing applications of Theranostic agents.

(A) Theranostic applications in oncology have gained importance in the management of remnant tumors using cancer-type specific biomarkers, including SSTR2-positive or NET-positive neuroendocrine tumors, NIS-positive differentiated thyroid tumors and PSMA-positive prostate cancer.
(B) The combination of vector-mediated gene transduction with the corresponding PET/SPECT-CT imaging probe not only benefits tracking of the efficiency of gene transduction but also establishes the fundamental principles to enlarge the field of theranostic applications by inducing the expression of an enzyme, receptor or transporter targeted by the corresponding theranostic radiopharmaceuticals.
(C) Surrogate imaging relies on the visualization by molecular imaging of the downstream effects (metabolism, proliferation, associated inflammation) of a gene or cell-based therapy paradigm. Image modified from Jacobs et al. (2021) [6].

Advantages of Theranostics Agents

- Precision Medicine in Treatments based on individual tumor biology
- Reduced Toxicity that Limits damage to healthy tissue
- Combinatorial Flexibility Can be paired with immunotherapy or targeted agents
- Cost-Effectiveness it Avoids unnecessary treatments and associated expenses

Advancements

- 225Ac-PSMA shows promise in cases resistant to 177Lu-based therapies.
- Theranostics + Immunotherapy (e.g., checkpoint inhibitors) is under active exploration.
- Non-oncology uses include cardiac sarcoidosis and other inflammatory diseases.

Challenges

Infrastructure Requirements it requires radiopharmaceutical production and nuclear medicine. Radiation Safety it has Strict handling and waste disposal protocols needed

- Variable Tumour Uptake it is Inconsistent radiotracer distribution can affect efficacy
- Resistance Development Receptor downregulation post-treatment may limit reuse

Barriers:

- Supply chain constraints, especially for isotopes like 177Lu
- Lengthy regulatory approval processes for new agents
- Reimbursement limitations in various healthcare settings

Conclusion

Theranostics is ushering in a new era of personalized oncology, combining diagnosis and treatment in one streamlined process. With continued innovation in isotopes, delivery vectors, and combination strategies, theranostics is poised to become a mainstay in precision medicine, offering hope, efficacy, and safety across a growing spectrum of diseases.

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And one more thing, we have conveyed this issue to you, as an enlightened Radiographer, now it is your responsibility to forward this issue to other Radiographers.

Thanks in advance,
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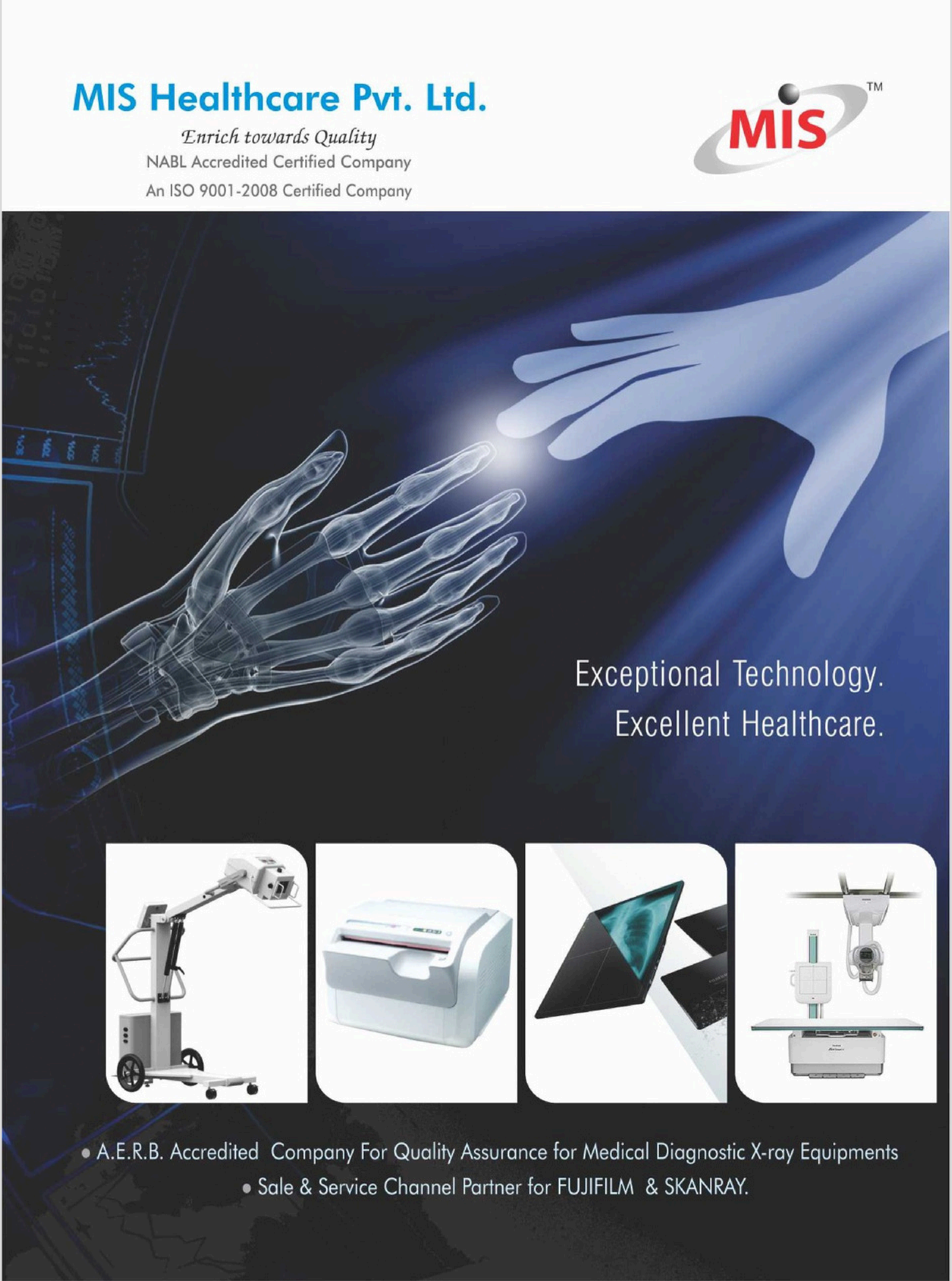
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A Comprehensive Study of Hematuria Evaluation Using CT Urography

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Keywords:
Hematuria, tumors, ct urography, kidney stones, bladder cancer.

Key Points:
CT urography is recognized for its high accuracy in detecting tumors and various causes of hematuria. This advanced imaging technique provides detailed visualization of the urinary tract, enabling clinicians to identify neoplasm and other underlying conditions that may contribute to the presence of blood in the urine. All cancers were seen on the nephrographic phase. Its precision and effectiveness make CT urography an essential tool in the diagnostic evaluation of urological disorders, ultimately aiding in timely and appropriate patient management.

Abstract:
The aim of this research paper is to investigate the prevalence and underlying causes of hematuria in a selected patient population. By conducting a retrospective analysis of medical records, the purpose of this study is to identify demographic trends, common risk factors, and associated clinical conditions related to hematuria. Ultimately, the goal is to enhance the understanding of hematuria's consequences in clinical practice, improve diagnostic accuracy, and inform better management strategies for affected patients. The evaluation of hematuria through CT urography is a crucial diagnostic approach in urology. This study aims to assess the effectiveness of CT urography in identifying the underlying causes of hematuria in patients. By analyzing imaging results, we investigate the prevalence of various abnormalities, such as urinary tract stones, tumors, and structural anomalies. Our findings suggest that CT urography not only enhances the understanding of hematuria but also significantly improves clinical decision-making and patient outcomes. This research underscores the importance of incorporating advanced imaging techniques in the evaluation of hematuria to ensure comprehensive patient care.

Materials and Methods:
I conducted a prospective study at Krsna Diagnostic Centre GMC Jammu from May 2024 to December 2024 .The focus of my research was on patients presenting with hematuria which was evaluated using NCCT KUB (kidneys , ureters and bladder) and CT UROGRAPHY to gather comprehensive data on the condition. This study aimed to identify the underlying causes and implications of hematuria in the patient population. The results of biopsies and clinical follow-up were used as the reference standard. Throughout the study, I collected data on various factors, including demographics, clinical history, and diagnostic outcomes. The findings revealed significant insights into the prevalence of different conditions associated with hematuria, which could enhance our understanding of this symptom and improve patient management strategies.

Results:
In this research, a comprehensive analysis was conducted involving a total of 930 patients diagnosed with hematuria. The gender distribution revealed that 702 of these patients were males, while 228 were females. With a mean age of 58 years (range 17 to 96) were included in the study. In total, 50% of the patients showed no clear cause for their hematuria, 25% male patients had bladder cancer, 30% of the males above 50 years had benign prostate hyperplasia (prostatomegaly), 10% had prostate cancer, 20% had urinary tract infection and 45% had renal calculi. 25% had cystitis. A small no. of females were diagnosed with bladder cancer, suggesting that it is not widespread among this group. And the urinary tract infection (UTI) was the common cause of hematuria in women. Gross hematuria was present in 10-20% of pyelonepritis cases in females. In males above 50 years, 30% of the chronic smokers had a history of hematuria and were subsequently diagnosed with cancer. Some patients who presented with hematuria had a history of blunt trauma to the bladder. Blunt trauma can cause injury to the bladder, leading to bleeding and subsequently hematuria. At our diagnostic centre, we received both outpatients and inpatients presenting with hematuria, reflecting the widespread occurrence of this condition in diverse patient groups.

- Prevalence of hematuria was more common among males (80%) compared to females (20%).
- Prevalence of painless hematuria was more common than painful hematuria.
- Abdominal pain was the most common complaint other than hematuria followed by fever.

Conclusion:
Hematuria is a significant clinical finding that can indicate a range of underlying conditions, from benign issues to serious diseases like cancer. Proper evaluation is crucial to determine the cause. Diagnostic approaches, including imaging studies like CT urography, play a vital role in identifying the source of bleeding. Early detection and appropriate management are essential for improving patient outcomes. Understanding the implications of hematuria can lead to timely interventions and better overall care for patients.

Introduction:
Hematuria can be defined as the presence of blood drops or clots in urine. It can be microscopic hematuria and gross hematuria. Microscopic hematuria indicates red blood cells (RBC) detection through urinalysis or urine microscopy without apparent visual blood. While macroscopic or gross hematuria refers to visible blood in urine. Infection can cause both gross and microscopic

hematuria. Whenever there is a gross hematuria in old persons, consider gross painless hematuria a sign of bladder or urologic cancer until proven otherwise. Hematuria itself is not a disease but rather a symptom or indication that there may be an underlying condition. It can signify various issues such as urinary tract infections (UTI), kidney stones, bleeding from prostate gland, trauma in bladder, bladder or prostate tumors, kidney and urinary tract tumours. Patients at high risk for urothelial carcinoma (UCC) of the bladder or upper urinary tract include those with significant risk factors, particularly a history of smoking and occupational exposures to chemicals. Smoking is one of the most critical risk factors, as tobacco smoke contains numerous carcinogens that can damage the cells lining the urinary tract, making smokers approximately three times more likely to develop bladder cancer compared to non-smokers. Additionally, certain occupations expose workers to hazardous chemicals linked to an increased risk of UCC. For instance, workers in the chemical industry, particularly those exposed to aromatic amines in dye manufacturing and rubber production, face a higher incidence of bladder cancer. Other at-risk occupations include painters, hairdressers, construction workers, and drivers who may encounter solvents, dyes, and diesel exhaust. Other factors contributing to UCC risk include age, with individuals over 55 being more susceptible, and gender, as men are more likely to develop the disease than women. Chronic irritation of the bladder from recurrent urinary tract infections or bladder stones, as well as a family history of bladder cancer, can also elevate risk. Hematuria requires immediate medical attention. For those identified as high-risk, regular monitoring through cystoscopy and urine cytology tests is crucial for early detection and improved outcomes. Diagnosis of the main cause behind hematuria is very important for the treatment of the condition effectively .Hematuria can be diagnosed by several modalities such as ultrasound, intravenous pyelogram (IVP), and cystoscopy and computed tomography (CT SCAN). Among these the computed tomography has become the most commonly used method for evaluating hematuria. The ct urography is now increasingly used as the initial imaging technique in the patients with hematuria. The concept of CT Urography (CTU) is more appropriate as both the renal parenchyma and urothelium can be evaluated with one relatively non invasive comprehensive examination. CT urography provides a detailed anatomic depiction of each of the major portions of the urinary tract-the kidneys, intrarenal collecting systems, ureters and bladder and thus allows patients with hematuria to be evaluated comprehensively.

Hematuria is an episodic condition and may stop after 2-3 urination. Drinking a lot of fluids can help treat hematuria efficiently. Coconut water, fresh lime water and and citrus fruits can help reduce the acidity of urine.

Causes:

- Urinary tract infection (UTI)
- Urinary tract stones (UT STONES)
- Bleeding from prostate gland
- Bladder or prostate tumor
- Kidney and urinary tract tumors
- Trauma to the kidney or bladder
- Certain medications such as anticoagulants
- Polycystic kidney disease

Symptoms with Hematuria:

- Urine can look red, pink or brown
- Burning micturition
- Painful urination
- Fever
- Frequent urinate
- Flank pain
- Pain in the bladder area

Imaging Protocol:

The role of CT in imaging the urinary tract has expanded in recent years, particularly with the advent of multidetector (MDCT) scanners and CT urography (CTU). Contrast-enhanced CT is firmly established as the overall most sensitive modality for determining the cause of hamaturia. It is the gold standard in the detection of renal parenchymal masses, calculi, upper tract urothelial tumors, and extrinsic lesions. In patients presenting with acute renal pain, CT KUB will identify ureteric and bladder calculi. Multiphase contrast-enhanced CT is also more sensitive than IVU and ultrasound in detecting renal masses. It also provides excellent lesion characterization as well as imaging the adjacent retroperitoneum and providing information about the local and distant spread of malignancies CTU has a greater sensitivity in diagnosing upper tract urothelial malignancy than IVU.CTU aims to generate multiphase thin-section images through the kidneys, ureters, and bladder that allow for the detection of the most common urological causes of hematuria, including calculi, renal masses, and urothelial tumors. An unenhanced scan is initially performed from the upper poles of the kidneys to the lower edge of the symphysis pubis. High attenuation oral contrast should be avoided, as dense contrast can make detection of ureteric calculi more difficult. Most medical institutions employ a three-phase MDCTU protocol for the evaluation of patients with hematuria. Most three-phase MDCTU protocols comprise an initial non-contrast phase to detect urinary tract calculi and a second phase, i.e. the nephrographic phase, which is acquired following a delay of 90-100 seconds after administration of 100 ml of intravenous iodinated contrast, to evaluate the renal parenchyma. This is followed by the pyelographic phase taken 5-10 minutes following contrast administration, to evaluate the urothelium from the pelvicalyiceal system to the bladder. These three-phase protocols are used at most institutions as they allow a thorough evaluation of the urinary tract for the most common causes of hematuria i.e. urinary tract calculi, renal neoplasms and urothelial tumors. Two-dimensional and three-dimensional intravenous urography-like images can be obtained by reformatting excretory phase images in the coronal or sagittal planes using volume rendering or maximum intensity projection techniques.

Discussion:

Hematuria is one of the most common signs of urinary tract diseases. Hematuria can come from any part of the urinary tract and has many causes, including stones, tumors, infections, injuries, medications, blood clotting disorders, and kidney diseases. One of the main reasons for checking patients with hematuria is to find urological cancers early and accurately. Therefore, tests that are very good at finding tumors are crucial. It's also important to identify other possible reasons for hematuria. Hematuria can be effectively assessed using a detailed CT scan that includes three phases: unenhanced, nephrographic, and excretory imaging. The unenhanced images, taken from the kidneys to the bladder, are great for spotting kidney stones, which are a common cause of hematuria. Nephrographic-phase images are best for showing any abnormal growths in the kidney tissue. Thin-section delayed images taken from the kidneys to the bladder show the urinary tract filled with contrast material, which helps in finding urothelial diseases. Because MDCT urography can examine both kidney tissue and the lining of the urinary tract in one test, many experts suggest it as a convenient option for assessing various urinary tract problems that cause hematuria.

Present study comprised of 930 patients who presented with hematuria and were referred to the radiology department from urology department for workup with ct urography .all the patients underwent CT urography and diagnosis was established after analyzing all the phases of study with required post processing techniques.

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