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Radiographers' Journal

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August 2025

Editorial

Shankar K. Bhagat
Editor-in-chief

Dear Readers,

It gives me immense pleasure to welcome you to the August 2025 issue of the Radiographers Journal. This month, our contributors have brought together a diverse collection of thought-provoking articles that reflect not only the scientific and technological advancements in radiology, but also the human spirit behind the profession. Each piece reminds us that our field continues to evolve—sometimes through incremental innovation, sometimes through paradigm-shifting breakthroughs, and often through the lived experiences of those who dedicate their lives to radiology.

We begin this issue with “Unseen Light – My Journey into Radiology and Why it Matters,” a personal narrative that beautifully illustrates how curiosity, perseverance, and compassion intertwine to shape a career in imaging sciences. Beyond technology, it reminds us of the human stories that radiology illuminates and the deep meaning behind our daily practice.

Moving into the realm of innovation, “Wearable Radiography: The Next Frontier in Diagnostic Imaging” explores an exciting development—portable, wearable devices that may soon make imaging more accessible, particularly in emergency and remote care. Complementing this is the discussion on “Lead-Free Apron,” which emphasizes how technological substitutes for traditional protective gear are helping reduce occupational hazards while also aligning with environmental sustainability.

Cardiac imaging receives special focus in this issue. In “Assessment of Coronary Artery Disease with Special Reference to CT Angiography,” the role of advanced imaging in early diagnosis and intervention is highlighted. This is enriched further by “Cardiac Imaging—Technical Advances in MDCT Compared with Conventional X-ray Angiography,” which critically reviews how modern multidetector CT is reshaping cardiovascular practice by enhancing both precision and patient comfort.

Artificial Intelligence continues to feature prominently across medical imaging. In “Sustainability & AI in Medical Imaging,” the authors reflect on how AI tools not only optimize workflow but can also reduce energy usage, contributing to greener healthcare systems. Expanding this discussion, “AI as a New Frontier in Contrast Media” delves into how machine learning can refine dosing, predict reactions, and personalize contrast delivery, thereby improving patient safety.

On the neuroimaging front, “High-Resolution Brain Perfusion Imaging with 3D Arterial Spin Labelling” demonstrates how cutting-edge non-invasive techniques are unlocking insights into cerebral blood flow and neurological disorders. Radiotherapy too is transformed through “Technical Advances and Clinical Applications of 4D Cone-beam CT,” which provides a comprehensive review of how time-resolved imaging is enhancing precision in treatment delivery.

Education and clinical training are not left behind. “Augmented Reality in Radiology: Revolutionizing Imaging, Interventions, and Education” paints a compelling picture of how immersive technologies are redefining how we learn, teach, and practice radiology. Meanwhile, “Role of Radiomics in Differentiating Benign and Malignant Tumors” highlights the growing importance of extracting quantitative imaging biomarkers to support clinical decision-making.

Finally, “Advancements in Medical Radiology through Multimodal Machine Learning” ties the issue together by examining how integrating diverse imaging modalities through machine learning creates more comprehensive diagnostic pathways—an emblem of the multidisciplinary spirit of modern medicine.

As you explore this issue, I encourage you to see the connections between these varied contributions. They reflect a profession at the intersection of human stories, technological breakthroughs, and a vision for a sustainable, patient-centered future. Radiology continues to be not just about “seeing the unseen,” but also about understanding, innovating, and healing.

Happy reading

F. No. Z/103/2024-AHS-DOHFW DEPARTMENT, FTS-8309547
Government of India
Ministry of Health and Family Welfare
National Commission for Allied and Healthcare Profession

2nd Floor, Academic Block,
NIHFW Campus, Munirka,
New Delhi- 110067

Circular No: NCAHP 01/2025 **Dated: 22.08.2025**

CIRCULAR

The National Commission for Allied and Healthcare Professions (NCAHP) has released the ten (10) curricula vide notice dated 24.04.2025 for various Allied and Healthcare Professional categories under the provisions of the National Commission for Allied and Healthcare Professions Act, 2021. In continuation of the above the following directives are issued for compliance:

1.1 **Implementation of Curriculum:** The institutions offering Allied and Healthcare Professional courses, affiliated to Universities/Deemed Universities, are directed to adopt and implement the prescribed NCAHP curricula as approved, mandatorily from the Academic Year 2026 – 2027 onwards.

1.2 **Constitution of Board of Studies:** The Universities and Deemed Universities conducting courses in Allied and Healthcare Professions are hereby informed to constitute a dedicated Board of Studies / Board of Education for Allied and Healthcare Education to ensure appropriate academic governance, effective curriculum implementation and alignment with standards and norms set by NCAHP.

1.3 **Responsibility for Implementation:** It shall be the responsibility of the State Allied and Healthcare Council to ensure the implementation of the above directives within their jurisdiction. In States/UTs where a State Allied and Healthcare Council has not yet been constituted, the responsibility shall lie with the Health Department of the respective State/UT Governments to ensure compliance and to facilitate the necessary academic and institutional arrangements accordingly.

2. These directives shall apply to the ten (10) curricula as mentioned in the **Notice dated 24.04.2025** and also to all such curricula as may be notified, released or updated by the Commission from time to time.

3. The State Allied and Healthcare Councils and State/UT Governments are requested to ensure implementation and to furnish an Action Taken Report (ATR) to the Commission within 45 days from the date of issue of this circular.

4. This circular is issued with the approval of the Competent Authority and is to be treated as **mandatory for all concerned stakeholders.**

22.08.2025
(Umesh Balonda)
Secretary, NCAHP

Copy to:

1. Chairpersons of State Allied and Healthcare Councils
2. Additional Chief Secretary / Principal Secretary / Secretary (Health) of all States/UTS

Copy to (for information):

Additional Secretary (AHS), Ministry of Health and Family Welfare, Nirman Bhawan, New

"Unseen light" - My journey into Radiology and Why it Matters

Bibin Joseph, Assistant Professor, MRIT**,** M S Ramaiah University of Applied Sciences, Bangalore, Karnataka

I never chose radiology.

Or maybe... radiology chose me.

Like many students, I too stepped into this field not knowing what awaited me. MRIT – Medical Radiology and Imaging Technology, sounded like a mouthful when I first heard it. I didn't grow up dreaming of X-rays or CT scans. Honestly, my first impression of "X-ray vision" came from cartoons and superhero animations where characters could magically see through walls or spot hidden objects. It felt more like fiction than fact. I barely knew who radiographers were or what they truly did.

But life doesn't always give us answers it gives us direction.
Through classroom lessons that sparked curiosity, hospital postings that humbled me, patient stories that stirred something deep within, and countless late night study sessions where fatigue met its purpose, I slowly uncovered a world far greater than I ever imagined.

"A world where images speak louder than words, where silence saves lives, and where I found not just a profession, but a calling."

The Hidden Hero of Medicine

Radiology is the unseen hero of healthcare. It is the eye of modern diagnosis. A person walks in with pain, uncertainty, fear and through imaging, we unlock answers without a single incision.

From detecting fractures to tumours, from tracking foetal development to guiding radiotherapy, radiology stands at the frontline of care. We are the ones behind the screens, capturing images that guide surgeons, physicians, and oncologists. We are not just technicians. We are diagnostic detectives. In many emergencies, we're the first to know something's wrong and the first to act. In the vast machinery of healthcare, radiology technologists are the unsung backbone delivering precision, enabling critical decisions, and quietly transforming lives from behind the scenes.

The Spark That Ignited the Revolution

What moved me most was the story of Sir Wilhelm Conrad Röntgen, who discovered X-rays in 1895. The invisible light that changed everything.

But Roentgen was only the beginning.
Many scientists gave their time, health, and even their lives to this field. Marie Curie, the pioneer of radioactivity, died from the very radiation she studied to help treat others. Clarence Dally, Thomas Edison's assistant, suffered the consequences of early fluoroscopy experiments. Their sacrifices became the stepping stones for safe, modern imaging today.

We are here because they believed in something bigger than themselves. Their courage, their suffering, their discoveries gave us a field that continues to save millions.

The Weight We Carry

Today, as a faculty member, I no longer see this just as a profession. I see it as a responsibility.

To train future radiographers who are not only skilled, but also compassionate, ethical, and resilient. Who don't just understand anatomy, but also humanity. Who respect the risks of radiation but use it not to harm but to heal.

Yes, we work with radiation. And yes, it has its effects. But like any powerful force, it is not the danger that defines it, it's how we control it, channel it, and use it to protect and heal.

As it was wisely said in Spider-Man, "With great power comes great responsibility." In radiology, that responsibility is real. We carry the burden of precision, safety, seeing what others cannot so we can help where others could not.

Through rigorous protocols, advanced shielding, and evolving technology, radiology today is not just powerful it is safer, smarter, and more compassionate than ever before.

The Path Ahead

- They are as dynamic as the images we produce:
- Radiologic Technologist
- CT / MRI Specialist
- Dosimetrist in radiation oncology
- Quality Assurance Radiographer
- Teleradiology Technologist
- Application Specialist for imaging companies
- Academic paths through M.Sc., Ph.D., research, and teaching. MRIT is not just a course, it is a launchpad to lead, explore, and evolve.

To the Brave Ones Reading This

To every student unsure about this path, I see you.

I was once you. Lost. Confused. Overwhelmed.

But the moment I realized the impact I could make, there was no turning back.

And maybe, like me, you'll realize that radiology is not just about images. It's about answers, hope, and healing.

There's a quote that stayed with me words from Erwin Smith, from Attack on Titan, who led his soldiers into the unknown:

"My soldiers, rage! My soldiers, scream! My soldiers, fight!"

This was not just a cry for battle. It was a call to courage, a reminder that even when the world doesn't see you, you fight for a future they can't yet imagine.

In radiology, that's who we are.

We are not always in the spotlight. But we are essential.

We do not wear capes. But we save lives.

We are the quiet backbone of modern medicine.

And every time we put on that lead apron or sit behind the console, we're continuing a legacy of courage!

So, to every student listening:
If you feel unsure... if you wonder whether this path is right...

Look at what you hold.
You don't just hold a scan,
You hold someone's hope.
You don't just see organs,
You see answers.
You don't just produce images,
You produce direction, precision, compassion and healing.

For Those Who Chose Radiology or Were Chosen by It

Welcome to the world where we see the unseen, where we serve in silence, where every scan has a story, and maybe just maybe this unseen light was meant for you too. Just like me, you may have stepped into this field not knowing what it truly holds.

But with time, you'll see its power, its purpose, and its profound impact. And maybe, like me, you'll find not just a career but a calling.

Be a Good Reader

Got the issue of the magazine, downloaded it, read it and deleted it. Only this does not prove you a good reader. You can agree with or add to the content published in the magazine, so in such cases please write us your comment or feedback. Similarly, debate openly on the issues rose in the magazine and the questions raised and send it to us in writing. With this act of yours, where other readers will be benefited; we will also get guidance in various forms. So, whenever the time demands, do not forget to pick up the pen.

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,
Editor

Demand for Functional Allied and Healthcare Professionals Council in Telangana State

- Delay despite Centre's directives and Supreme Court orders
- National Commission to regulate allied health professions

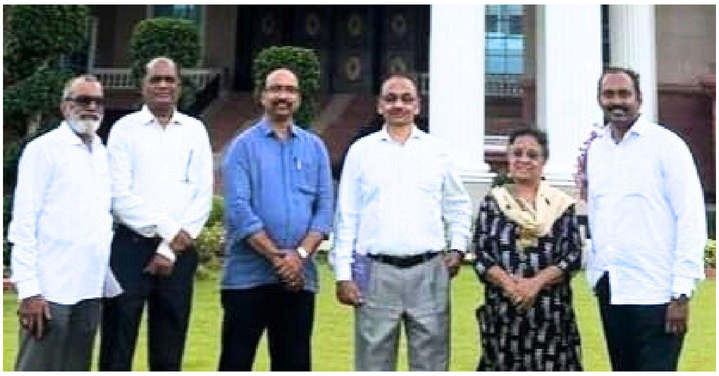
In March 2021, the Union Government established the National Commission for Allied and Healthcare Professions. The legislation sought to bring 57 categories of allied health professionals—excluding doctors and nurses—under one regulatory framework. The law mandated the creation of state councils in all states. Following repeated directives from the Centre, the Supreme Court also directed states to set up such councils without delay. Except for eleven states, the rest have already constituted them.

Telangana's half-hearted implementation

Telangana formally announced the formation of its council in 2022. However, the body has remained largely on paper. The government appointed Dr. Vijay Kumar of NIMS as chairman along with three co-opted members. Yet, it failed to appoint other professional members or provide an office for the council. With the chairman's tenure ending before full appointments could be made, the council has remained defunct.

Hopes pinned on the new government

After the change of government, allied health professionals expected decisive steps to establish a functional council. However, no move has been made so far. The Joint Forum of Allied and Healthcare Professionals, led by general secretary Manchala Ravinder, and the Society of Indian Radiographers submitted representations to Health Minister Dr. Damodar



Raja Narasimha, Principal Secretary Christina, and Additional Secretary Ayesha. They stressed the importance of a council that could ensure recognition, standards, and accountability for allied health professionals.

Stakeholders press for immediate action

Several prominent figures participated in the meeting that discussed the issue. Among them were NIMS Allied Health Sciences College Principal and National Commission member Sirdandas Srinivasulu, former state council chairman Dr. Vijay Kumar, Telangana president of the Society of Indian Radiographers Damodara Naidu, Joint Forum general secretary Manchala Ravinder, treasurer M.A. Waris, and psychiatric social worker Anita Regolu. The representatives urged the government to constitute a fully functional state council without further delay.

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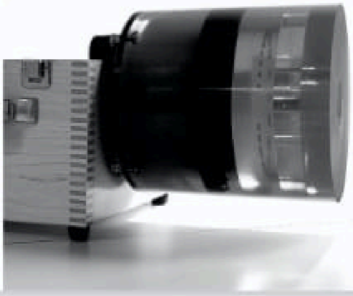

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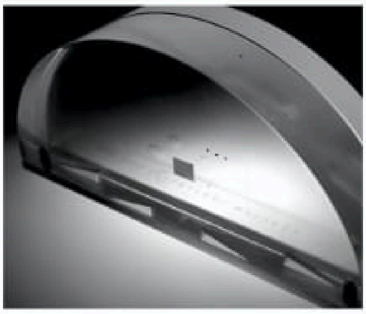

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Wearable Radiography: The Next Frontier in Diagnostic Imaging

Firdous Nazir, Radiographic Technologist, DMST, Pulwama, Jammu & Kashmir

Introduction:
When X-Rays Step Off the Machine and Onto Your Skin
Radiography has come a long way since Wilhelm Röntgen's accidental discovery of X-rays in 1895. From bulky glass tubes and plate films to sleek digital detectors, each leap forward has been driven by a single vision—making medical imaging faster, safer, and more accessible.

Now, in 2025, a new chapter is being written in that story: wearable radiography.
Imagine a soft, flexible patch on your chest that continuously monitors lung health, or a lightweight vest that tracks fracture healing without repeated trips to the hospital. Instead of stepping into a dedicated imaging room, the "scanner" becomes part of what you wear—integrated into your daily life.

This is not science fiction anymore. Advances in sensor miniaturization, nanomaterials, and low-dose radiation technology have brought wearable radiography out of research labs and into pilot clinical trials worldwide.

From Room-Sized Machines to Body-Worn Devices
Radiography began with static, room-based systems. For decades, X-ray machines were stationary, large, and resource-intensive. Portable X-ray units arrived during wartime in the 20th century, enabling bedside imaging for injured soldiers and immobile patients. This mobility transformed workflows, but even portable systems still relied on rigid detectors and handheld emitters.

Wearable radiography represents the next step in this evolution—one where the device is so small, lightweight, and flexible that it can be attached directly to the patient's body, allowing imaging to occur continuously or on demand without repositioning or travel.

This shift mirrors other healthcare trends—think wearable ECG monitors or continuous glucose sensors—where the goal is to integrate diagnostics into everyday life rather than confining them to clinical settings.

How Wearable Radiography Works
At its core, wearable radiography uses the same principles as conventional X-rays: ionizing radiation passes through the body, with tissues absorbing or scattering it differently depending on their density. These differences are captured by a detector and converted into an image.

The difference lies In the form factor, materials, and operating parameters:
Miniature Low-Dose X-ray Sources
Engineers have developed tiny X-ray emitters—some no bigger than a coin—that operate at ultra-low doses suitable for repeated or prolonged monitoring. The goal is to minimize radiation exposure while still capturing clinically useful information.

Flexible Detectors
Instead of rigid plates, wearable devices use bendable, lightweight detectors made from organic semiconductors, thin-film transistors (TFTs), or flexible scintillators. These can contour to the body, maintaining good contact even during movement.
Wireless Data Transmission
Captured images or sensor readings are transmitted via Bluetooth, Wi-Fi, or dedicated medical IoT networks to a clinician's workstation or a secure cloud server. This enables remote interpretation—perfect for telemedicine setups.
On-Board Processing
Some wearable radiography devices include built-in AI algorithms that pre-process images, highlight anomalies, or send urgent alerts without waiting for human review.

Types of Wearable Radiography Devices
While still emerging, wearable radiography devices are already being explored in several forms:
Diagnostic Patches
Thin, adhesive patches embedded with a small X-ray emitter and detector array. They can be placed over the chest, limb, or injury site to take periodic images.
Radiographic Vests and Belts
Garments equipped with multiple detectors for broader coverage, such as monitoring rib fractures or spine alignment over time.
Smart Casts
Orthopedic casts with embedded radiographic sensors that can monitor bone healing without removal.
Hybrid Wearables
Devices that combine radiography with ultrasound or thermal imaging for multiparametric monitoring.

Applications in Healthcare
The potential use cases for wearable radiography are vast, but a few stand out as particularly impactful:
Fracture Healing Monitoring
Instead of scheduling multiple follow-up X-rays, a wearable cast could check bone alignment and healing progress daily.
Lung Disease Tracking
Continuous imaging could help monitor pneumonia recovery, detect early signs of fluid buildup, or track tumour response to therapy.
Post-Surgical Follow-up
After orthopedic or thoracic surgery, wearable radiography could reduce the need for hospital visits while giving surgeons real-time healing data.
Sports Medicine
Athletes recovering from injury could benefit from more frequent, non-disruptive imaging to guide training modifications.

Remote and Rural Healthcare
In areas without full radiology facilities, wearable devices could transmit images to specialists hundreds of miles away.

Benefits over Conventional Systems
Continuous Monitoring: Captures changes over time, not just snapshots.
Patient Convenience: No repeated trips to imaging centres.
Faster Clinical Decisions: Immediate access to up-to-date images.
Improved Compliance: Easier for patients to stick with monitoring plans.
Integration with AI: Automated analysis for faster triage.

Challenges and Concerns
While the technology is promising, wearable radiography also faces significant hurdles:
Radiation Safety
Even with ultra-low doses, continuous exposure must be carefully monitored. Regulatory bodies will require strict safety protocols.
Image Quality
Flexible detectors may not yet match the resolution of stationary digital radiography, especially for deep or subtle lesions.
Cost and Accessibility
Cutting-edge devices are expensive to develop, and widespread use will depend on manufacturing scalability.
Data Privacy
Continuous imaging creates a stream of sensitive data—raising concerns about encryption, storage, and misuse.
Regulatory Approval
Medical device clearance can take years, especially for devices emitting ionizing radiation.

Case Studies: Early Trials
Fracture Recovery at Home
A pilot study in Japan tested a wearable smart cast with built-in radiographic sensors on 20 patients. Images taken daily were transmitted to orthopedic clinics, allowing physicians to adjust care remotely. Healing times were comparable to standard care, but patients reported higher satisfaction.

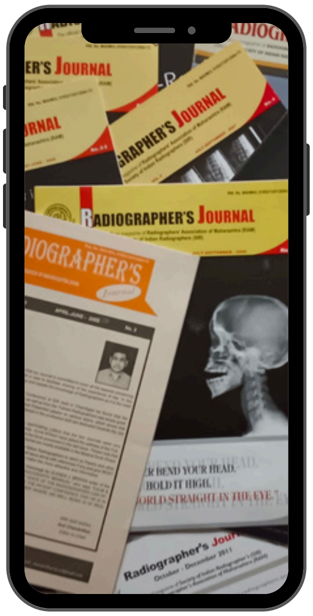
Pulmonary Monitoring in COPD
In Germany, researchers used chest-worn patches on COPD patients for 14 days. While image resolution was lower than hospital systems, the ability to track changes in lung inflation patterns proved valuable.

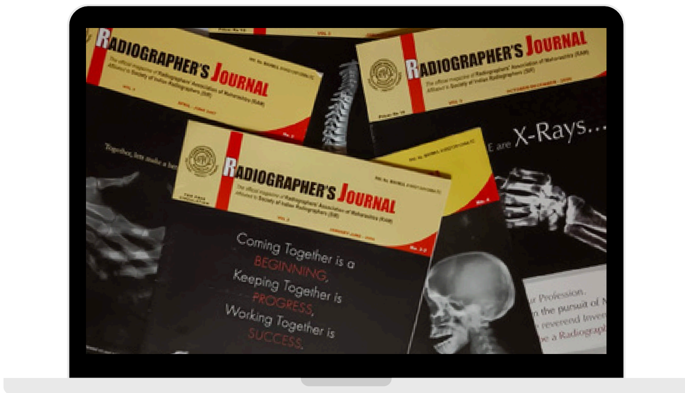
Future Possibilities
The next decade could bring remarkable developments in wearable radiography:
Zero-Radiation Wearables: Devices using alternative modalities like electrical impedance or magnetic resonance to complement or replace X-ray doses.
AI-First Systems: Fully automated preliminary diagnosis before a radiologist even views the scan.
Integrated Health Dashboards: Combining radiography data with heart rate, oxygen saturation, and activity levels for a full health profile.
Public Health Applications: Wearables for outbreak monitoring—imagine detecting early signs of tuberculosis in high-risk areas without large-scale screenings.

Conclusion: A Step Closer to Invisible Medicine
Wearable radiography is more than just a clever gadget—it represents a paradigm shift in how we think about medical imaging. By merging flexibility, connectivity, and advanced sensor technology, it moves radiography from the clinic into the patient's daily life.

There are still questions to answer—about safety, ethics, and feasibility—but the trajectory is clear. If the 20th century was about bringing imaging to the bedside, the 21st is about bringing it to the body itself.

And perhaps, in the not-so-distant future, the phrase "Let's take an X-ray" will no longer mean rolling into a special room—it will mean glancing at your smartwatch or peeling back a diagnostic patch, and simply... looking.





SVCPMS AHPCON 2K25

Organized by Sri Venkateshwaraa College of Paramedical Sciences (SVCPMS), Ariyur, Puducherry on 21 - 22, August 2025

A two-day international conference, “SVCPMS AHPCON 2K25,” was organized by Sri Venkateshwaraa College of Paramedical Sciences (SVCPMS), Ariyur, Puducherry, in association with Society of Indian Radiographers- Puducherry Chapter on August 21st and 22nd, 2025 Themed “Redefining Healthcare: The Vital Role of Allied Health Professionals,” the event highlighted the significant contributions of allied health professionals in shaping modern healthcare.

The inaugural ceremony began with a prayer song and lamp lighting, followed by a warm welcome address by Dr. C. Ananda Vayaravel, Dean of SVCPMS. The Chief Guest, Dr. B. Vidhya, Chief Operating Officer of SVGI, delivered the presidential address and released the college magazine “ALLIEDZINE 2K25,” commemorating 15 years of excellence at SVCPMS. During the conference, pioneers who have served in the field of Allied Health Sciences for more than 15 years including Mr. Shanmugam, President, Dr. S. Tamijeselvan, General Secretary and Mr. Kannan, EC member of SIR – Puducherry chapter were felicitated for their dedicated contributions.

The academic sessions featured six national speakers: Dr. Niranjan Gopal, Additional Professor, Department of Biochemistry, AIIMS Nagpur; Dr. Parivalavan Rajavelu, Consultant Surgeon, Sundaram Medical Foundation, Founder of Skills for Med, Chennai; Dr. Suresh Seshadri, Director of Medi Scan Systems, Chennai; Dr. V.K. Mohan, Professor,

Department of Anaesthesiology, JIPMER, Puducherry; Dr. Rashima Asokan, Professor, Department of Optometry and Head of Occupational Optometry Clinic, Sankara Nethralaya, Chennai; and Mr. R. Akash, Founder of Global Groups & Network and Managing Director of GEN Academy. One international speaker, Mr. K.P. Mohamed Akram, Cardiac Physiologist at New Cross Hospital, United Kingdom, also shared insights on advancements and challenges in healthcare.

Alongside the lectures, academic and cultural competitions provided students with opportunities to showcase their skills, creativity, and knowledge. In total, over thirty colleges and more than seven hundred students from all over India participated in the conference, making it a grand success. At the end of the two day event the prizes were distributed by Dr. C. Ananda Vayaravel, Dean of SVCPMS, Mr. R. Shanmugham, President SIR-PY and Dr. S. Tamijeselvan General Secretary, SIR-PY.

Lead Free Apron

Pratik Virat, Assistant Professor, Department of Radio-imaging Technology, CT University Ludhiana, Punjab

Abstract
Lead aprons have been the mainstay of radiation protection in medical settings for many years, protecting patients and healthcare workers from ionizing radiation. However, their inherent disadvantages—hefty weight, possible lead toxicity, and disposal-related environmental issues—have prompted the creation of sophisticated substitutes. The benefits of lead-free aprons and the technological developments propelling their growing popularity are examined in this article. The main driving force behind this shift is increased safety, since lead-free materials remove the dangers of lead exposure during production, use, and disposal. Most importantly, these cutting-edge aprons provide notable ergonomic and comfort enhancements. They greatly lessen the physical strain on medical professionals who wear them for extended periods of time by being much lighter—typically by 20–50%—which helps to prevent musculoskeletal strain and weariness. Because lead-free aprons use non-toxic, frequently recyclable composite materials that make disposal easier and reduce ecological effect, they are a considerably more environmentally conscious option.

Notwithstanding these benefits, lead-free aprons continue to exhibit radiation attenuation qualities that are on par with or better than those of conventional lead aprons. This is accomplished by advanced engineering, the use of materials such as composites of bismuth and antimony, and occasionally even the use of nanomaterials and multi-layered structures to maximize X-ray absorption. Improved durability, lower disposal costs, and better employee well-being over time provide a strong return on investment, even though the initial costs may be somewhat higher. The article also discusses important factors that healthcare facilities should think about throughout this change, such as staff training and regulatory compliance. In the end, the switch to lead-free aprons represents a significant advancement in contemporary radiation safety, guaranteeing a safer, lighter, and more environmentally friendly future for medical settings.

Keywords: X-ray, radiation, hazardous

Introduction

The large, sometimes unwieldy lead apron has been a staple and essential piece of equipment in medical imaging departments all around the world for almost a century. These ostensibly straightforward clothes have been instrumental in saving lives in anything from busy X-ray rooms to interventional radiology suites, serving as an essential barrier against the undetectable but dangerous effects of ionizing radiation. This pervasiveness highlights a basic reality: protection is not only recommended but definitely necessary for patients and healthcare professionals in settings where radiation exposure is frequently necessary for diagnostic precision. Due to its dense atomic structure, the lead apron has long been the main tool used to accomplish this important shielding, successfully attenuating X-rays and protecting key organs from any cellular damage and long-term health hazards. Nevertheless, despite its effectiveness, the continued use of lead has always involved a number of trade-offs. One heavy metal that poses serious problems is lead. Because of its significant weight—often several kilograms—medical personnel who wear these aprons for extended periods of time suffer bodily harm, which over years of use can lead to musculoskeletal strain, exhaustion, and discomfort. In addition to the ergonomic issues, the protective material itself has drawbacks: Lead is a well-known environmental contaminant and neurotoxic. Although contained within the apron, there are real health and environmental issues about the possibility of lead exposure during production, if the apron is broken, or—most importantly—during its final disposal. From manufacturing to final disposal, the lifecycle of a lead apron adds to a toxic waste stream that needs to be managed carefully and expensively to avoid contaminating land and water.

The field of radiation protection is currently undergoing a subtle but significant transition in response to these long-standing problems. Lead-free aprons are quickly becoming a revolutionary and better option, propelled by developments in material science and an increasing focus on environmental sustainability and occupational health. More than a simple material change, these cutting-edge clothes signify a paradigm leap toward safer, more intelligent, and more conscientious radiation shielding solutions. These new-generation aprons claim to provide comparable or even better protective capabilities by utilizing advanced composite materials, all without the harmful weight or toxicity that comes with lead.

This article explores the strong justification for this important change. We will examine the many advantages of lead-free aprons, including their unquestionable environmental benefits, improved safety profile, and ability to greatly increase user comfort and lessen physical strain. We will also discuss the state-of-the-art materials and technology that make these aprons capable of offering strong radiation attenuation.

This discussion aims to demonstrate why lead-free aprons are not just an alternative but the unavoidable future of personal radiation protection by looking at the factors that healthcare facility should take into account when implementing these new solutions. This will redefine the standards for comfort, safety, and environmental stewardship in medical environments around the world. A lighter, more environmentally friendly, and intrinsically safer era in medical imaging is gradually replacing the bulky, hazardous lead apron.

Why the Shift to Lead-Free?

First and foremost, increased safety is crucial. One known hazardous heavy metal is lead. Even if they are enclosed, lead still poses a danger of exposure, especially during production, if the apron is broken, or when it is disposed of at the end of its useful life. Lead-free substitutes totally remove this harmful component, protecting the environment and medical personnel from possible lead exposure.

Second, the lighter weight and enhanced comfort may have the biggest direct effects on regular users. Medical personnel who wear traditional lead aprons for extended periods of time experience severe physical strain due to its infamously hefty weight. Fatigue, persistent pain, and musculoskeletal problems can result from this ongoing load. Made from cutting-edge composite materials like bismuth and antimony, lead-free aprons are significantly lighter—typically by 20–50%. This significant weight loss immediately results in improved comfort, increased mobility, and a healthier workforce, lowering the likelihood of work-related accidents and enhancing general wellbeing.

Thirdly, there is a growing concern about environmental responsibility. Lead-containing product disposal is a hazardous waste problem that necessitates expensive and specific procedures to avoid polluting the environment. Since lead-free aprons are made of non-toxic and frequently recyclable materials, they provide a far more sustainable option that supports international initiatives to lessen hazardous waste and encourage environmentally friendly healthcare practices.

Lastly, contemporary technology has fully handled the crucial issue of similar or higher attenuation. The first doubts about the protective potential of lead-free substitutes have mostly been dispelled. Thorough testing demonstrates that these novel materials can successfully block ionizing radiation, frequently outperforming lead in terms of effectiveness. This ensures that safety is not sacrificed for comfort or environmental advantages. The case for the broad use of lead-free aprons is strengthened by this technological parity.

The Technology Behind the Protection

Modern lead-free aprons perform better than their predecessors, which is evidence of important developments in material science and engineering. In contrast to their predecessors, these aprons go beyond the straightforward dependence on the high density of lead and instead make use of a thorough understanding of atomic characteristics and material interactions with radiation.

The use of bismuth and antimony composites is a fundamental component of radiation protection without lead. Like lead, the heavy elements bismuth (atomic number 83) and antimony (atomic number 51) have good X-ray attenuation qualities, particularly in the diagnostic energy range frequently used in medical imaging. These components combine to provide flexible, strong, and noticeably lighter shielding materials when included into polymer matrices. Manufacturers frequently keep the exact ratios and production procedures of these composites as trade secrets. They are optimized to maximize the material's flexibility and durability as well as its ability to block radiation.

By using the photoelectric process and Compton scattering, these composites efficiently absorb X-ray photons, transforming the dangerous radiation into less energetic forms or scattering it away from the wearer. These polymer-embedded composites' flexibility enables ergonomic, comfortable apron designs that fit the body, which is essential for medical personnel who do lengthy procedures.

Beyond these main substitutes for heavy metals, research and development is still looking at innovative approaches, such as using nanomaterials. Nanotechnology holds the prospect of much lighter and more effective shielding, though it is still a developing subject. Researchers hope to attain superior attenuation with less material by spreading metallic nanoparticles (such as tungsten, bismuth oxide, or cerium oxide) within a polymer matrix. Compared to their micro-sized counterparts, nanoparticles' higher surface-area-to-volume ratio enables more efficient interaction with X-ray photons. By producing materials with similar protection at even lower weights, this tiny engineering can improve user comfort and possibly open the door to new, more covert radiation protection techniques. Although they are not currently commonly used in commercial aprons, nanomaterials are the next step in creating a radiation shield that is both incredibly lightweight and highly effective.

Additionally, multi-layered designs are used in several high-performance lead-free aprons. In order to maximize attenuation over a wider range of X-ray energy, this intricate design combines various lead-free materials in precise configurations. A typical design, for example, might have layers with varying atomic numbers that are positioned to maximize absorption and reduce the creation of secondary radiation (such as K-edge fluorescence).

This layering method provides complete protection against dispersed radiation as well as the main X-ray beam, which is a major worry in clinical settings, especially in India's crowded hospitals and diagnostic facilities. The outer layers, which enclose the protective core and guarantee the apron's lifetime and hygienic use, are usually composed of strong, easily cleaned materials like nylon or ripstop. In addition to being substantially lighter and more ecologically responsible, lead-free aprons may offer strong, dependable protection that satisfies strict national and international safety regulations thanks to this clever layering technique and cutting-edge composite materials.

Adopting the Change: Considerations for Healthcare Facilities

Even though switching to lead-free aprons has many benefits, healthcare facilities must carefully examine and strategically plan for this change, especially in a country with a diversified and quickly changing healthcare system like India. Three important issues must be addressed for adoption to be successful: cost, regulatory compliance, and staff education.

One important first factor is cost. Because of their sophisticated materials and production techniques, lead-free aprons are frequently more expensive up front than conventional lead or lead-composite aprons. This distinction may play a significant role in procurement choices in India, where healthcare spending may be limited. For example, lead-free solutions, particularly sophisticated full-wrap variants, can be much more expensive, potentially reaching INR 35,000 to INR 65,000 or even higher depending on the brand and features, whereas a normal lead apron might cost between INR 4,000 and INR 15,000. Healthcare institutions must, however, take into account the long-term financial advantages in addition to the purchase price. Among these are lower expenses for disposing of lead aprons as hazardous waste, which can add up over time. Long-term cost savings can also be achieved by reducing staff injuries and related medical leaves or workers' compensation claims brought on by heavy aprons, as well as by the greater durability and perhaps extended lifespan of lead-free aprons. Using lighter aprons to promote employee well-being can also boost morale and lower employee turnover, which indirectly lowers costs. For lead-free alternatives, facilities may think about leasing possibilities, replacing aprons as they wear out, or implementing the change gradually.

Regulatory compliance cannot be compromised. The main regulatory authority for radiation safety in India is the Atomic Energy Regulatory Board (AERB). Any lead-free aprons purchased by healthcare facilities must adhere to the strict attenuation criteria and quality requirements established by AERB.

The required protection levels and testing procedures for personal protective equipment are described in the AERB's safety rules and guidelines, such as those relating to radiation safety in diagnostic X-ray equipment. Specific stated standards for "lead-free" aprons as a distinct category are constantly changing, despite the fact that AERB recommendations highlight the ALARA (As Low as Reasonably Achievable) principle for radiation exposure and provide dose limitations. Facilities must confirm that manufacturers submit the proper certificates and test reports attesting to the lead-free materials' equivalent lead equivalency (e.g., 0.25 mm Pb, 0.35 mm Pb, and 0.5 mm Pb) as determined by certified laboratories. Maintaining continuous operational compliance and avoiding fines requires keeping abreast of AERB circulars and recommendations about new radiation protective products.

A thorough staff education program is essential for a seamless and successful transfer. Only when users are adequately trained and comprehend the worth of the technology can its benefits be completely realized, even with the best equipment. At first, healthcare workers who are used to wearing traditional lead aprons may be dubious or ignorant about the benefits of lead-free substitutes. Training plans should emphasize that protective qualities are preserved or improved and clearly state the advantages, such as lighter weight and increased comfort. Proper donning and doffing practices, how to check for deterioration, and care and maintenance to extend the lifespan of an apron should all be covered in education.

Staff members' sense of accountability and ownership can also be increased by highlighting the environmental advantages and the eradication of lead toxicity. Additionally, preventing premature wear and tear and ensuring that employees understand how to use and store the new lighter aprons will strengthen the investment. The healthcare institution may foster a culture of safety and innovation by addressing any concerns and ensuring the smooth incorporation of lead-free aprons into routine clinical practice through regular refresher courses and open forums for feedback.

The Path forward

An important turning point in radiation safety has been reached with the switch to lead-free aprons, signalling a day when strong protection won't have to be weighed down by toxicity. The overall advantages of this change are significant and wide-ranging, affecting not just the immediate consumer but also the environment and the larger healthcare ecosystem.

At its core, improved safety and comfort are what characterize the future of lead-free aprons. Physical strain will be significantly reduced for healthcare workers, who are the front-line fighters in medical imaging. This will improve their overall quality of life and job longevity by reducing fatigue and musculoskeletal problems. This direct increase in occupational health is priceless since it makes workers in India's demanding healthcare facilities more content and productive. Eliminating lead completely also reduces the health and environmental risks it poses, which is ideal for the nation's and the world's expanding demands for sustainable healthcare practices. Because these materials are non-toxic and recyclable, they provide an ethical approach to waste management that reduces environmental impact for future generations.

The prospects for lead-free radiation protection are extremely bright. It is anticipated that ongoing developments in material science will produce materials that are even lighter, more flexible, and possibly more affordable. We should expect form factor advancements that could result in more integrated and covert protective clothing. Attenuation efficiency will probably be pushed by research into new composite materials and nanotechnologies, enabling thinner but no less efficient shielding. The cost difference between lead and lead-free aprons is also anticipated to decrease as manufacturing techniques improve and technology advances, making them more affordable for a greater number of healthcare facilities, particularly those in India's smaller cities and rural regions.

The transition to lead-free aprons is, in summary, a significant paradigm shift in radiation protection rather than just a small improvement. It represents a comprehensive approach to safety that takes into account the welfare of users, environmental stewardship, and unwavering protective capabilities. Although careful cost planning, regulatory compliance and extensive staff training are necessary for the initial implementation, the long-term benefits greatly outweigh the expense. In India, where healthcare is still developing quickly, adopting lead-free aprons shows a forward-thinking, progressive dedication to protecting its most precious resources: its people and its earth. Embracing and more sustainable future for radiation protection is more important than simply replacing out-dated technologies.

A lighter, more responsible, and fundamentally safer era in medical imaging is emerging as the time for the bulky, poisonous lead apron is gradually coming to an end.

Discussion

A complicated but important topic of conversation in contemporary healthcare is the continuous transition from conventional lead aprons to lead-free substitutes for radiation protection. This development is fuelled by a combination of expanding occupational health awareness, technology developments, and a growing commitment to environmental stewardship—all of which are especially important in a nation like India with its extensive healthcare system.

The technological maturity and performance equivalency of lead-free materials are two of the main topics of this discussion. Much of the initial doubt over the ability of non-lead materials to match lead's powerful radiation attenuation properties has been removed. Using advanced composites of bismuth, antimony, and other heavy metals contained in flexible polymer matrices, modern lead-free aprons have shown comparable or even better protective properties. This is crucial since any safety compromise is intolerable. These materials' capacity to efficiently absorb X-ray photons across diagnostic energy ranges—often via multi-layered designs—guarantees that patients and medical personnel get the protection they want without the inherent disadvantages of lead. Future developments in nanotechnology promise even lighter and more effective shielding. The conversation frequently focuses on the observable advantages to healthcare personnel' well-being in addition to performance. Radiologists, cardiologists, and other interventional experts have historically experienced severe musculoskeletal problems, such as persistent shoulder and back discomfort, as a result of the sheer weight of lead aprons. Because they are significantly lighter, lead-free aprons directly solve these ergonomic issues. Comfort is only one factor; other benefits include lowering the risk of chronic workplace injuries, enhancing employee retention, and maybe boosting procedural efficiency as workers feel less worn out. Any action that enhances the health and working circumstances of medical personnel is a big plus in a nation like India where there may be a lack of healthcare workers. Nonetheless, the discussion also covers useful adoption factors. Particularly for schools on a tight budget, the greater initial cost of lead-free aprons in comparison to their lead counterparts continues to be a topic of discussion. Initial procurement selections necessitate cautious financial planning, even when the long-term cost benefits (lower disposal costs, fewer personnel injuries) are appealing. Moreover, adherence to regulations is crucial. The Atomic Energy Regulatory Board (AERB) in India has strict guidelines for radiation safety gear. Although the AERB recommendations outline the necessary lead equivalency (e.g., 0.25 mm Pb, 0.5 mm Pb), they typically do not distinguish between different materials as long as the protective efficacy is demonstrated. In order for lead-free aprons to satisfy these defined "lead equivalent" criteria, healthcare facilities must make sure they have undergone extensive testing and certification. Facilities should include these tests in their procurement procedures, and manufacturers are required to back up their promises with verifiable data. Lastly, a critical component of the conversation is awareness and education. Successful integration requires closing the information gap among healthcare personnel about the advantages and appropriate use of lead-free aprons. More acceptance and compliance can be achieved by clearing up any misunderstandings and emphasizing the benefits in terms of comfort, safety, and the environment. The aggressive adoption of lead-free aprons is not just a technological advancement but also a pledge to a safer, healthier, and more sustainable future for everyone engaged in radiation-intensive medical procedures as India's healthcare industry grows and modernizes.

Conclusion

An important and essential development in the realm of radiation protection is the transition from conventional lead aprons to their lead-free equivalents. Lead aprons were an essential protective garment for many years, but their intrinsic disadvantages—heavy weight, lead toxicity, and difficulties with environmental disposal—presented constant worries for both the environment and medical practitioners. Lead-free solutions are currently at the forefront due to strong evidence, which promises a more sustainable and user-friendly future for medical imaging environments.

The indisputable advantages of lead-free technology form the basis of this shift. They offer comparable or even better radiation attenuation, guaranteeing complete safety without the lead-related health hazards. Medical staff have increased comfort and less musculoskeletal strain as a direct result of the significant weight loss, which enhances their long-term health and job happiness. Additionally, their non-toxic makeup and frequently recyclable nature greatly reduce environmental effect, bringing healthcare procedures into line with international sustainability goals and India's increasing emphasis on environmentally friendly solutions.The long-term benefits clearly exceed these difficulties, even while factors like the initial cost, rigorous adherence to regulatory compliance from organizations like the AERB, and thorough staff training are essential for a smooth transition. Investing in lead-free aprons is an investment in the future of healthcare technology, environmental integrity, and worker health.

In the end, switching to lead-free aprons signifies a paradigm shift toward safer, more intelligent, and more responsible radiation protection—it's not merely a material improvement. Adoption of these cutting-edge technologies will be crucial as medical imaging technology develop in order to guarantee that protection is efficient, comfortable, and environmentally responsible. A lighter, safer, and more sustainable future in radiation protection for everyone is being ushered in by the gradual end of the heavy, toxic lead apron period.

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KASTURBA MEDICAL COLLEGE
MANGALORE
(A constituent unit of MAHE, Manipal)

23RD NATIONAL CONFERENCE OF SOCIETY OF INDIAN RADIOGRAPHERS

IMAGINE

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

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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).

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Assessment of Coronary Artery Disease with Special Reference to CT Angiography

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Abstract
Coronary artery disease (CAD), or coronary heart disease (CHD),tends to develop when cholesterol builds up on the artery walls , creating plaques . These plaques can narrow the arteries , reducing blood flow to the heart , or cause inflammation in and hardening of the blood vessel walls .A clot can sometimes obstruct blood flow , causing serious health problems .Computed coronary artery angiography has become the go-to method for diagnosing coronary artery disease. The noninvasive plaque imaging is becoming quite common due to its effectiveness and reliability in providing information that was once only accessible through invasive intravascular imaging methods. Computed tomography angiography derived physiological assessments of epicardial conductance and myocardial resistance ,providing non-invasive alternatives to the traditional catheter based intracoronary pressure and velocity measurements .

Keywords : Coronary artery disease (CAD), left main coronary artery (LMCA),left circumflex artery (LCx), invasive coronary angiography (ICA).

Introduction

Coronary artery disease (CAD) is another term used for atherosclerotic heart disease, that occurs when the blood vessels supplying the heart muscle (coronary arteries) become narrowed or blocked .This narrowing is typically due to the buildup of plaque , which is made up of cholesterol , fat , calcium , and other substances found in the blood . As the plaque accumulates , it can restrict blood flow to the heart ,leading to various symptoms such as chest pain (angina), shortness of breath ,and in severe cases heart attack .Coronary artery disease can lead to other problems , too, including heart failure and arrhythmias .CAD is a significant cause of morbidity and mortality worldwide , affecting millions of people each year .CAD affects both men and women . several factors can increase of developing the disease , including: Age , Family history , High blood pressure , High cholestrol , Poor diet ,Obesity or over weight , Diabeties , Smoking, Life style .Early detection and management of CAD are crucial to prevent complications such as heart attacks ,heart failure , and sudden cardiac death . Various diagnostic tests , including CT Angiography , can help in the assessment of coronary artery disease by providing detailed images of the coronary arteries , allowing healthcare providers to identify blockages and determine the extent of the disease .coronary computed tomography angiography provides non invasive assessment of coronary stenosis severity and flow impairment .Angiography to diagnose and treat diseases and conditions in the blood vessels. Angiographic tests produce images of large blood vessels throughout the body. Most tests use different things.

Angiography is performed using

X-ray and catheter
Computed tomography (CT)
Magnetic resonance imaging (MRI)

CT angiography from a CT scan as produce detailed images of both blood vessels and tissue in different parts of the body During the test, different substances are injected into a small catheter and inserted into the vein hands A radiologist takes high-resolution CT images as the contrast material flows through the blood vessels .One of the main advantages of coronary CTA is its ability to provide a comprehensive view of coronary artery disease without the need for invasive procedures such as traditional coronary angiography.

Coronary Arteries

The typical configuration consists of two coronary arteries, a left main coronary artery (LMCA) and a right coronary artery (RCA), arising from the left (posterior) and right (anterior) aortic or coronary sinuses, respectively, at the beginning of ascending aorta. These are the only two branches of the ascending aorta.

The right coronary artery courses in the right atrioventricular groove to the inferior surface of the heart, whereupon it turns anteriorly at the crux as the posterior descending artery (PDA) in the right dominant circulation. The left coronary artery has a short common stem (and is hence often referred to as the left main coronary artery), that bifurcates into the left circumflex artery (LCx), which courses over the left atrioventricular groove, and the left anterior descending artery (LAD), which passes towards the apex in the anterior interventricular groove. Occasionally, there is a trifurcation (in ~15%), with the third branch, the ramus intermedius, arising between the LAD and LCx. In left dominant hearts, the LCx supplies the posterior descending artery (PDA).

Branches:

Left Coronary Artery (LCA)

- Left Anterior Descending Artery (LAD
- Diagonal Branches (D1, D2, etc.)
- Septal Perforators (S1, S2, etc.)
- Circumflex artery (LCx)
- Obtuse Marginal Branches (OM1, OM2, etc.)
- Ramus Intermedius artery (RI)

Right Coronary Artery (RCA)

- Conus Artery
- Sinoatrial Nodal Artery
- Acute Marginal Branches (A1 or AM1, A2 or AM2, etc.)
- Inferior Interventricular artery (PDA)
- Posterior Left Ventricular (PLV) branch

Most hearts are right dominant (60%) where the PDA is supplied by the RCA. However, up to 20% of hearts may be left dominant, where the PDA is supplied by the LAD or LCx, or codominant, where a single or duplicated PDA is supplied by branches of both the RCA and LAD/LCx (20%).

Indication

Symptoms of coronary artery disease happen when the heart doesn't get enough oxygen-rich blood. Coronary artery disease symptoms may include:

Chest pain, called angina: You may feel squeezing, pressure, heaviness, tightness or pain in the chest. It may feel like somebody is standing on your chest. The chest pain usually affects the middle or left side of the chest. Activity or strong emotions can trigger angina. There are different types of angina. The type depends on the cause and whether rest or medicine

makes symptoms better. In some people, especially women, the pain may be brief or sharp and felt in the neck, arm or back.
Shortness of breath: You may feel like you can't catch your breath.
Fatigue: If the heart can't pump enough blood to meet your body's needs, you may feel unusually tired.

Symptoms of coronary artery disease may not be noticed at first. Sometimes symptoms only happen when the heart is beating hard, such as during exercise. As the coronary arteries continue to narrow, symptoms can get more severe or frequent.

A completely blocked coronary artery will cause a heart attack. Common heart attack symptoms include:

- Chest pain that may feel like pressure, tightness, squeezing or aching.
- Pain or discomfort that spreads to the shoulder, arm, back, neck, jaw, teeth or sometimes the upper belly.
- Cold sweats.
- Fatigue.
- Heartburn.
- Nausea.
- Shortness of breath.
- Lightheadedness or sudden dizziness.

Chest pain is usually the most common symptom of heart attack. But for some people, such as women, the elderly and those with diabetes, symptoms may seem unrelated to a heart attack. For example, they may have nausea or a very brief pain in the neck or back. Some people having a heart attack don't notice symptoms.

Classical indications for a coronary ct angiography are the following :

- Congenital coronary artery anomalies
- Coronary artery disease
- Chronic coronary syndrome
- Rule out significant luminal stenosis
- Coronary atherosclerotic plaque evaluation
- Acute coronary syndrome without ECG changes and negative troponin
- Surgical or interventional planning of chronic coronary occlusions
- Patency assessment of coronary bypass grafts in symptomatic individuals
- Alternative if invasive coronary angiography (ICA) is not possible or carries a high risk
- Unclear findings after invasive coronary angiography (ICA)
- Visualization of cardiac veins

Contraindications of Coronary Angiography

There are generally no absolute contraindications to performing a CCTA. However, a history of a severe anaphylactic reaction to iodinated contrast precludes a repeat contrast administration. The following are the relative contraindications.

- Acute thyroid storm
- Pregnancy
- Uncontrolled blood pressure
- Problems with blood coagulation(coagulopathy)
- Severe anemia
- Fever
- Renal insufficiency
- Inability to hold breath for more than 5 seconds.
- Patients on radioactive iodine therapy
- Hemodynamic instability
- Acute decompensated heart failure
- Patient's height and weight above the recommended scanner thresholds

Preparation for Ct Coronary Angiography

- Checking indications, contraindications, explanation of the examination and obtaining informed consent is obvious as in other CT examinations.
- Beyond that patient preparation for cardiac CTA includes the following: Checking contraindications for nitrates and beta blockers
- Preparation for a CT coronary angiography typically begins with a consultation with doctor. During this consultation, it's essential to discuss any existing medical conditions, allergies, and medications you are taking. It's particularly important to mention if you have any kidney problems or if you are pregnant, as these conditions can affect the safety and approach of the procedure.
- Medication management is another crucial aspect of preparation. Your doctor might ask you to temporarily stop taking certain medications that could interfere with the scan. Additionally, to ensure clear images, your doctor may prescribe beta-blockers (metoprolol 50 -100 mg one hour before the exam) to slow your heart rate if it is too high.
- Fasting is generally required for a few hours before the procedure, usually around 4 to 6 hours. This means avoiding both food and drinks. However, staying hydrated is important, so drinking plenty of water the day before the procedure is encouraged. This helps your body process and flush out the contrast dye that will be used during the scan.
- On the day of the scan, wear comfortable clothing and avoid any metal objects, such as jewelry, glasses, or dentures, as these can interfere with the imaging process. Lastly, plan to arrive at the hospital or imaging center early to complete any necessary paperwork and to allow time to relax before the procedure begins. No caffeine for 12 hours, An electrocardiogram signal needs to be acquired

Techniques

CT coronary angiography involves several specialized techniques to ensure accurate and detailed images of the coronary arteries:
Patient Preparation and Positioning: The patient is positioned on the CT scanner table, usually in supine with both arms above their head. Electrodes are placed on the chest to monitor the heart's electrical activity (ECG) during the scan.
ECG Gating: This technique synchronizes the CT imaging with the cardiac cycle, reducing motion artifacts and improving image quality. Prospective ECG gating captures images at specific points in the cardiac cycle, while retrospective ECG gating records images throughout the cycle, allowing for more detailed analysis.
Contrast Administration: An iodine-based contrast dye is injected into a vein, usually in the arm, to enhance the visibility of the coronary arteries. The timing of the contrast injection is crucial to ensure the dye is at the right concentration in the arteries during the scan.
Low-Dose Techniques: Modern CT scanners use advanced technology to minimize radiation exposure. Techniques such as automatic exposure control, iterative reconstruction, and dose modulation adjust the radiation dose based on the patient's size and the area being scanned.

High-Resolution Imaging: Multi-slice CT scanners with 64 slices or more provide high-resolution images. These scanners can capture multiple cross-sectional images of the heart in a single rotation, allowing for detailed 3D reconstructions of the coronary arteries.

Breath-Hold Instructions: Patients are usually instructed to hold their breath for short periods during the scan to reduce motion artifacts caused by breathing.

Post-Processing and Analysis: After the scan, the images are processed using specialized software that reconstructs the data into 3D models of the coronary arteries. This allows for detailed analysis of any blockages, stenosis, or other abnormalities.

These techniques collectively ensure that CT coronary angiography provides accurate, detailed images necessary for diagnosing and evaluating coronary artery disease.

Conclusion

In conclusion, the assessment of coronary artery disease (CAD) using CT angiography marks a substantial advancement in the field of cardiovascular diagnostics. This non-invasive imaging technique offers high-resolution, three-dimensional images of the coronary arteries, enabling clinicians to precisely identify and evaluate the presence, location, and severity of arterial blockages and stenosis. The detailed anatomical visualization provided by CT coronary angiography surpasses many traditional diagnostic methods, offering significant benefits in terms of accuracy and patient comfort.

The procedure leverages several advanced techniques to ensure optimal image quality and patient safety. ECG gating synchronizes image acquisition with the cardiac cycle, reducing motion artifacts and enhancing the clarity of the coronary arteries. The administration of iodine-based contrast dye is meticulously timed to highlight the coronary vessels, allowing for the precise detection of plaque, calcifications, and other abnormalities. Moreover, modern CT scanners employ low-dose techniques, such as automatic exposure control and iterative reconstruction, to minimize radiation exposure without compromising image quality.CT coronary angiography also facilitates comprehensive risk assessment and treatment planning. By providing a detailed assessment of coronary anatomy, this technique aids in the early detection of CAD, enabling timely intervention and potentially preventing adverse cardiovascular events. It allows clinicians to evaluate the extent of atherosclerosis, assess the significance of lesions, and plan appropriate therapeutic strategies, whether they involve medical management, percutaneous coronary intervention, or surgical options.

Furthermore, the non-invasive nature of CT coronary angiography reduces the risks associated with traditional invasive procedures, such as catheter-based coronary angiography. It is generally well-tolerated by patients, requires minimal recovery time, and can be performed on an outpatient basis. This enhances patient compliance and allows for broader application in various clinical settings.

Overall, CT coronary angiography has become an indispensable tool in the comprehensive management of coronary artery disease. Its ability to provide accurate, detailed, and timely information about coronary anatomy and pathology significantly improves diagnostic accuracy, informs clinical decision-making, and ultimately enhances patient outcomes. As technology continues to evolve, the role of CT coronary angiography in the assessment and management of CAD is expected to expand further, reinforcing its importance in contemporary cardiovascular care.

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QUIZ to Recapitulate

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

1. When the National Commission for Allied and Healthcare Professions (NCAHP) Act officially notified in the Gazette of India by the Government of India?

2. For what purpose 'Hydroquinone' has ben used in the Radiology department?

3. In Enteroclysis, where should the distal (internal) end of a nasojejunal catheter be positioned?

4. The "Jug Handle" view is done to evaluate which anatomical structures?

5. What is the recommended source-to-image receptor distance (SID) for routine adult chest radiography?

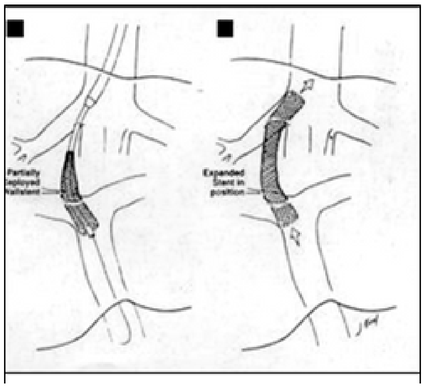
6. Which modern imaging modality has largely replaced conventional myelography?

7. What is IHE in Radiology?

8. Name the view

9. Identify the Image and mention its use.

10. Name the investigation & Purpose

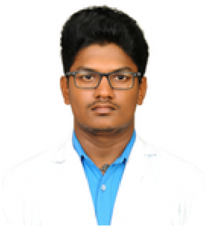


- Please send your answers through email on **pkpopli@gmail.com** on or before **10th September 2025.**
- Send your **Name with Hospital/Institution Information** and Passport size **photograph** along with the answers.
- **Best 3 participants** (early birds and correct) **in each month will get the 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 - June 2025 issue

1. Medical Radiology, Imaging & Therapeutic Technology Professional Council and National Commission for Allied and Healthcare Professions
2. In photostimulable phosphor (PSP) plate of CR system.
3. Both internal carotid arteries and both vertebral arteries.
4. Two meters or 6 feet
5. To distend and to examine the terminal ileum and ascending colon, specifically the cecum.
6. No compression given.
7. Second generation CT.
8. Mortise View (ankle joint) done with 15-20 degree medial rotation of foot.
9. Sialography of submandibular gland.
10. Pneumoencephalography (PEG), It was done to visualize the brain's ventricles and subarachnoid spaces (PEG is now obsolete).

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



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Sustainability & AI in Medical Imaging

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Abstract

Global warming poses significant health risks, requiring healthcare providers, including radiologists, to minimize carbon emissions while addressing emerging medical challenges. Artificial intelligence applications in radiology can accelerate magnetic resonance imaging, enhance appointment scheduling, and decrease redundant scans, thereby reducing environmental impact. The article explores methods to optimize AI's ecological footprint against its advantages, emphasizing healthcare accessibility, financial efficiency, and improved clinical results. Reducing the environmental impact of healthcare operations, particularly in clinical radiology and radiotherapy (CRR), is essential for minimizing ecological damage. This research seeks to develop guidelines for implementing environmentally responsible practices in these fields. Major environmental concerns in clinical radiology and radiotherapy (CRR) encompass power consumption, disposal of medical waste, and transportation impacts. Including encouraging eco-friendly commuting and leveraging AI technology to optimize healthcare resources utilization. Environmental sustainability is greatly influenced by medical imaging practices. This article encourages imaging professionals to adopt environmentally conscious techniques to reduce their carbon footprint.

Keywords: Environmental sustainability, Artificial intelligence, green imaging, recycle, green practices, carbon foot printing

Introduction

According to the World Health Organization, the most significant hazard to human health has emerged as climate change(1). The detrimental impacts of climate change on public health and welfare are a major global issue(2).To contribute to environmental sustainability and mitigate the detrimental effects of climate change, immediate and deliberate action needs to be taken(2).The healthcare industry is a resource-intensive sector which uses plenty of water and electrical power and generates an extensive spectrum of trash in several waste categories, including regulated medical waste(2). Globally, the healthcare industry produces over 4 million tons of trash a year, the majority of which pollutes the environment(3). Medical imaging has been estimated to be responsible for up to 1% of worldwide GHG emissions, whereas health care accounts for 8% to 10% of overall greenhouse gas (GHG) emissions in the US. New research revealed that radiological contrast media waste is increasingly contaminating aquatic environments, mostly as a result of a boom in contrast-enhanced CT and MRI procedures during the last decade(4).

AI can help facilitate radiology's increased sustainability by optimizing the administration of imaging resources. It is necessary that the radiologists and AI scientists understand the dual nature of AI; while it has the potential to improve sustainability in medical imaging, it also has an adverse effect on greenhouse gas emissions. We possess the capacity to make rational decisions and formulate strategies to optimize AI's beneficial effects while limiting its negative environmental effects(1).

Adverse Effect of AI in Medical Imaging on Environmental Sustainability

The global health care system, encompassing medical imaging, has to deal with the significant quantity of greenhouse gas (GHG) emissions produced during the provision of treatment while simultaneously managing the health implications of climate change. The amount of greenhouse gas emissions from data centres and computational activities in radiology is escalating. The reason for this is the swift rise in big data and artificial intelligence (AI) applications, which has led to substantial energy costs for creating and implementing AI models.(1)

Applications of artificial intelligence in radiology contribute to substantial greenhouse gas emissions, but if utilized attentively they also have the potential to positively impact environmental sustainability. The entire AI and informatics infrastructure must be reevaluated to determine how the development and implementation of AI technologies in radiology affect GHG emissions both directly and indirectly. This involves considering into parameters like data storage, energy source selection, and AI model development and deployment.(1)

AI Models Fabrication and Implementation- AI model deployment, validation, and training require a large amount of computing power, resulting of substantial power consumption and production of greenhouse gases. Guidelines for sustainable AI software are insufficient, and there is no precise data on emissions from AI in radiology. The energy consumption and associated greenhouse gas emissions of AI model development vary according to the size and complexity of the database; the type of AI model; The amount of memory utilized, the number, kind, and processing time of computer cores, the algorithm run time, and the efficiency of the data centre.

AI model training uses a lot of energy more than 626 000 kg of carbon dioxide, and some models release as much CO2 as several automobiles over the span of their lifespans. Due to frequent use, significant emissions might also result from the inference phase, which is where predictions occur. Emissions may be estimated using a variety of criteria with the application of tools such as the Machine Learning Emissions Calculator. Numerous aspects are taken considered by this calculator, including the hardware type, training duration, and the geographical area. Reducing the number of processor cores and using energy-efficient technology may substantially reduce emissions.(1)

Recommendations for AI Software Sustainability in Radiology

In radiology to reduce greenhouse gas (GHG) emissions and enhance environmental sustainability, sustainable AI software development and implementation are significant. By complying to these guidelines, the radiology sector can aim for a more sustainable AI integration that achieves a balance between the advantages of AI and the need to mitigate its negative effects on the environment.

·Specific Efficiency Criteria- For radiology AI models, clear efficiency criteria and reporting guidelines are crucial to advancing sustainability. These measurements might assist stakeholders understand the GHG emissions related to various AI technologies by being comparable to the Energy Star rating system used for appliances.

Awareness about energy utilization- Several aspects, such as the model's complexity, the kind of algorithms utilized, and the data centres efficiency, can greatly affect the energy needs and greenhouse gas emissions for developing AI models. To choose AI software effectively, among should be aware of these considerations.

Optimization mechanism- The optimal trade-offs between energy usage and training speed may be found by putting open-source optimization tools into practice. Energy savings from this method might be substantial, with deep learning models potentially saving ranges from 15% to 76%.

Maintenance of resources- GHG emissions may be reduced during AI simulations by employing techniques like cutting down on CPU and GPU core counts without appreciably lengthening execution times. For example, emissions were reduced by 33% when CPU cores were reduced from 60 to 30.

Alternative strategies- Energy usage may be further decreased by investigating other energy sources and applying small machine learning (TinyML). Compared to conventional approaches, TinyML's use of tiny, low-powered edge devices to run AI models may be greener.

Research initiatives- Initiatives to educate and explore the environmental effects of AI in radiology are severely needed; these efforts may help guide plans to reduce greenhouse gas emissions and encourage sustainable practices in the radiology community.(1)

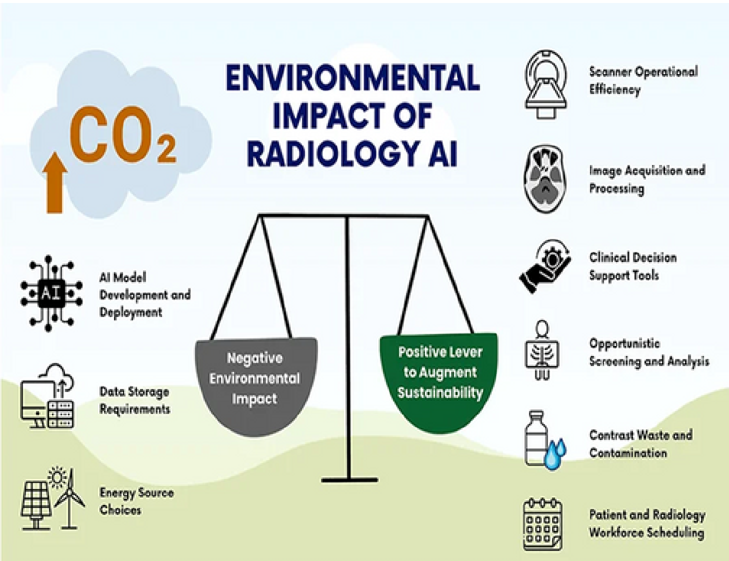

Figure.1 Artificial intelligence (AI) in radiology has negative impact on the environment as well as substantial potential and strategies for improving sustainability.(1)

Goals for greening radiology:

i. Reducing water and energy use- The need for sustainable technology for medical imaging is illustrated by the notion that MRI and CT scanners consume an enormous quantity of electricity—enough to run a small town—particularly in developing countries. cryogen free MRI, monitoring energy consumption, encourage low-energy imaging modalities and turning off workstation monitors while not in use may substantially reduce energy consumption. Hospitals may save energy with a payback period of approximately 2.2 years by implementing efficient lighting and control systems. Motion and daylight sensors, which may save energy usage by around 7%, are common the controllers. In comparison to conventional incandescent bulbs, energy-efficient bulbs such as fluorescent and LED lights use less energy and last longer. LEDs use around 75% less energy, which makes them a better option for hospitals.

ii. Implementing biodegradable materials - Using biodegradable goods instead of single-use ones, such as cornstarch-based drinking cups.

iii. Minimizing waste- The cost of managing paper might be up to 31 times higher than the cost of purchasing it. Primary care providers can save over $86,000 over five years by using electronic health records (EHR), mostly because of reduced medication costs and fewer billing mistakes. Organisation should consider green purchasing using tools like National Association of State Procurement Officials (NASPO's) green shopping recommendations to buy from energy-efficient businesses, reuse goods. Compared to reusable alternatives, which are more sustainable, single-use medical products result in increased pollution and resource consumption.

- **Reusing-** Healthcare is one of the industries that must transition from a single-use model to a circular economy in order to benefit the environment. Medical equipment must be developed and produced in a circular economy to ensure it is recyclable, upgradeable, and modular. Use reusable surgical gown and refilling hand sanitizer instead of single use gowns.
- **Teleradiology-** Teleradiology and hybrid practice positions are in greater demand because to the COVID-19 pandemic experience, and they may help reduce transportation-related pollution and energy consumption.
- **Anesthesia Gas-** In most surgical procedures, gas anesthetics are a major source of greenhouse gas emissions.

iv. Recycling and/or efficient trash disposal- Separating trash into solid and medical waste during radiology operations can assist decrease hazardous waste and increase recycling, especially prior to, during, and following the procedure.(4)

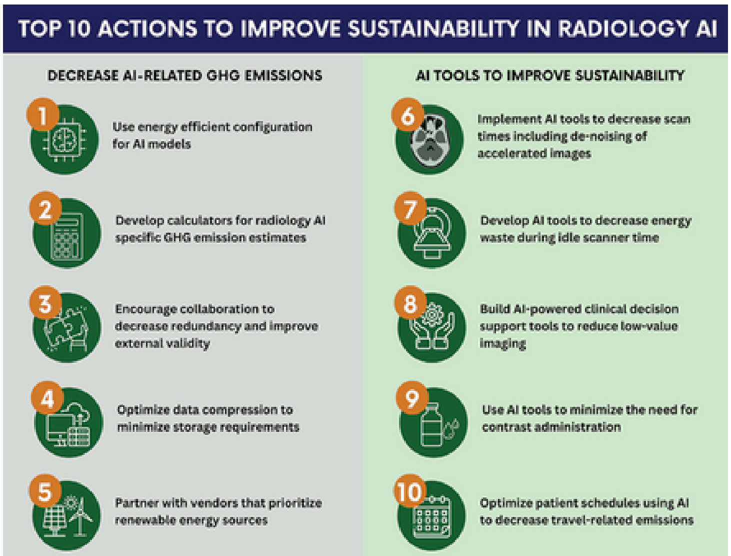

Fig.2- Ten ways to render artificial intelligence (AI) in radiology more sustainable, with an emphasis on reducing greenhouse gas (GHG) emissions and optimizing image processing and acquisition with AI technologies.(1)

Proposals for greener CRR practice

There are several ways to offer ES in Clinical radiology and radiotherapy (CRR) practice, ranging from simple adjustments to more extensive and persistent modifications that call for the participation of multiple stakeholders. Therefore, promoting education and practitioners' and other stakeholders' active involvement is key to achieving a greener clinical practice.

1.Regulated resource consumption: four-step strategy for green habits centred around water and energy conservation, waste reduction, the use of biodegradable products, and being certain that garbage is disposed of or recycled properly. Integrating auto-shutdown features into imaging and related equipment allows for energy economy. Since motion-sensitive lights and light-emitting diodes have the potential for preserving around 75% of energy, their use was suggested. eliminating consequently radiological requests and exams, appropriately disposing of waste, implementing circular economy ideas into effect, such as recycling and reusing equipment parts, and encouraging paperless CRR practices.

2.Periodic Auditing for Resource and Energy- Energy consumption and waste management in CRR departments should be regularly audited in order to monitor performance and avoid complications. Similarly, radiopharmaceutical doses for CRR activities should be simplified for optimal waste management.

3.Development of policies and establishment of ES working groups- To build environmental sustainability into clinical radiology, policymakers should form bodies to influence and fund the laws and policies. The international CRR community can use committees or teams to monitor and encourage greener practices across departments in sub-regions globally, in collaboration with equipment manufacturers.

4.Education and research in sustainability- To increase awareness among practitioners, ES should also be incorporated into clinical radiology and radiography education and training, as well as continuous professional development (CPD) programmes. Prioritizing sustainability in healthcare and research requires specialized funding quota structures.(3)

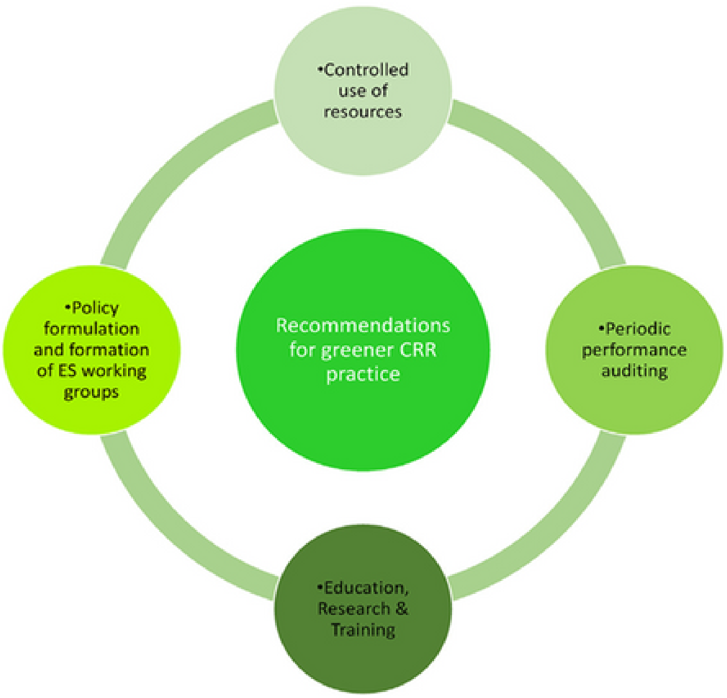

Fig.3- Greener CRR practice recommendations(3)

Importance of Sustainable Waste Management in Radiology

Waste management in the field of radiology can help improve cost savings and reduce the carbon footprint. This was demonstrated by a department that saved almost €10,000 and 20,513 kg of CO_2 per year. Improper disposal of contrast media can lead to soil and water pollution, but proper disposal allows for recycling.

Clinical waste can also be incinerated to produce electricity, and recycling with the recovery of silver from old radiographs generates revenue and minimizes storage. waste disposal training for staff can improve practices such as their clinical and recycling waste, specifically in CT and interventional radiology. Staff and patients should have easy access to recycling choices, and buying patterns should be changes to avoid non- recyclable supplies in order to achieve long-lasting improvements.(5)

Conclusion

Reducing the detrimental environmental effects of healthcare requires the implementation of AI-supported sustainable practices in medical imaging. Reusable medical equipment has been selected over single-use items in order to minimize resource consumption and pollution. Significant energy usage savings can result from the implementation of energy-efficient procedures, such as the employing of cryogen-free MRI systems and monitoring to optimize energy consumption. Handling the complications imposed on by climate change and moving forward a more sustainable future in radiology necessitate prompt and deliberate effort.

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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.

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Dear Colleagues,

We are delighted to announce the **7th State Conference of SIR TN – RAD-SALEM 2025**, organized by the **Society of Indian Radiographers – Tamil Nadu Chapter**, in association with **Government Mohan Kumaramangalam Medical College, Salem.** We extend our warm greetings to you all.

Usually, national and state-level conferences had been conducted only in Chennai. With the welfare of students from other districts in mind, state-level conferences were successfully held in Tiruchirappalli (2022) and Tirunelveli (2023). These events witnessed enthusiastic participation from nearby districts and greatly benefited the student community.

This year, Salem, known as the Steel City of India, has been chosen as the venue. The city is surrounded by the Shevaroy, Kalrayan, Kolli, and Pachaimalai Hills, and flanked by the Kaveri River valley, offering both cultural richness and scenic beauty.

We take immense pleasure in inviting you to participate in this academic celebration on **13th September 2025** at the **Auditorium, Government Mohan Kumaramangalam Medical College,** located on **Steel Plant Road, Salem – 636030,** approximately 8 km from Salem Junction Railway Station.

Theme: "Radiologic Advancement and Development Through Scientific Approaches to Learning and Education in Medical Imaging (RAD-SALEM 2025)."

This conference will focus on the latest technologies in radiography and allied fields, providing valuable academic enrichment for all participants.

The vision for the **Society of Indian Radiographers - Tamil Nadu Chapter (SIRTNPY**) was conceptualized in 1995, during the Roentgen Centenary Celebrations in Bangalore. In 2008, SIRTNPY was formally established, bringing together experienced radiographers and young professionals committed to uplifting the field. Since then, we have organized numerous CMEs, workshops, and state & national conferences, staying abreast of emerging trends in radiology and imaging.

To date, SIRTNPY has conducted 6 State-Level Conferences, 2 National Conferences, and several CME programs. **RAD-SALEM 2025** marks the **15th milestone** in our academic journey. We remain steadfast in our commitment to quality education and scientific excellence. The scientific committee is dedicated to curating a dynamic, knowledge-rich experience that meets the aspirations of both students and professionals.

This conference will be highly beneficial to students, budding technologists, and practicing radiographers, offering a vibrant platform for learning, interaction, and collaboration. On behalf of the organizing committee, we cordially invite you to participate in this academic fest. We also encourage you to share your expertise and experiences with students and colleagues to make this event a grand success.

With warm regards,
The Organising Committee
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High-Resolution Brain Perfusion Imaging with 3D Arterial Spin Labelling

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Introduction

John A. Detre and associates first proposed Arterial Spin Labelling (ASL) as a non-invasive MR perfusion imaging method in the early 1990s. It uses magnetically labelled arterial blood water as an endogenous contrast in place of gadolinium (Gd), allowing for a quantitative assessment of tissue perfusion. " In order to label the blood in an ASL MRI, radiofrequency (RF) pulses are used to invert the signal. Labelled images with a labelling duration (LD) are then obtained following a post-label delay (PLD), which gives the labelled blood enough time to perfuse into the tissue. The perfusion contrast is provided by the signal difference between the labelled and control images, which are likewise obtained under the same circumstances aside from the blood's labelling (Fig 1).

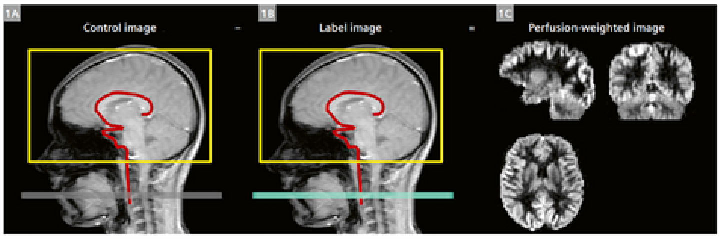


Figure 1. An illustration of how to estimate cerebral perfusion using the ASL principle. ASL MRI is a method of subtraction: Using RF pulses, arterial blood entering the brain is magnetically labelled at the neck in the label image (1A); the control image (1B) uses the same setup as the label image, with the exception that the blood is not labelled. The perfusion-weighted picture (1C) is obtained by comparing the control and label.

Clinical Application of Arterial Spin Labelling

Owing to notable technological developments in recent years, ASL has developed into a dependable method appropriate for regular clinical usage in neurological applications. Despite having been developed initially to measure cerebral blood flow (CBF), ASL now has many uses outside of perfusion, such as vessel-selective ASL, ASL-based fMRI, and body ASL, which is being developed to apply ASL to any part of the human body other than the brain, such as the liver, kidney, or heart.

A useful list of indications for the use and interpretation of ASL in clinical neuroimaging includes paediatric neuroradiology applications, brain tumours, neurodegenerative diseases, seizures/epilepsy, arteriovenous malformations and fistulas, acute ischaemic stroke and steno-occlusive disease, and more. Without using radiation or the requirement to administer a gadolinium-based contrast agent, ASL-based perfusion can offer useful supplementary information to help identify and interpret brain lesions. As conventional dynamic susceptibility contrast (DSC) MR perfusion studies are more prone to susceptibility artefacts that arise in the presence of air and haemorrhagic foci, ASL-based perfusion can offer useful complementary information to aid in the finding and interpretation of brain lesions, radiation-free, and without the need for gadolinium-based contrast agent administration. For example, abnormal perfusion can highlight areas of focal cortical dysplasia in epilepsy, which might be difficult to identify even at high fields. Additionally, it is well-suited to provide information about tumour grading, especially in the post-operative space.

Imaging of High-resolution Perfusion

ASL's primary drawback is its poor intrinsic signal-to-noise ratio (SNR), which results from the labelled blood's T1 relaxation during transit from the labelling spot to the tissue and the tiny amount of labelled blood per tissue volume. Currently, it is feasible to create high-quality perfusion maps using the most recent ASL sequences in clinical routine in less than four to five minutes thanks to effective labelling, excellent background suppression, and the use of 3D readouts. Because their brains are smaller, paediatric imaging necessitates smaller voxel sizes, and the selected image resolution also limits the assessment of lesion behaviour, such as in the presence of a brain tumour; lowering the voxel size directly lowers SNR. One strategy to make up for this loss is to do more control-label acquisitions, which would lead to noticeably longer acquisition times. Short acquisition times are necessary to prevent overuse of sedation or anaesthesia or an increase in motion-related artefacts. Thus, to produce higher-resolution maps, creative and alternative methods must be used. This study investigated the optimisation of high-resolution ASL-based CBF imaging using a 3D GRASE segmented readout and a PCASL research sequence with strong background suppression in conjunction with a 3D CAIPIRINHA acceleration scheme [12]. The target voxel resolution was set at 2.5 × 2.5 × 2.5 mm3, and protocols were evaluated in both adult and paediatric populations with full brain coverage.

For denoising and resolution improvement, two 3D deep learning (DL) techniques were used: Deep Resolve Boost, a k-space-to-image reconstruction method, and Deep Resolve Sharp, a super-resolution technique. Two separate, consecutive processing phases make up the DL reconstruction. First, images created with Deep Resolve Boost are produced at the desired resolution. Second, a DL-based super-resolution technique with a factor-of-two interpolation was used to interpolate the acquired pictures for Deep Resolve Sharp.

ASL imaging protocol

Using a PCASL 3D GRASE study sequence, MRI data were obtained on a MAGNETOM Prisma system (software version syngo MR XA30, Siemens Healthineers, Erlangen, Germany)

Protocol imaging parameters	Units	Value
Field of view	[mm^2]	200 × 200
In-plane resolution	[mm^2]	2.5 × 2.5
Matrix size	-	80 × 80
Number of slices	-	54
Slice thickness	[mm]	2.5
Phase / Slice oversampling	[%]	10 / 12.5
Echo / Repetition time	[ms]	16.4 / 4000
Refocusing flip angle	[deg]	160
CAIPIRINHA acceleration factor	-	2 × 2, shift 1
Number of shots	-	4
EPI / Turbo factor	-	21 / 15
Receiver bandwidth	[Hz/px]	2500
Number of label-control averages	-	12 / 15
Total scan time	[min:sec]	6:50 / 8:26

Table 1: Imaging parameters of the optimized high-resolution 3D ASL GRASE protocol.

fitted with a 32-channel head coil. 2. PLD times were set at 1.5 seconds for children and 1.8 seconds for adults, while LD was set at 2 seconds. Using a four-pulse background suppression approach, the labelling plane was carefully positioned at the level of the C1–C2 spine, perpendicular to the brain-feeding arteries, and away from any dental implants that might be present.

Clinical examples

Case 1

According to a previous MRI, a 15-year-old male with intractable epilepsy had two probable focal cortical dysplasia (FCD) lesions: one in the right precentral gyrus and one in the left parietal lobe. Hypometabolism in this area is also confirmed by FDG-PET.

The left FCD region (red arrow) is visible in both the perfusion and anatomical images in Figure 2. An obvious pattern of hyper perfusion that suggests paroxysmal epileptiform activity during the MRI test can be seen in the ASL-derived maps.

All 54 slices of the mean perfusion map that were reconstructed with DL using just N = 8 measurements (total equivalent acquisition time < 5 minutes) are displayed in Figure 3. A more thorough visualisation of grey matter perfusion, which is most apparent inside the FCD region, is made possible by the DL reconstruction, which sharpens images while maintaining SNR.

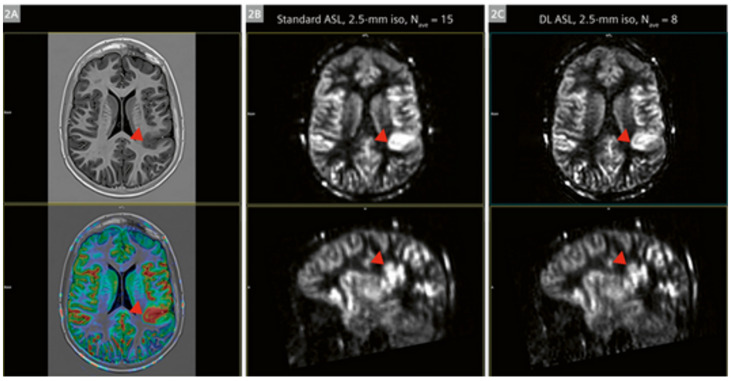


Figure 2:Case of epilepsy (15-year-old male). The left parietal lobe's focal cortical dysplasia is indicated by red arrows, which also show elevated perfusion activity during the MRI. Panel (2A) shows the high-resolution 2D T1-weighted TIRM image (top) and the overlaid perfusion map (bottom). Panel (2B) shows the acquired 2.5-mm isotropic mean perfusion-weighted map in both axial (top) and sagittal (bottom) views. Panel (2C) shows the reconstructed 2.5-mm isotropic mean perfusion-weighted map after applying DL algorithms and averaged

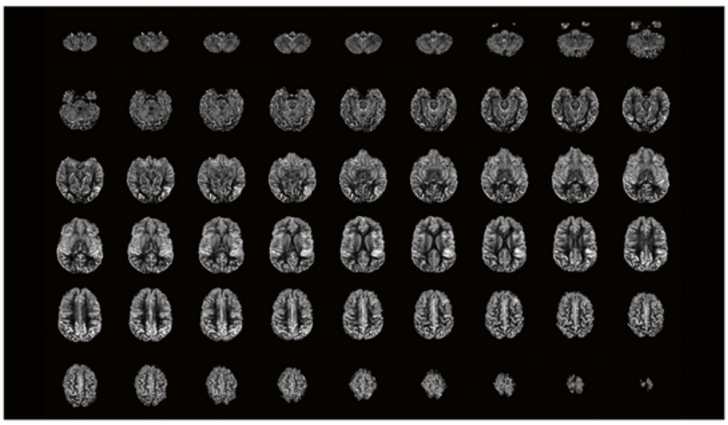


Figure 3: Mean ASL-derived perfusion-weighted map of Case 1, after applying DL in the reconstruction.

Case 2

A 34-year-old woman with persistent epilepsy is exhibiting focal seizures that have been present for a long time, along with a structural lesion that may indicate a neuroglial tumour or a benign dysembryoplastic neuroepithelial tumour (DNET). These low-grade tumours are very common in chronic or drug-resistant epilepsy, and they develop in the cortex where the seizures occur. Figure 4 displays the patient's most recent control MRI. Since the patient has been stable over the past 15 years, surgery has not yet been required. The lesion may be distinguished from the surrounding cortex with clarity because to the high-resolution perfusion maps. With a shorter acquisition time, the DL reconstruction produces crisper images.

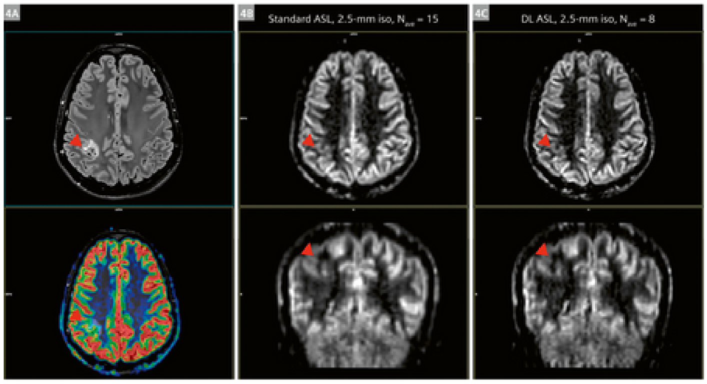


Figure 4: Epilepsy case (34-year-old female). The red arrow points to the cortical seizure area where a DNET tumour has formed, which shows a hypoperfusion pattern in the ASL-derived perfusion maps. Panel (4A) shows the axial view of the 3D T2 FLAIR (top) and the overlaid perfusion map (bottom). Panel (4B) shows the acquired 2.5-mm isotropic mean perfusion-weighted map in both axial (top) and coronal (bottom) views. Panel (4C) shows the reconstructed 2.5-mm isotropic mean perfusion-weighted map after applying DL algorithms.

Case 3

A 49-year-old man has epilepsy linked to a brain tumour as a result of a multifocal glioblastoma. Patients with brain tumours are more likely to experience seizures, thus any new onset at this age is a warning indication to check for abnormalities in the brain. The patient's pre-operative MRI is displayed in Figure 5. Both pre-Gd ASL-based and post-Gd DSC perfusion maps were obtained because contrast was used in this instance. During this examination, two ASL acquisitions were made: one with the optimised high-resolution parameters (2.5-mm isotropic) and one with standard resolution (3.75-mm isotropic). Better tumour extent delineation in the perfusion maps is made possible by the greater resolution.

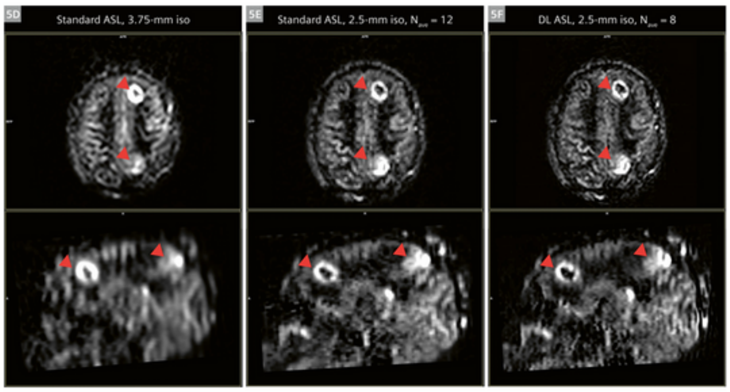
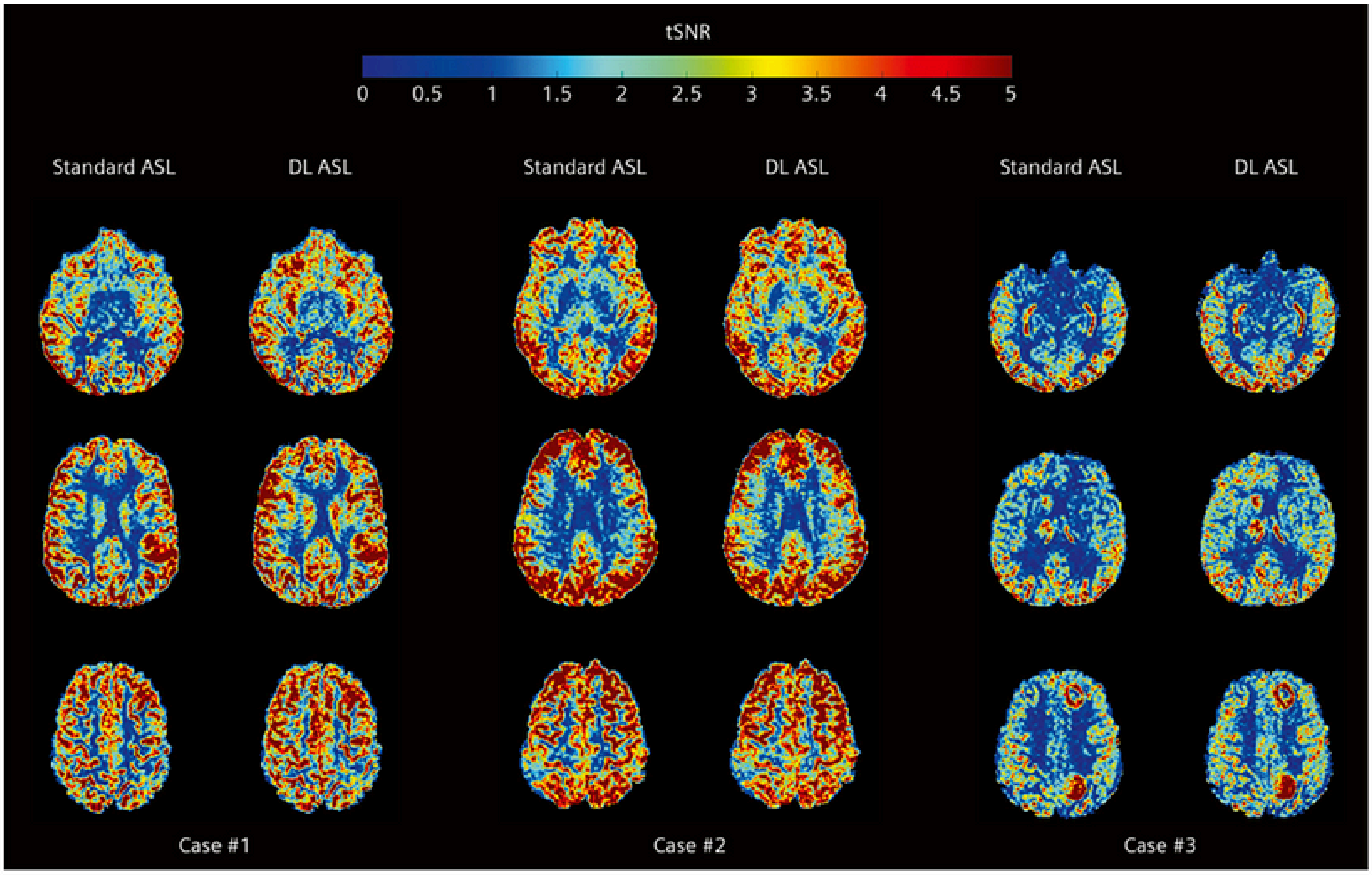


Figure 5:Glioblastoma case (49-year-old male). The red arrows point to the multiple contrast-enhancing tumour lesions, also showing increased perfusion activity in comparison to the non-affected brain tissue. Panel (5A) shows the axial view of the post-Gd 3D T1 SPACE image. Panel (5B) shows the DSC-derived CBV map, displaying increased blood volume in the contrast-enhancing tumour regions. Panel (5C) again shows the post-Gd 3D T1 SPACE image overlaid on top of the ASL-perfusion map. Panel (5D) shows the acquired mean perfusion-weighted map with standard 3.75-mm isotropic resolution, in both axial (top) and sagittal (bottom) views. Panel (5E) shows the acquired mean perfusion-weighted map with high 2.5-mm isotropic resolution in both axial (top) and coronal (bottom) views. Panel (5F) shows the reconstructed 2.5-mm isotropic mean perfusion-weighted map after applying DL algorithms.

The SNR values for the three clinal instances are contrasted between the standard and DL reconstructions in Figure 6. By averaging the perfusion signal voxel-wise over all measurements and dividing the result by its standard deviation, temporal SNR maps were produced. After using the DL-based reconstruction, it should be noted that a pattern of SNR increase is always seen. This pattern is particularly noticeable ventrally and corresponds with regions of the receive coil's lower intrinsic signal profile. Additionally, keep in mind that the baseline SNR depends on the voxel's underlying perfusion value; as a result, hyper-perfused areas (such as GM or tumour locations) will likewise display higher values in the SNR maps.



Conclusion

ASL is a non-invasive MR imaging method that makes it possible to assess cerebral perfusion quantitatively and without the use of gadolinium. Therefore, it presents a compelling substitute for traditional DSC perfusion, particularly for patients who need frequent follow-ups, like paediatric patients, or who have contraindications associated to gadolinium, like allergies or renal dysfunction. Assessing perfusion in regions vulnerable to susceptibility artefacts, like those near the base of the skull, air, or blood, which are commonly seen in the post-operative context, has also shown beneficial.

Additionally, it might be especially useful in areas with high permeability, where contrast leaking into the extravascular space can make DSC's calculation of blood volume incorrect. Clinical scan times for ASL with a spatial resolution of 3–4 mm isotropic are now possible thanks to recent technological developments including PCASL, background signal suppression, and 3D readouts, which have significantly increased ASL's SNR and image quality. In order to detect regions of aberrant perfusion activity, the case studies in this paper show that high-resolution ASL perfusion imaging is both feasible and diagnostically effective. To help pinpoint the exact location of seizure activity in epilepsy, for example, ASL can identify regions that are hyper- and hypo-perfused and associated with epileptogenic foci. It provides crucial information about tumour grading in brain tumours and is especially helpful for postoperative evaluations where artefacts may complicate traditional imaging.

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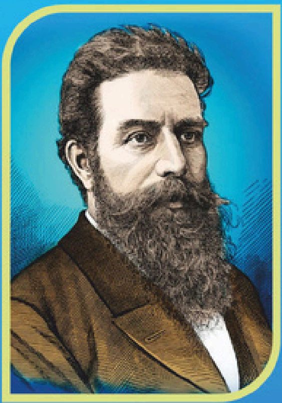

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AI as a New Frontier in Contrast Media

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Abstract

Medical imaging is undergoing a revolution thanks to artificial intelligence (AI), especially in the area of contrast media. With an emphasis on three main areas—dose optimization, contrast-free imaging, and improved image analysis—this paper examines AI as a revolutionary force in the use of contrast media. Although contrast chemicals have long been necessary to increase diagnostic precision, exposure must be kept to a minimum because to worries about negative reactions and patient discomfort. AI presents encouraging answers to these problems. AI-driven dose optimization predicts the optimal contrast dose for diagnostic-quality images by using patient-specific information such as demographics, body composition, and previous imaging. By minimizing contrast exposure while preserving or increasing diagnostic yield, this individualized approach lowers the risk of contrast-induced nephropathy and other negative outcomes. Additionally, AI is facilitating the advancement of contrast-free imaging methods. Convolutional neural networks (CNNs) and generative adversarial networks (GANs) are two examples of deep learning models that are trained to produce artificially improved contrasted images from non-contrast scans. In certain therapeutic situations, this novel method may be able to do away with the requirement for contrast agents, which would be advantageous for patients who have contraindications or a high risk of negative reactions. Additionally, AI improves contrast-enhanced image analysis. Artificial intelligence (AI) systems may identify tiny patterns and features in images that human viewers might overlook, improving the sensitivity and specificity of pathology detection. Additionally, by quantifying contrast enhancement patterns, these algorithms can offer important insights regarding the properties of tissues and the course of disease. Recent developments in AI-driven contrast media research are summarized in this study, along with the possible advantages and drawbacks of each strategy. It also discusses the difficulties of applying AI solutions in clinical settings, such as data collection, model verification, and legal issues. This article offers a thorough summary of how AI is changing medical imaging and enhancing patient care by examining AI as a new frontier in contrast media.

Keywords: AI, contrast, radiology, medical imaging, pathology

Introduction

Contrast chemicals are now essential components of contemporary medical imaging, greatly increasing the accuracy of diagnosis through better tissue distinction and anatomical structure visualization. Nevertheless, there are several restrictions on using these agents. Patient discomfort from intravenous injection and worries about possible negative effects, such as allergic reactions and contrast-induced nephropathy, have prompted efforts to reduce contrast exposure and investigate alternate imaging methods. Medical imaging is only one of the many scientific fields where artificial intelligence (AI) is becoming a game-changer. Artificial Intelligence provides creative answers to the problems outlined above in the context of contrast media. The three main areas of dosage optimization, contrast-free imaging, and improved image processing are the subject of this review, which examines AI as a new frontier in contrast media. AI-driven dose optimization uses patient-specific data to forecast the lowest effective dose needed to produce diagnostic-quality pictures, thereby personalizing the administration of contrast. This strategy could preserve or even increase diagnostic yield while lowering the chance of unfavourable outcomes. Additionally, by using deep learning models to create artificially enhanced contrast images from non-contrast scans, AI is facilitating the development of contrast-free imaging tools. For patients who cannot use contrast chemicals, this novel method presents a possible substitute. Lastly, By identifying subtle visual features and measuring contrast enhancement trends, artificial intelligence (AI) improves the interpretation of contrast-enhanced images, improving diagnostic precision and providing insights into the course of disease. This review summarizes current developments in these fields and emphasizes how AI has the potential to change how contrast media are used in medical imaging in the future.

Current AI utilization in radiology

Even though there are a number of widely used systems, the current state of AI use in radiology varies by institution. Many of the present AI systems are being used in limited ways as tools to improve the workflow of radiologists, which is in line with the more recent idea of "working with radiologists." A large number of these AI systems are classified as "micro-optimizations." Rather than completely automating the radiologic process, the main objective of micro-optimization algorithms is to support the radiologist in his or her everyday duties. Pixel-based optimizations and nonpixel-based optimizations are the two types of micro-optimizations. Radiologists can more effectively devote their time and energy to image interpretation, consulting, and patient care by employing AI to standardize and expedite time-consuming, repetitive, or non-interpretive duties.

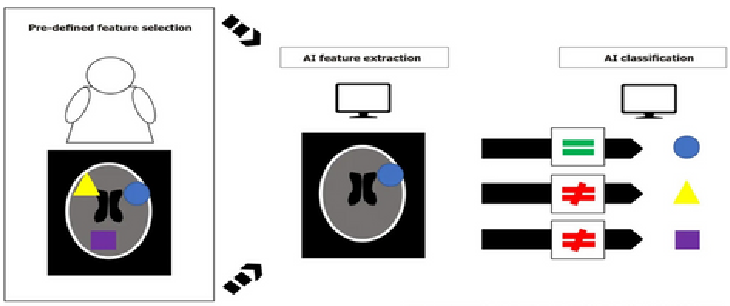

Figure 1Machine-learning requires pre-defined feature inputs which are then extracted in order to classify target image characteristics.

AI for contrast dose optimization

AI-driven contrast dosage optimization seeks to minimize patient risk while optimizing diagnostic information through personalized contrast administration. Conventional contrast dosing frequently uses standardized procedures based on body surface area or patient weight, which might not take into consideration individual differences in physiology, renal function, or particular therapeutic indications. By utilizing patient-specific data, such as demographics, body composition, medical history, and previous imaging examinations, AI provides a more sophisticated approach.

Large databases of patient data and related imaging results are used to train AI algorithms, which frequently use machine learning models. These models learn to forecast the ideal contrast dosage needed for each person to obtain images of diagnostic quality. By drastically lowering contrast exposure, this individualized strategy can lower the chance of negative outcomes like contrast-induced nephropathy and allergic responses.

In order to estimate pre-procedural dose modifications and possibly even real-time dose adjustments during the imaging operation based on image quality feedback, a number of methodologies are used, including predictive modelling. By lowering the needless use of contrast agents, this improves patient safety while also increasing cost-effectiveness. The effectiveness and safety of AI-driven contrast dose optimization across a range of imaging modalities and therapeutic applications are being further validated by ongoing research and clinical trials.

AI for contrast-free imaging

Synthetic contrast-enhanced images can be created from non-contrast scans thanks to AI, which is transforming the potential for contrast-free imaging. Specifically, generative adversarial networks (GANs) and convolutional neural networks (CNNs) are deep learning models that have been trained on paired datasets of contrast and non-contrast images. These models can forecast how tissues might appear with contrast enhancement because they understand the intricate links between the two image kinds. For patients who cannot use contrast chemicals, such as those with allergies or renal impairment, this approach has enormous promise. Patients who are undergoing repeated imaging treatments and those who are at high risk of adverse responses can benefit from it. AI-powered contrast-free imaging is still a developing subject, but it has showed promise in a number of applications, including as abdominal, brain, and cardiovascular imaging. The goals of ongoing research are to increase these models' robustness and accuracy, broaden their therapeutic usefulness, and solve any potential drawbacks.

AI for enhanced image analysis with contrast

AI greatly improves contrast-enhanced image analysis by automating difficult processes and offering insights that are not possible with human intelligence. Diagnoses can be made early and with greater accuracy thanks to deep learning models' exceptional ability to identify small lesions and describe them using texture, contrast enhancement patterns, and other picture attributes. For identifying tiny cancers or minute variations in tissue perfusion, this is especially useful. AI makes it possible to precisely quantify contrast enhancement as well. Tissue perfusion, vascularity, and other physiological characteristics can be objectively measured by AI algorithms that analyse dynamic changes in signal intensity over time. The prognosis, treatment response, and illness severity are all aided by this quantitative data.

Image analysis is further improved by the integration of AI and radiomics. Many quantitative features are extracted from photos using Radiomics and then fed into AI algorithms. This method improves diagnostic precision and tailored therapy by applying extensive information about tissue properties and disease processes to contrast-enhanced pictures.

AI also improves the consistency and dependability of diagnostic evaluations by lowering intra- and inter-reader variability. AI tools reduce subjective interpretation by offering objective analysis, which results in more consistent diagnosis from various radiologists. By incorporating these AI technologies into clinical processes, image analysis is streamlined, productivity is increased, and patient care is eventually improved.

Broader consideration:

Regulatory Landscape for AI in Medical Imaging

With important organizations like the FDA in the US and the EU leading the pace with their AI Act and MDR, the regulatory environment for AI in medical imaging is changing quickly. The special features of AI-based software as a medical device (SaMD) are covered by these rules. Clinical validation is one of the main priorities. To demonstrate safety and efficacy for their intended purpose, AI algorithms must pass stringent testing, which frequently calls for comprehensive clinical trials and empirical data. Regulators stress the importance of broad and representative training datasets to guarantee generalizability and prevent biased results because data bias is a serious risk. Transparency and explain ability are also becoming more significant. It is essential for regulators and medics to comprehend how AI makes its decisions. AI applications are categorized by the FDA using a risk-based methodology, which places more stringent criteria on devices that pose a greater danger. Predetermined Change Control Plans (PCCPs), which specify how modifications will be handled and verified, are crucial for adaptive AI that learns continuously. After deployment, real-world performance monitoring is advised to gauge AI efficacy. Data privacy and cybersecurity are critical. There are still issues with addressing ethical issues, establishing assessment metrics, and keeping up with the quick changes in technology. The regulatory environment is becoming clearer in spite of these obstacles, offering a framework for the ethical development and application of AI in medical imaging.

Ethical consideration and bias in AI algorithm

When using AI for medical imaging, ethical issues are crucial, especially when it comes to algorithmic prejudice. Although bias can originate from a number of sources, it mostly occurs in the training data. An AI model may perform differently across subgroups, resulting in differences in diagnosis and treatment, if the data used to train it is not representative of the target population (for example, overrepresentation of particular demographics or illness severities). This may exacerbate already-existing health disparities or possibly lead to the development of new ones. When applied to photographs from a different ethnic group, for instance, an AI algorithm that was trained largely on images from that group may perform less accurately. Careful data curation is necessary to address bias and guarantee representative and diverse datasets. Furthermore, in order to detect and lessen any biases, continuous monitoring and assessment of AI performance across various subgroups is essential. Building confidence and guaranteeing the moral application of AI in medical imaging also depend on transparency in algorithm development and implementation.

Cost-Effectiveness and Implementation Challenges

AI in medical imaging offers both considerable implementation hurdles and cost-effectiveness opportunities. Regarding cost-effectiveness, AI has the potential to lower healthcare expenses in a number of ways. By minimizing the use of contrast agents, AI-driven dose optimization lowers material costs. By increasing diagnostic accuracy, enhanced image analysis might lessen the necessity for invasive procedures or follow-up exams. In the long term, streamlined processes made possible by AI automation can help save workforce expenses and increase efficiency. Better patient outcomes and more efficient therapies can result from earlier and more precise diagnosis, which also lowers costs.

Nonetheless, there are a number of implementation issues that must be resolved. AI hardware and software might come with a hefty upfront cost. AI tool integration into current clinical workflows can be challenging and necessitate major improvements to IT infrastructure. It can be costly and time-consuming to gather and curate data for AI model training. Additionally, for deployment to be successful, staff training on the usage and interpretation of AI outputs is essential. The complexity and expense are further increased by regulatory obstacles and the requirement for continuous validation and monitoring. A comprehensive cost-benefit analysis that considers both immediate expenditures and long-term savings is necessary for the effective application of AI in medical imaging.

Future directions and emerging trends

In contrast to media, artificial intelligence has a dynamic future, with a number of new trends influencing its course. The creation of increasingly complex AI models that can incorporate multi-modal input is one such avenue. More comprehensive and individualized diagnostic evaluations will be possible by integrating imaging data with clinical data, genetics, and patient history. The move toward more explainable AI (XAI) is another trend. Building trust and guaranteeing appropriate clinical usage of AI requires a knowledge of how these algorithms arrive at their results as it becomes more integrated into clinical decision-making. The goal of XAI approaches is to increase the transparency and interpretability of AI decision-making processes. Another fascinating area of exploration is real-time AI analysis during imaging operations. AI systems that can give real-time feedback during scans may be able to optimize image capture parameters, allow for dynamic dosage modifications, and even direct interventional treatments. Furthermore, without exchanging private patient information, federated learning techniques will enable AI models to be trained on a variety of datasets from various institutions. This method can solve privacy issues while enhancing the robustness and generalizability of AI models.

Lastly, it is anticipated that AI will be included into larger healthcare ecosystems. To offer smooth and all-encompassing assistance for clinical decision-making, AI technologies will be progressively integrated with radiology information systems (RIS), electronic health records (EHRs), and other healthcare IT systems.

Conclusion

The use of contrast media in medical imaging is about to undergo a revolution thanks to artificial intelligence, which will provide creative answers to persistent problems and open the door to more individualized and efficient patient care. The three main topics of dosage optimization, contrast-free imaging, and improved image analysis have been the emphasis of this review's exploration of AI as a new frontier in contrast media.

By using patient-specific data to reduce contrast exposure while preserving or enhancing diagnostic quality, AI-driven dose optimization provides a customized method of administering contrast. This approach could lower the chance of unfavourable outcomes, enhance patient comfort, and save money. A paradigm change has occurred with the introduction of AI-powered contrast-free imaging methods, which provide a good substitute for individuals who are allergic to contrast agents or who are at high risk of negative reactions. AI increases access to diagnostic imaging for a larger population by producing artificial contrast-enhanced pictures from non-contrast scans, hence removing the requirement for contrast administration in some clinical circumstances. The interpretation of contrast-enhanced pictures is also greatly improved by AI, which makes it possible to quantify contrast enhancement patterns, identify minor anomalies, and provide objective measurements of tissue properties. These developments enhance the precision of diagnoses, enable individualized treatment planning, and enhance patient outcomes. Even while there has been a lot of development, there are still a number of obstacles. To fully utilize AI in contrast media, it is imperative to address potential biases in AI algorithms, ensure regulatory compliance, and overcome implementation challenges. The goal of ongoing research and development is to enhance AI models' generalizability, accuracy, and robustness while also facilitating their smooth integration into clinical workflows. To sum up, artificial intelligence is changing the way contrast media are used in medical imaging. AI is ushering in a new era of individualized, effective, and efficient patient care by improving image processing, enabling contrast-free imaging, and optimizing dosage. To fully realize AI's disruptive potential in this subject, further research, teamwork, and responsible application are required.

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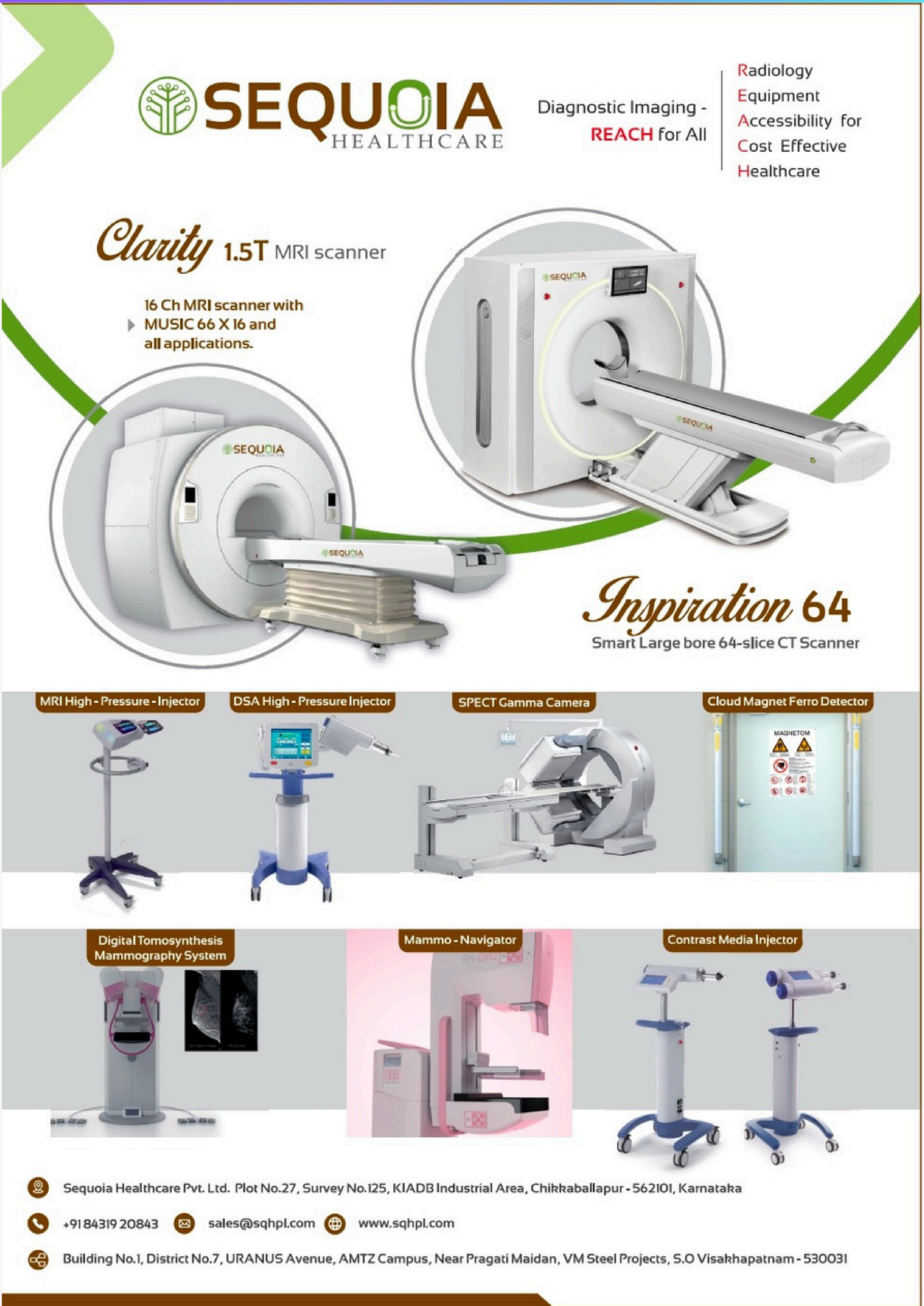
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Technical advances and clinical applications of 4D cone-beam CT in radiation therapy

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Abstract

Cone-beam CT (CBCT) is the most widely used onboard imaging technique for target localization in radiation therapy. Conventional 3D CBCT uses x-ray cone-beam projections at various angles around the patient to create 3D images of the patient in the treatment room. However, because it does not have time-resolved information, 3D CBCT is limited in its ability to image disease sites affected by respiratory motions or other dynamic changes within the body. To overcome this limitation, 4D-CBCT was developed to incorporate a time dimension in the imaging to account for the patient's motion during the acquisitions. For example, respiration-correlated 4D-CBCT splits the breathing cycles into distinct phase bins and reconstructs 3D images for each phase bin, ultimately creating a full set of 4D images. Tumor localization in the thoracic and abdominal regions, where respiratory movements impact localization accuracy, benefits greatly from 4D-CBCT.For hypo fractionated stereotactic body radiation therapy (SBRT), which administers significantly larger fractional doses in fewer fractions than traditional fractionated treatments, this is particularly crucial. Nevertheless, because 4D-CBCT requires obtaining enough x-ray projections for every respiratory phase, it has several drawbacks, such as lengthy scanning periods, high imaging doses, and reduced image quality.

Key Words: 4D Cone-Beam CT (4D-CBCT), Radiation Therapy, Image-Guided Radiation Therapy (IGRT), Respiratory Motion, Tumor Tracking, Stereotactic Body Radiation Therapy (SBRT), Hypo fractionation

Introduction

Cone beam computed tomography (CBCT) has been a mainstay of image-guided radiation therapy since its development in the late 1990s. The system uses either a megavoltage radiation beam delivered by the linear accelerator (linac) or a kilo voltage beam created using an additional x-ray tube mounted on the radiation delivery unit to image the object from multiple projection angles and reconstruct 3D or 4D images (3D images at different breathing phases). The resulting images provide precise and detailed information about the patient's anatomy, which is used to visualize the tumor and surrounding healthy tissues in three dimensions to confirm the patient's position and guarantee the treatment is administered to the right place. 4D-CBCT enables real-time tracking and viewing of the interior structures in contrast to conventional 3D imaging methods. Since motion can greatly impact the precision of treatment for malignancies of the lung, liver, and pancreas, this is especially crucial. 4D-CBCT makes treatment more accurate and precise by taking internal structural movement into consideration. 4D-CBCT pictures are often produced by classifying projections into distinct respiration bins and then using an algorithm to reconstruct 3D-CBCT for each bin independently.(1) This leads to a longer acquisition time (3–4 minutes for full fan1,2 from Elekta XVI System, and 8–10 minutes for half fan scans3 from Varian Onboard Imager v1.3) and a larger imaging dosage in comparison to a typical 3D-CBCT scan that takes 1 minute to collect. Long cycles and erratic breathing can also result in streaking errors, under sampling, and intra-phase movements. 4D-CBCT is essential for significantly increasing the accuracy of radiation therapy, which in turn improves tumor control and reduces harmful effects on healthy tissues. To increase 4D-CBCT efficiency and image quality at various stages, a number of techniques have been developed, including pre-processing, reconstruction, acquisition, sorting, and post-processing.(2) Fig.1

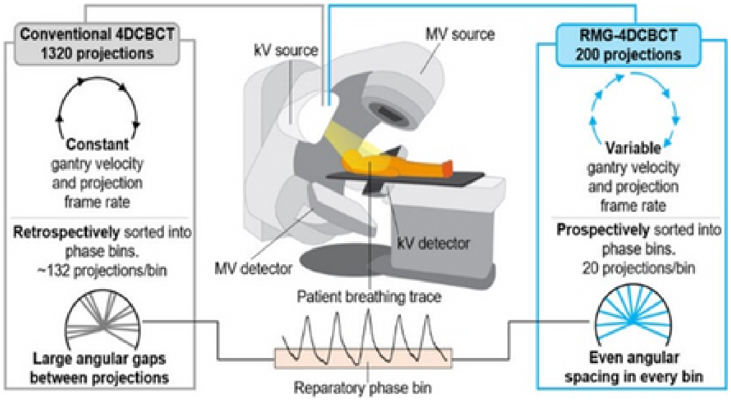

Figure:1 Radiation delivery unit to image the object from multiple projection angles and reconstruct 3D or 4D images (3D images at different breathing phases).

increasing the accuracy of radiation therapy, which in turn improves tumor control and reduces harmful effects on healthy tissues. To increase 4D-CBCT efficiency and image quality at various stages, a number of techniques have been developed, including pre-processing, reconstruction, acquisition, sorting, and post-processing.(2) Fig.1

Image Acquisition

Introducing time as a fourth dimension to conventional cone-beam CT imaging has greatly improved image-guided radiation therapy thanks to 4D Cone-Beam Computed Tomography (4D-CBCT). This ensures more accuracy in radiation therapy for the thoracic and abdominal regions by allowing the collection of dynamic anatomical movements, such as those brought on by breathing motion.

Respiratory-correlated imaging is the initial step in the picture acquisition process. Using external markers or internal surrogates, like infrared cameras or respiratory belts, the patient's breathing cycle is tracked and segmented into several phases.(3) The CBCT gantry then revolves around the patient, acquiring a sequence of 2D X-ray projections at every step. A complete 4D dataset is created by reconstructing these projections into 3D pictures for every breathing phase. The ability to change the picture acquisition parameters to meet clinical requirements—for example, choosing more breathing phases for increased accuracy or fewer phases for faster imaging—is one noteworthy feature.(4) Researchers are continuously trying to find solutions for issues including motion artifacts, longer scanning times, and increased radiation dosages that can affect picture capture in 4D-CBCT.

Developments in 4D-CBCT Acquisition Technology

The efficiency and accuracy of 4D-CBCT image capture have been improved by recent developments. To lessen motion artifacts, motion-compensated reconstruction techniques have been developed, such as Simultaneous Motion Estimation and Image Reconstruction (SMEIR). These methods provide more accurate depictions of anatomical structures by combining geometric and biomechanical models to account for organ motion during image reconstruction. There have also been notable developments thanks to deep learning technologies.(5) Automated phase sorting and motion artifact reduction are made possible by AI-based algorithms that evaluate respiratory motion patterns in real-time. These algorithms make the technology more accessible for clinical usage by cutting down on imaging time while simultaneously enhancing overall image quality.

Shorter acquisition times and lower radiation exposure have also been made possible by hardware advancements like faster X-ray detectors and gantry rotation rates. With the use of adaptive approaches, physicians can now modify imaging parameters while the scan is being performed, guaranteeing that the obtained images satisfy particular treatment planning specifications.(6) By integrating state-of-the-art technology and sophisticated imaging methods, 4D-CBCT is a potent tool in contemporary radiation therapy that guarantees accurate tumor localization. Its clinical significance could be further increased with subsequent advancements in picture capture techniques.(7) If you want to discuss any particular topic in further detail, please let me know. Fig.2

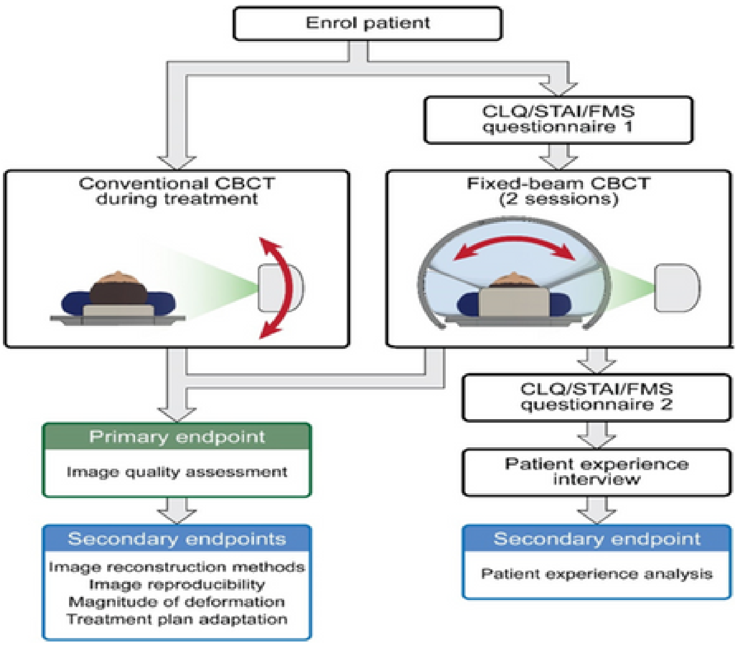

Figure:2 These methods provide more accurate depictions of anatomical structures by combining geometric and biomechanical models to account for organ motion during image reconstruction.

Projection sorting

In 4D cone-beam computed tomography (4D-CBCT), projection sorting is a crucial procedure that guarantees precise motion-correlated picture reconstruction. Sorting 2D X-ray projections into distinct respiratory stages of the patient's breathing cycle is what it entails. Following the reconstruction of 3D images for each phase using these projections, a thorough 4D dataset that records anatomical motion brought on by respiration is produced. This phase-based classification is guided by respiratory signals, which are frequently acquired using internal surrogates like diaphragm movement or external markers like respiratory belts.(8)

Abnormal breathing patterns or inconsistent respiratory signals might cause phase misalignment or insufficient projection data for specific phases, which makes projection sorting difficult. The goal of sophisticated techniques like phase-based and amplitude-based sorting is to increase the process' resilience. Hybrid algorithms are recent developments that combine the advantages of existing methods and further minimize motion-induced distortions.

Because deep learning makes it possible to automatically discover and repair anomalies in real-time, it has also revolutionized projection sorting. By adjusting to each person's unique breathing patterns, these AI-powered methods improve accuracy.(9) The precision of projection sorting is essential for producing high-quality 4D-CBCT pictures, improving tumor localization, and guaranteeing that radiation therapy works, especially in areas where respiratory motion is present.

Pre-processing of images

In order to maximize input data for medical imaging technologies such as 4D cone-beam computed tomography (4D-CBCT), pre-processing of images is an essential step. Before undergoing additional processing or reconstruction, the raw picture data must be prepared to improve image quality, lower noise, and guarantee consistency. Artifact correction, normalization, and noise reduction are important pre-processing processes. Techniques for reducing noise, including median or Gaussian filtering, are used to reduce pixel intensity fluctuations brought on by ambient influences or imaging equipment. This guarantees the preservation of important anatomical characteristics while eliminating needless distortions. Addressing problems such as motion-induced artifacts during picture capture or streak artifacts brought on by metallic objects is the main goal of artifact correction, especially for 4D-CBCT. Motion-compensation methods and sophisticated algorithms are frequently used to fix these artifacts.(10)

Normalization modifies brightness, contrast, and scaling to align the image data for consistency. By ensuring that every image has a uniform range of pixel values, this stage makes sure that the images are appropriate for analysis and reconstruction. In certain situations, key anatomical features may also be highlighted by applying picture enhancing techniques such edge sharpening. Effective pre-processing is necessary to guarantee accurate tumor localization in radiation therapy and to increase the precision of later 4D-CBCT image reconstruction.

Techniques for image reconstruction

In medical imaging modalities such as 4D cone-beam computed tomography (4D-CBCT), image reconstruction techniques are essential. For accurate clinical interpretation and treatment planning, these techniques convert unprocessed 2D X-ray projection data into high-quality 3D or 4D images.

1. Filtered Back Projection (FBP): This well-known and conventional method projects the gathered data onto a reconstruction grid using mathematical filters. Despite its efficiency, it can be susceptible to noise and distortions, especially in datasets that are impacted by motion

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2. Iterative Reconstruction (IR): This technique minimizes disparities by comparing obtained data to picture estimates in an iterative manner. When compared to FBP, iterative methods like simultaneous algebraic reconstruction technique (SART) and algebraic reconstruction technique (ART) provide better image quality and noise control.

3. Motion-Compensated Reconstruction: By including respiratory motion models into the reconstruction process, motion-compensated approaches, such as simultaneous motion estimation and image reconstruction (SMEIR), mitigate motion artifacts in 4D-CBCT.
4. Deep Learning-Based Techniques: Neural networks are used in contemporary methods to improve image quality and minimize artifacts. Real-time reconstruction capabilities are provided by AI-driven techniques while preserving accuracy and clarity.

Better image quality, accuracy, and radiation therapy applicability are made possible by these methods' ongoing development.(11) If you want me to go into further detail about any particular approach, please let me know.

Post-processing of the image reconstruction
In 4D cone-beam computed tomography (4D-CBCT), post-processing of reconstructed images is essential for improving image quality, minimizing artifacts, and guaranteeing that the images are prepared for clinical interpretation or treatment planning. The goal of this stage is to improve the reconstructed data's accuracy and usability.

Important post-processing duties consist of:
Artifact Removal: To remove image distortions brought on by metallic implants or motion artifacts during the acquisition process, methods such as streak and ring artifact correction are performed.
Image Registration: To guarantee precise alignment, post-processed pictures are registered with datasets from treatment planning or prior scans. Because treatment plans for adaptive radiation therapy depend on stable anatomical placement, this stage is especially important.(12)

Clinical Applications
Lung tumor localization and motion control
Radiation therapy precision depends on lung tumor location and motion control, especially for cancers impacted by respiratory motion. By offering detailed imaging that records tumor movements throughout the respiratory cycle, 4D cone-beam computed tomography (4D-CBCT) has significantly improved these procedures. This time imaging capacity reduces the possibility of radiation exposure to nearby healthy tissues by enabling exact tumor localization. 4D-CBCT allows for precision targeting during therapy by accurately mapping the tumor's location throughout the breathing cycle. In methods like stereotactic body radiation treatment (SBRT), which administers high radiation doses in fewer sessions, this is especially important. Strategies like respiratory gating, which delivers radiation only at certain moments in the breathing cycle, and tumor tracking, which continuously modifies the radiation beam to follow the tumor's movements, are informed by the motion data obtained from 4D-CBCT.(13) Image quality may be impacted by issues including motion artifacts and irregular breathing patterns, even if 4D-CBCT has increased the accuracy of treatment delivery. By enhancing picture accuracy and lessening the effects of motion-related distortions, recent developments such as motion-compensated reconstruction methods and AI-driven algorithms have lessened these problems.

Dosimetry, adaptive therapy, and radiomics analysis
The development of precision radiation therapy depends heavily on dosimetry, adaptive therapy, and radiomics analysis. The goal of dosimetry is to precisely measure and compute the radiation dose that is administered to the tumor while limiting exposure to the healthy tissues around it. Advanced dosage calculation algorithms and Monte Carlo simulations are two methods that guarantee accurate dose distribution, enhancing therapeutic effectiveness and lowering adverse effects.(14)

The following are important details about radiomics analysis, adaptive therapy, and dosimetry:
Dosimetry
- Ensures accurate radiation dosage measurement and computation to the tumor while protecting nearby healthy tissues.
- Advanced algorithms and Monte Carlo simulations are two methods that increase dose accuracy, minimize side effects, and improve therapeutic results.

Adaptive Treatment
- Real-time treatment plan adjustments are made to account for anatomical changes that occur during therapy, such as organ movement or tumor shrinking.
- With the help of imaging technologies like 4D-CBCT, it improves precision while exposing healthy tissues to less radiation.
- Rapid replanning for individualized treatment is made possible by AI-driven solutions that expedite the adapting process.

Analysis of Radiomics
- Extracts quantifiable characteristics from medical photographs that would not be apparent to the human eye, such as texture and shape.
- Combines genetic, clinical, and imaging data to forecast prognosis, tumor recurrence, and response to treatment.
- Encourages individualized treatment planning, making it possible to develop therapies that are specific to each patient's needs.

Lung function ventilation imaging
During radiotherapy, 4D-CBCT-derived ventilation imaging is employed in clinical settings to track lung function, especially in patients with thoracic malignancies. In order to reduce radiation exposure to healthy tissues and, consequently, treatment-related problems, it aids in the identification of functional lung areas. By monitoring changes in lung function throughout treatment, this method also supports adaptive therapy.(15)

The following are important details regarding 4D cone-beam computed tomography (4D-CBCT) lung function ventilation imaging:
Respiratory Motion Tracking: By comparing imaging data with respiratory cycle phases, 4D-CBCT records dynamic lung motion, allowing for a fine-grained view of ventilation patterns.
Deformable Image Registration (DIR): This method accurately evaluates airflow and regional lung function by aligning pictures from various respiratory phases.
Quantitative Metrics: 4D-CBCT is used to generate functional metrics that provide information about localized lung function, such as ventilation maps and airflow distribution.
Clinical Applications: Helps reduce radiation exposure to healthy lung tissues and enhances treatment results by identifying functional lung regions during radiotherapy for thoracic malignancies.
Advanced Techniques: By lowering artifacts, the combination of motion modeling and deep learning improves accuracy and increases the dependability of the imaging process.

Support for Adaptive Therapy: 4D-CBCT monitors alterations in lung function during therapy, directing modifications to improve patient care.

Liver and other organs

The application of 4D-CBCT goes beyond lung imaging to include other anatomical locations impacted by motion brought on by respiration. Interestingly, 4D-CBCT has been used for liver imaging, however there are certain difficulties. The main challenge is the weak x-ray contrast between healthy parenchyma and liver cancers. Although iodinated contrast agents are frequently employed in liver 4D-CT to improve tumor visualization, logistical limitations and worries about contrast toxicity make their use in 4D-CBCT challenging. To help in localization, fiducial markers have been used close to liver tumors. Additionally, they offer point-based motion correspondence but are unable to treat liver volumetric deformations.(16) Retained lipiodol may act as a stand-in for tumor movements in patients who have received transcatheter arterial chemo-embolization with lipiodol.

However, lipiodol retention varies from patient to patient and gradually fades, making it less accurate for tumor location.
Limitations of 4D-CBCT

It is important to recognize that 4D-CBCT has various limitations even though it can record the volumetric movements of anatomical components on board. The clinical relevance of current 4D-CBCT is severely limited by the fact that it takes a substantially longer scanning time and a higher imaging dosage than 3D-CBCT, and it produces images of limited quality. Even though numerous methods have been created to speed up 4D-CBCT acquisition, lower imaging doses, and significantly enhance image quality, further testing and application are required before these innovative advancements may be used in clinical settings. To increase the use of this useful imaging technique in radiation therapy, 4D-CBCT's efficiency, imaging dosage, and quality must be optimized according to the therapeutic task. The temporal resolution of 4D-CBCT is another limitation. The breathing cycle is divided into a finite number of bins using 4D-CBCT, which then creates 3D pictures for each respiration bin. Consequently, the amount of bins needed for sorting and reconstruction limits the temporal precision of 4DCBCT. The temporal resolution may be enhanced by increasing the number of bins, but the image quality will be further deteriorated due to more severe under sampling in each bin. In phase-resolved 4D-CBCT imaging, ten bins are most frequently utilized, and each bin's temporal resolution is approximately one tenth of the breathing cycle. 4D-CBCT is prone to intra-bin motion artifacts and is unable to record the motion information within each bin.

Clinical and Technical Road Map

Significant advancements have been made in a number of 4D-CBCT imaging technological areas. The development of new models to further improve the effectiveness, caliber, and precision of 4D-CBCT imaging is highly promising given the growth of AI and deep learning. Recent developments in artificial general intelligence (AGI), transformers, and diffusion models present new chances to completely rethink the 4DCBCT procedure and greatly improve its performance. These approaches ought to be customized for particular projects in light of the particular difficulties in this discipline rather than being directly borrowed. Furthermore, in-depth clinical assessments are necessary for subsequent research. For 4D-CBCT to be used in a variety of therapeutic applications, such as localization, adaptive therapy, dosimetry, functional imaging, or radiomics analysis for outcome prediction, it must be quick, low-dose, and high-quality.

Conclusion

Localizing moving targets, including liver and lung cancers, requires the use of 4D-CBCT. In the age of stereotactic radiation therapy, where high radiation doses are administered in each fraction and great target localization precision is required, this is particularly crucial. Due to advancements in linear accelerator hardware, the 4D-CBCT is now the most widely used instrument in clinics for 4D patient imaging. A number of methods, including acquisition, sorting, pre-processing, reconstruction, and post-processing, have been developed to increase 4D-CBCT efficiency and image quality at various stages. The emergence of artificial intelligence (AI) and deep learning has led to a notable advancement in 4D-CBCT imaging recently, with the potential to significantly and efficiently increase 4D-CBCT image quality. These new technologies have the potential to significantly expand the use of 4D-CBCT from target localization to outcome prediction and adaptive therapy, potentially resolving the limitations of traditional 4D-CBCT techniques. Rapid, low-dose, high-quality 4D-CBCT can be created in the future to capture various patient motions and combine with other imaging modalities to offer a broad range of radiology and radiation oncology applications.

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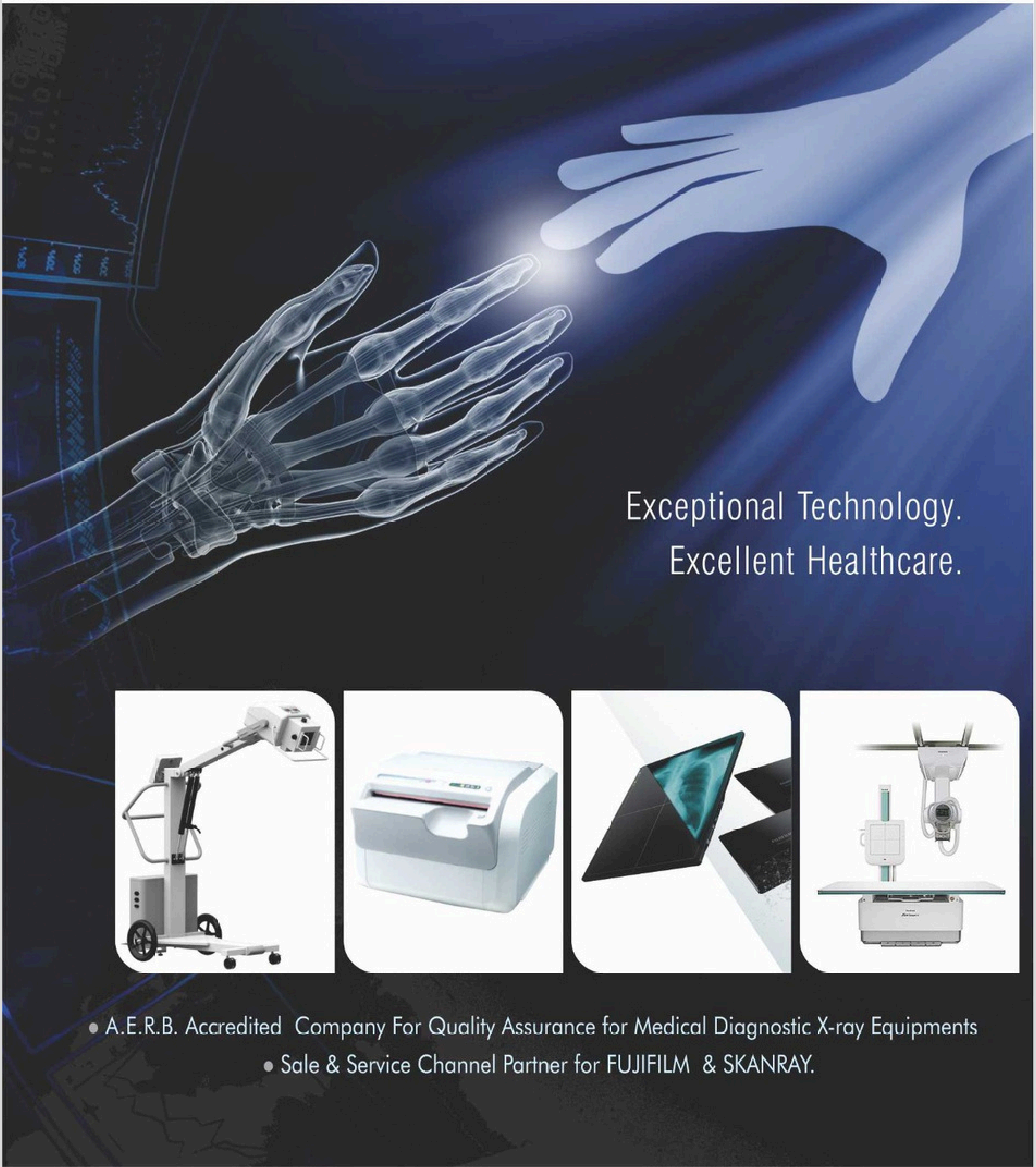
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Cardiac Imaging-Technical Advances in MDCT Compared with Conventional X-ray Angiography

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Coronary artery disease (CAD) represents the major cause of morbidity and mortality in Western populations. The prime diagnostic tool that allowed the development of rational treatment techniques for this disease is invasive coronary angiography ((CA) an X-ray fluoroscopy guided procedure), which is associated with a low rate of life threatening complications. More than 40% of the invasive CA studies are also carried out for the purpose of ruling out CAD. Non-invasive cardiac assessment has therefore been a goal of investigators for decades; echocardiography (ECG), nuclear medicine techniques, and MRI have been used non-invasively for a variety of cardiac indications, although no single technique provides a comprehensive assessment.

The prospect of imaging the heart and coronary arteries using computed tomography (CT) has been anticipated since the development of CT more than three decades ago. The lack of speed and poor temporal resolution of previous generations of CT scanners prevented meaningful evaluation of the coronary arteries and cardiac function. Most early assessments of the coronary arteries with CT were performed with electron beam computed tomography (EBCT), developed in the early 1980s. EBCT has been mostly used for the noninvasive evaluation of coronary artery calcium (CAC), but other applications, including assessment of coronary artery stenosis (CAS), have been reported in limited cases; however, EBCT is expensive and is not widely available.

Recent advances in CT technologies, especially multiple-row detector computed tomography (MDCT), have dramatically changed the approach to the non-invasive imaging of cardiac disease. With sub-millimeter spatial resolution (less than 0.75mm), improved temporal resolution (50- 200ms), and ECG gating, the current generation of CT scanners (16-64-row detectors) makes imaging possible, and has the potential to accurately characterize the coronary tree.

Technical Differences between CA Performed Under X-ray Fluoroscopy and MDCT

Even though both techniques utilize X-ray radiation, there are potential risk differences (stochastic and non-stochastic risks) due to the nature of exposure. There are also fundamental technical differences between CA performed invasively with X-ray fluoroscopy (conventional method) and non-invasively with MDCT.

The conventional angiographic image represents an instantaneous, two dimensional (2-D) planar projection of the 3-D contrast filled vessel lumen resulting in tissue superposition. During selective angiography, the operator obtains a 3-D understanding of the anatomy by repetitive injection and visualization of the artery of interest in different planes oblique to the body axis. Since the procedure is carried out under the guidance of continual or pulsed X-ray fluoroscopy, the spatial resolution (less than 0.2mm) and temporal resolution (less than 1s) are quite high and are considered the gold standard for comparing imaging capabilities of other modalities, such as CT.

On the other hand, CT acquires multiple axial tomographic image slices, which are combined into 3-D volumetric data sets. Subsequent image reformation or reconstruction can provide 3-D or 4-D images for volumetric visualization. In addition, tomographic image acquisition during CT angiography (CTA) provides additional information about the arterial wall and structures surrounding the arteries, which are not part of the conventional angiographic image.

Technological Developments in MDCT

By late 1998, all major CT manufacturers launched MDCT scanners capable of providing at least four slices/sections per rotation with minimum gantry rotation times of 0.5s. This enabled volumetric data eight times faster than the earlier single-row detector CT to be obtained with a scan time of 1s. Irrespective of the number of detector rows in the longitudinal (Z-axis) direction, the number of slices obtained per CT gantry rotation depends on the number of data acquisition system (DAS) channels. The drive toward an increased number of thinner detector dimensions is mainly due to the demand for obtaining high spatial resolution in the longitudinal direction over a large scan volume, so as to obtain isotropic resolution in all three dimensions. Current MDCT scanners are capable of obtaining 16- 64 slices per gantry rotation with slice thickness in the longitudinal direction as thin as 0.5mm. A number of novel image reconstruction algorithms are developed to handle the large volume data sets. The improved longitudinal (Z-axis) resolution, along with improved temporal resolution due to ECG gating, provides a scan technique considered well suited for CT imaging of the heart and other moving organs.

The key issues for successful cardiac imaging are that the imaging modality should have the capability to provide high spatial and temporal resolution. It is therefore appropriate to examine the technological advances enabling MDCT to perform cardiac imaging.

Spatial Resolution

There are a number of factors that can influence the spatial resolution in a CT image. The trans axial (X-Y plane) resolution in CT has been quite high from the beginning, which is dependent on the image matrix and the field of view and is in the order of 0.5- 0.25mm (one to two line-pairs/mm). The challenge concerns resolution in the longitudinal direction, which is influenced by the MDCT detector array design, slice thickness, reconstruction algorithms and increments, pitch, patient motion, and other technique factors.

Starting with four slices per rotation, the detector designs quickly migrated to 16 thin slices and have rapidly advanced to yield up to 64 thin slices (see evolution of detector array designs in Figure 1). The longitudinal resolution in modern MDCT scanners is in the order of 0.7- 0.3mm (0.7 to 1.5 line pairs/mm), and is rapidly approaching the resolution achievable in trans axial direction. The technology is fast advancing with the goal of obtaining isotropic resolution. This is accompanied by faster scan times resulting in extended volume coverage making angiographic techniques feasible with MDCT scanners. Even though the spatial resolution of conventional cardiac catheter remains unchallenged, the advances in MDCT technology are impressive.

Temporal Resolution

High temporal resolution is needed to minimize motion artifacts caused by cardiac pulsation. Since rapid movement is present during the systole phase, imaging is performed during the diastole phase. Desired temporal resolution for motion-free cardiac imaging in the diastole phase ranges from 150-250ms in order to image heart rates between 70 and 100 beats per minute (BPM), and less than 50ms to image during other phases. The temporal resolution in conventional X-ray fluoroscopy is high since the images are acquired with rapid exposure rates ranging from 7.5 to 30 frames per second.

The temporal resolution in MDCT depends on the gantry rotation times, type of ECG triggering, reconstruction methods, pitch, and other factors. Current MDCT scanners are capable of obtaining up to 64 slices per gantry rotation, and have a gantry speed as low as 330ms. One way to achieve high temporal resolution is by ECG triggering. Most cardiac CT procedures are performed with either prospective ECG triggering or retrospective ECG gating.

Prospective ECG triggering has long been used in conjunction with EBCT and more recently with single-slice spiral CT.A prospective trigger signal is derived from the patient's ECG and the scan is started at a defined point in time, usually during diastole. MDCT allows the simultaneous acquisition of several slices within one heartbeat. The data is acquired from only part of the cardiac cycle and is the most dose efficient way of ECG synchronization; however, the ECG-triggering technique greatly depends on a regular heart rate and is bound to result in mis-registration and motion artifacts. On the other hand, retrospective ECG gating effectively overrides the limitations of prospective ECG triggering by acquiring data throughout the cardiac cycle and allowing image reconstruction on selected part of the cardiac cycle. Retrospective ECG gating creates image stacks reconstructed at exactly the same phase of the heart cycle. The downside to this method is the radiation exposure; only partial data is used in the image reconstruction, and the rest is discarded.

Temporal resolution in MDCT is further improved by the type of image reconstruction; namely partial or segmented reconstruction. During partial image reconstruction, the data is either acquired or used in only part of the gantry rotation (half plus fan angle) resulting in a temporal resolution of up to half the gantry rotation speed, i.e. as low as 200ms. On the other hand, even higher temporal resolution is achieved with multi segmented image reconstruction, where partial data from multiple heart cycles yields a temporal resolution of less than 100ms. However, multi-segment reconstructed images are prone to reduced spatial resolution due to the variation in heart cycles. Although EBCT shows a favorable temporal resolution (up to 50ms), it is outperformed by MDCT due to their limitation in spatial resolution and poor contrast-to-noise ratio.

Pitch

The concept of pitch was introduced with the advent of spiral CT and is defined as the ratio of table increment per gantry rotation to X-ray beam width. Pitch values of less than one implies tissue overlapping and higher patient dose and pitch values greater than one imply extended imaging and reduced patient dose. However, in cardiac imaging the need for high spatial and temporal resolution demands that the pitch values need to be as low as 0.2- 0.4, implying a tissue overlap of 50% to 75%, resulting in significant radiation exposure to patients.

Future

It is certain that future technological advances will further enhance the role of MDCT in cardiac imaging. Manufacturers already have prototype scanners with 256-row detectors and flat panel technologies that can scan the entire heart in single CT gantry rotation. Improvements in data processing and reconstructing are forthcoming, and will further enhance MDCT capability, not just in imaging but also in quantifying cardiac functions. Research in the areas of multiple tubes to acquire cardiac data with superior temporal resolution is being worked on. In the near future, because of shorter examination times, improved spatial and temporal resolution, and cross-sectional imaging capabilities, CA procedures performed for diagnosis purposes in catheterization laboratories will be better suited for MDCT scanners.

Conclusion

Cardiac imaging with MDCT is evolving rapidly with technological advances. Widespread availability, shorter examination times of a non-invasive nature, and increasing numbers of studies demonstrating high sensitivity and specificity in diagnosing early onset of cardiovascular diseases (CVDs) will enable MDCT systems to play even greater role in diagnosis and follow-up treatment for CAD in the near future. At the same time, since the number of cardiac CT examinations is increasing and the examinations involve substantial radiation doses, strong indications for the procedure and improved and standardized scanning protocols are essential for further advancement of MDCT for cardiac imaging.

Augmented Reality in Radiology: Revolutionizing Imaging, Interventions, and Education

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Abstract
Augmented Reality (AR) has emerged as a transformative tool in radiology, offering immersive, real-time visualization of anatomical structures and imaging data superimposed on the physical environment. AR applications span diagnostic interpretation, interventional radiology, surgical planning, and medical education. This review explores the technical foundations of AR, current clinical applications, recent innovations, and integration with artificial intelligence (AI), alongside challenges and future directions. By enhancing spatial understanding, procedural precision, and user interaction, AR represents a paradigm shift in radiological practice.

Introduction

Radiology, as a cornerstone of modern medical diagnostics and interventions, is continuously evolving through the integration of cutting-edge technologies. Among these, Augmented Reality (AR) stands out as a transformative innovation with the potential to revolutionize the way imaging data is interpreted, visualized, and applied in clinical practice. Unlike Virtual Reality (VR) which immerses users in a completely synthetic, computer-generated environment AR overlays digital content onto the physical world, thereby blending virtual elements with the real-time clinical setting (Azimi et al., 2020). This fusion enables radiologists and clinicians to perceive and interact with medical imaging data in ways that were previously not possible.

In the radiological workflow, AR can superimpose CT, MRI, PET, or ultrasound images directly onto the patient's anatomy, providing spatially accurate, three-dimensional (3D) visualization of internal structures. This capability not only enhances diagnostic interpretation but also improves the precision of image-guided procedures such as biopsies, ablations, catheter placements, and surgical planning. Furthermore, AR systems support real-time decision-making by integrating dynamic imaging data with live feedback, thus offering greater situational awareness and spatial orientation during complex interventions.

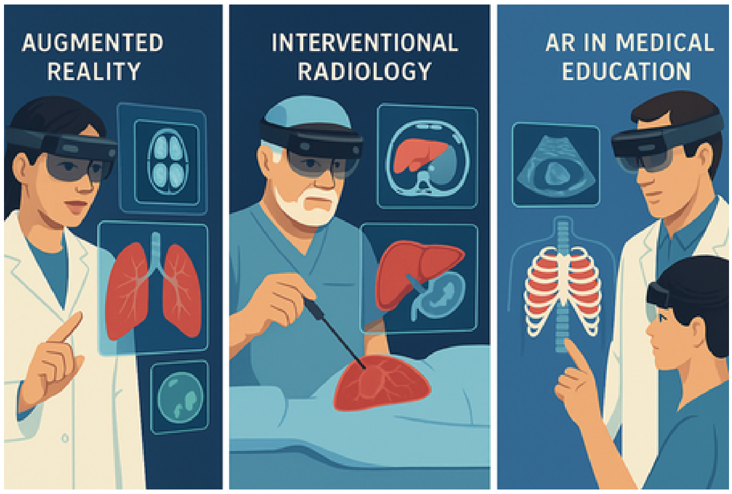
As radiology shifts toward minimally invasive techniques, personalized imaging protocols, and multidisciplinary care models, the need for technologies that can bridge the gap between traditional two-dimensional (2D) images and the three-dimensional (3D) anatomical reality becomes increasingly critical. AR addresses this challenge by providing an intuitive interface where anatomical structures are visualized in context, facilitating clearer communication among radiologists, surgeons, and trainees. In doing so, AR not only augments diagnostic and procedural accuracy but also holds immense promise in education, telemedicine, and collaborative care, marking a pivotal step toward the future of radiological practice.

Technical Foundations of Augmented Reality in Radiology

Core Components

AR systems used in radiology typically consist of the following components:

Data Source: CT, MRI, PET, or ultrasound datasets serve as input.
3D Reconstruction: Segmentation algorithms generate patient-specific 3D models (Fotouhi et al., 2019).



Registration and Calibration: Aligns digital overlays with real-world patient anatomy using fiducial markers, optical tracking, or electromagnetic sensors.
Display Interfaces: Includes head-mounted displays (e.g., Microsoft HoloLens), smartphones, tablets, or projection-based displays.

Interaction and Navigation

Advanced AR systems enable users to interact with imaging data through gestures, voice commands, or haptic feedback, often powered by game engines like Unity3D or Unreal Engine, and SDKs such as Vuforia, ARKit, or ARCore (Muensterer et al., 2014).

Clinical Applications of AR in Radiology

Interventional Radiology

AR assists in guiding needles, catheters, and ablation tools by overlaying CT/MRI-based 3D models onto the patient during procedures. Studies show increased accuracy and reduced procedure time (Fida et al., 2018).
Use cases: Liver biopsies, spinal injections, renal ablations.
Outcomes: Reduced fluoroscopy time and radiation exposure.
Example: Marescaux et al. (2004) reported AR-guided laparoscopic adrenalectomy enhanced spatial awareness and procedural accuracy.

Surgical Navigation

AR integrates intraoperative radiological images with the surgical field, allowing surgeons and radiologists to "see through" tissue layers in real-time.
Neurosurgery: AR improves tumor localization and planning via superimposed MRI images.
Orthopedic surgery: AR aids in alignment of implants using fluoroscopic overlays (Condino et al., 2020).

Diagnostic Imaging Interpretation

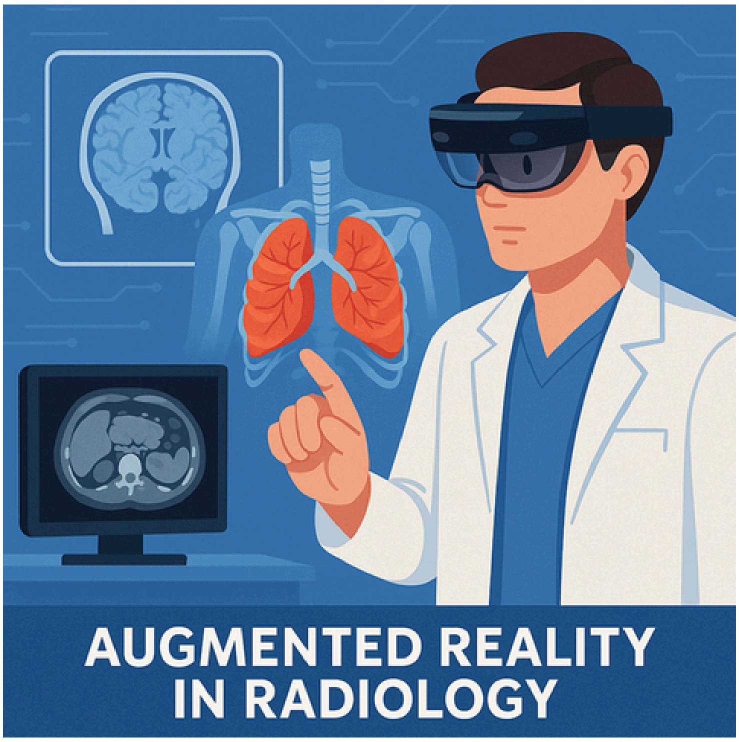
- Radiologists benefit from viewing 3D reconstructions overlaid on patients or within a digital environment, especially for complex cases such as congenital heart disease or oncology.

Improves understanding of anatomical relations.

- Enhances reporting for referring clinicians using AR-enabled image walkthroughs.

Radiology Education and Simulation

- AR enhances interactive learning for students and trainees:
- Simulation of radiographic positioning techniques.
- AR-guided ultrasound training with anatomical overlays on mannequins or volunteers.
- Real-time quizzes and feedback (Kourouklidou et al., 2022).



Recent Innovations and AI Integration

AR-AI Synergy

- Integration of AR with artificial intelligence enables context-aware overlays, decision support, and dynamic segmentation.
- AI can assist in real-time anatomical labeling and risk assessment during interventions (Fotouhi et al., 2020).
- Machine learning improves registration accuracy and predictive visualization of complications.

Teleradiology and Remote AR Collaboration

AR enables remote radiology consultation and tele-guidance in interventional procedures using shared AR spaces. This is crucial in resource-limited or emergency settings.

Example: Chan et al. (2021) demonstrated an AR-supported teleradiology system where experts remotely assisted in complex trauma triage.

Future Perspectives

Miniaturization of Devices: Development of lighter, more ergonomic headsets.

Standardization and Guidelines: Need for regulatory frameworks and best-practice protocols.

Large-scale Clinical Trials: Validation of AR effectiveness across imaging modalities and specialties.

Integration into PACS and EHRs: Seamless interoperability will drive clinical adoption.

Personalized AR: Patient-specific anatomy and disease models enabling personalized imaging-based therapy.

Conclusion

Augmented Reality is redefining the landscape of radiology by offering spatially immersive, intuitive, and data-rich experiences for both clinicians and learners. Though the technology faces to enhance diagnostic accuracy, procedural precision, and educational engagement is immense. As AR continues to merge

Benefits of AR in Radiology

ADVANTAGE	DESCRIPTION
Enhanced spatial awareness	Allows 3D visualization of complex anatomy during planning or interventions
Improved procedural accuracy	Facilitates real-time, image-guided interventions with reduced complications
Reduced radiation dose	Minimizes need for fluoroscopic validation in procedures
Educational enhancement	Improves understanding through interactive, immersive experiences
Streamlined workflow	Reduces interpretation time and boosts collaboration among teams

Limitations and Challenge

CHALLENGE	IMPACT
Calibration and registration errors	Misalignment can lead to inaccurate procedures
Hardware constraints	Devices like HoloLens may be bulky, expensive, and battery-limited
Software integration	Lack of interoperability with PACS/RIS systems
Learning curve	Radiologists may require training in AR interface navigation
Ethical and privacy concerns	Handling of real-time patient data in cloud-based or wireless AR systems

with AI, 5G, and teleradiology platforms, it is poised to become a central pillar in the future of radiological practice.

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Role of Radiomics in Differentiating Benign and Malignant Tumors

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Abstract
Radiomics, an emerging field in medical imaging analysis, transforms standard radiological images into high-dimensional data to extract quantitative features that can reflect tumor heterogeneity and pathology. Differentiating benign from malignant tumors remains a critical step in diagnostic and therapeutic decision-making in oncology. This paper reviews the current advancements in Radiomics, focusing on its application in distinguishing between benign and malignant tumors. The literature reveals that radiomics, when integrated with machine learning and deep learning algorithms, significantly enhances diagnostic accuracy and supports non- invasive, personalized cancer care. Despite its promise, challenges such as standardization, data sharing, and clinical validation remain.

Keywords: Radiomics, Benign Tumors, Malignant Tumors, Medical Imaging, Machine Learning, Oncology.

Introduction

Medical imaging plays a pivotal role in cancer diagnosis, staging, and treatment monitoring. Traditionally, radiologists interpret these images visually, which can be subjective and limited by inter-observer variability. In recent years, Radiomics has emerged as a powerful tool that quantifies the data embedded in medical images, offering insights into tumor biology beyond what is visually perceptible.

Radiomics leverages advanced algorithms to extract and analyze hundreds of quantitative features from standard imaging modalities like CT, MRI, and PET. This data can be used to characterize tumor shape, texture, and intensity, enabling precise discrimination between benign and malignant lesions. The integration of Radiomics with artificial intelligence (AI) has further revolutionized cancer diagnostics by enabling predictive modeling and risk stratification.

Literature Review

Theoretical Foundations of Radiomics

The concept of radiomics was introduced by Lambin et al. (2012), who emphasized the potential of high-throughput feature extraction from medical images for oncology applications. Gillies et al. (2016) described radiomics as the process of converting images into mineable data, laying the groundwork for non-invasive precision medicine.

Radiomics in Lung Tumor Classification

Aerts et al. (2014) demonstrated that CT-based radiomic features could predict survival and differentiate between benign and malignant pulmonary nodules. Their study included over 400 features and revealed that texture heterogeneity was significantly associated with malignancy.

Hawkins et al. (2016) developed machine learning models using CT-derived radiomics to classify lung nodules, achieving an area under the curve (AUC) of 0.90. The models outperformed traditional size-based criteria in identifying malignant lesions.

Brain Tumors and Radiomics

Zhou et al. (2018) analyzed MRI images of gliomas and found that radiomic features could differentiate low-grade from high-grade gliomas with a sensitivity of 89%. The features included entropy, contrast, and shape descriptors.

Kickingereder et al. (2016) reported that radiomic profiling of glioblastomas correlated strongly with molecular subtypes and survival, indicating that imaging phenotypes are reflective of genomic signatures.

Breast Cancer Detection

MRI-based radiomics has proven effective in distinguishing benign fibroadenomas from malignant carcinomas. Leithner et al. (2019) achieved over 90% accuracy using multiparametric MRI features and random forest classifiers.

Prostate and Liver Tumors

Sun et al. (2018) employed radiomics on multiparametric MRI to classify prostate cancer, showing that texture and shape features could distinguish between benign prostatic hyperplasia and cancerous lesions.

Choi et al. (2016) demonstrated the application of contrast-enhanced CT radiomics in identifying malignant liver lesions, with their model achieving an AUC of 0.87.

Limitations Highlighted in Literature

While the accuracy and potential of radiomics are well-documented, authors like Yip and Aerts (2016) have highlighted key challenges, such as reproducibility, the need for large annotated datasets, and the lack of standardization in image acquisition.

Methodology

This paper uses a systematic review methodology to evaluate studies published between 2012 and 2024 related to the role of radiomics in differentiating benign and malignant tumors.

Data Sources

To ensure a comprehensive and systematic evaluation of the current research on the role of radiomics in differentiating benign and malignant tumors, an extensive literature search was conducted. The selection of data sources, keywords, and inclusion criteria were carefully designed to maximize the quality, relevance, and scope of the review. The key components of the data sourcing process are detailed below:

Databases Used

A variety of well-established, peer-reviewed academic and scientific databases were utilized to collect relevant studies. These databases were chosen based on their broad coverage of medical imaging, computer science, artificial intelligence, oncology, and clinical diagnostics:

PubMed (MEDLINE)

Scope: Biomedical and life sciences literature.
Relevance: PubMed was critical for accessing clinical and radiological studies, especially those focusing on oncology, diagnostic radiology, and radiomics applications in cancer.
Search Strategy Example: ("radiomics" AND "malignant tumor") AND ("CT" OR "MRI" OR "PET") AND ("classification" OR "diagnosis").

Scopus
Scope: Multidisciplinary coverage across health sciences, physical sciences, and engineering.
Relevance: Scopus provided access to journals not indexed in PubMed and helped capture interdisciplinary studies involving data science and medical imaging.
Search Filters Used: Subject areas (Medicine, Engineering, Computer Science), years (2012–2024), article type (Research Articles, Reviews).

IEEE Xplore
Scope: Electrical engineering, computer science, and related technical fields.
Relevance: Essential for accessing machine learning and artificial intelligence models used in radiomics, especially for feature extraction, algorithm design, and classifier performance.
Typical Search String: ("radiomics" AND "tumor classification" AND "machine learning").

Springer Link
Scope: Scientific, technical, and medical (STM)literature.
Relevance: Provided access to high-impact journals publishing radiomics-related research in diagnostic imaging, oncology, and medical data analysis.
Search Method: Advanced search using combinations of keywords and filters for medical imaging, tumor diagnosis, and statistical validation.

Keywords Used
To ensure comprehensive retrieval of relevant literature, a list of specific and combination-based keywords was used. Boolean operators (AND, OR) were applied to refine the search:

Primary Keywords:
- Radiomics
- Benign Tumor
- Malignant Tumor
- Tumor Classification
- Imaging Biomarkers
- Texture Analysis
- Medical Imaging
- Feature Extraction
- Machine Learning in Radiology

Keyword Combinations:
- Radiomics AND Benign vs Malignant Tumor
- Radiomic features AND Imaging Biomarkers
- Radiomics AND Tumor Heterogeneity AND Diagnostic Accuracy
- Texture analysis AND Cancer Imaging

These keywords were strategically combined depending on the database's syntax and advanced search options. Synonyms and MeSH terms (for PubMed) were also used where applicable.

Inclusion Criteria
To maintain the scientific validity and relevance ofthe systematic review, specific inclusion criteria were defined. These criteria were strictly applied during the screening process:

Peer-Reviewed Studies Only
- Only studies published in peer-reviewed journals were included to ensure credibility and scientific rigor.
- Conference proceedings with full-length papers and strong validation were selectively considered.

Publication Language: English
- Only studies published in English were included to ensure consistency and accuracy in interpretation and analysis.
- Non-English studies were excluded due to potential issues in translation and contextual understanding.

Time Frame: 2012–2024
- The review focused on research published over the last 12 years to capture the
- emergence and evolution of radiomics as a diagnostic tool.
- This time frame reflects the period during which radiomics gained prominence in medical literature.

Study Subject: Human Subjects Only
- Only studies involving human participants were included to ensure clinical relevance.
- Animal or purely in-vitro/in-silico studies were excluded unless directly applicable to human tumor imaging.

Imaging-Based Tumor Analysis
- Included studies must have involved medical imaging modalities such as CT, MRI, PET, or ultrasound as a basis for radiomic feature extraction.
- Studies using radiomics for purposes other than tumor differentiation (e.g., treatment planning, radiotherapy toxicity prediction) were excluded unless tumor classification was a core component.

Diagnostic Comparison: Benign vs. Malignant Tumors
A key inclusion criterion was that the study must include comparative analysis between benign and malignant tumors, either through feature-based statistical comparisons or classifier-based prediction performance.
Availability of Performance Metrics

Studies had to report at least one diagnostic performance metric (e.g., AUC, accuracy, sensitivity, specificity) to be considered eligible for inclusion in performance-based comparative synthesis.

Screening Process
Step 1: Titles and abstracts of all retrieved studies were screened independently by reviewers.
Step 2: Full-text articles were downloaded for studies that met the inclusion criteria.
Step 3: Duplicates were removed and final eligibility was determined based on full-text analysis and relevance to the research question.

This meticulous and structured data sourcing strategy ensured the selection of high-quality, relevant studies for the systematic review. By using trusted databases, well-defined keywords, and strict inclusion criteria, the methodology upheld the scientific rigor necessary for synthesizing evidence on the effectiveness of radiomics in differentiating benign and malignant tumors.

Data Extraction and Analysis
The extracted data from the included studies were systematically categorized and analyzed to determine how radiomics has been utilized to differentiate benign from malignant tumors. This section outlines the specific key metrics used in evaluating the studies and provides an in-depth discussion of each parameter.

Imaging ModalityUsed
Radiomics is highly dependent on the type of imaging modality utilized to acquire medical images, as the nature and quality of these images significantly affect feature extraction and model

performance. Each included study was examined for the specific imaging modality used, such as:

Computed Tomography (CT): Frequently used for lung, liver, and abdominal tumors due to its high-resolution anatomical imaging. CT-based radiomics benefits from consistency in grayscale values (Hounsfield units), enabling reliable feature extraction.
Magnetic Resonance Imaging (MRI): Preferred for soft-tissue tumors such as brain, breast, and prostate cancers. MRI provides multi-parametric imaging (T1, T2, DWI, etc.) which enables advanced radiomic analyses, especially texture and shape characterization.
Positron Emission Tomography (PET): Offers metabolic information, which, when combined with anatomical CT images (as PET/CT), enhances the radiomic analysis for highly metabolic cancers like lymphoma or lung cancer.
Ultrasound (US): Less commonly used in radiomics but still relevant in breast and thyroid tumors. Texture-based radiomics features can still be derived from high- resolution ultrasound images with proper image preprocessing.

Studies were grouped based on the modality used, and comparative analysis was conducted to evaluate which modality yielded better diagnostic performance in radiomics-based tumor classification.

Type of Tumor
A crucial aspect of the review was to assess how effectively radiomics can distinguish between benign and malignant tumors across different anatomical sites. The types of tumors examined in the studies included:

Lung Nodules: Radiomics is often used to differentiate between benign granulomas and malignant primary lung cancers in CT scans.
Brain Tumors: Differentiation between benign meningiomas and malignant glioblastomas or metastases using MRI-based radiomics is a common application.
Breast Lesions: Radiomics from mammography, ultrasound, or MRI is used to separate fibroadenomas (benign) from ductal carcinoma (malignant).
Liver Lesions: Radiomics is employed to distinguish hemangiomas (benign) from hepatocellular carcinoma or metastases.
Kidney Masses: CT or MRI radiomics features help in differentiating benign renal cysts or angiomyolipomas from renal cell carcinoma.
Prostate Tumors: Radiomic features from multiparametric MRI help in assessing the risk and malignancy level of prostate nodules.
Thyroid Nodules: Texture analysis and intensity-based features from ultrasound images are used for malignancy prediction.

Each tumor type's performance was assessed individually to evaluate whether radiomics models perform consistently or vary based on tumor location and imaging modality.

Feature Categories Extracted

Radiomic features are mathematical descriptors that quantify tumor characteristics. The studies were assessed for the type and category of features extracted from imaging data, typically falling into the following groups:

Shape-Based Features
These describe the geometry and spatial form of the tumor, such as:
- Volume
- Surface area
- Compactness
- Sphericity
- Elongation

Malignant tumors often exhibit irregular shapes and invasive contours, while benign lesions are more likely to be smooth and symmetric.

First-Order Statistical Features (Intensity-Based)
These features summarize the distribution of individual voxel intensities within the region of interest (ROI):
- Mean, Median
- Standard Deviation
- Skewness, Kurtosis
- Entropy
- Minimum, Maximum intensity

Malignant tumors typically show greater heterogeneity in intensity, reflected by higher entropy and standard deviation values.

Second-Order Texture Features
These capture the spatial arrangement of pixel intensities, often indicating intra-tumoral heterogeneity:
GLCM (Gray Level Co-occurrence Matrix): Features like contrast, homogeneity, correlation.
GLRLM (Gray Level Run Length Matrix): Describes consecutive pixel runs with the same gray level.
GLSZM (Gray LevelSize Zone Matrix): Quantifies zonesof the same intensity.
NGTDM (Neighborhood Gray Tone Difference Matrix): Measures local intensity differences.

Texture features are critical in malignancy detection as malignant tumors often exhibit more irregular internal textures compared to benign masses.

Higher-Order Features
These involve filters or mathematical transforms applied to the original image to emphasize hidden patterns:
Wavelet Transforms: Decompose images into multiple frequency bands.
Laplacian of Gaussian (LoG): Highlights edges and texture variations.

These features are especially helpful in multi-parametric MRI or PET imaging, where sub-visual cues may indicate malignancy.

Each study was analyzed for the number, type, and selection method of radiomic features, as well as whether feature selection or dimensionality reduction techniques (e.g., LASSO, PCA) were applied.

Diagnostic Performance Metrics
To evaluate the clinical utility of radiomics in tumor classification, diagnostic performance metrics were extracted and compared across studies. The key performance indicators included:

Accuracy
Represents the proportion of correctly identified tumors (both benign and malignant) over the total number of cases.

Sensitivity (Recall or True Positive Rate)

- Measures the ability of the model to correctly identify malignant tumors.
- High sensitivity is critical to minimize false negatives (i.e., missed malignancies).

Specificity (True Negative Rate)

Measures the model's ability to correctly identify benign tumors. High specificity ensures that benign cases are not misclassified as malignant.

Area Under the Receiver Operating Characteristic Curve (AUC or AUROC)

- AUC measures the model's overall ability to discriminate between benign and malignant tumors across all threshold levels.
- An AUC of 1.0 indicates perfect classification, while 0.5 suggests no discriminative power.
- Most high-quality radiomics studies reported AUC valuesin the range of 0.80 to 0.95, reflecting strong classification performance.

F1-Score and Precision (in some studies)

- F1-Score is the harmonic mean of precision and sensitivity, useful in imbalanced datasets.
- Precision indicates how many of the predicted malignant tumors were actually malignant.

All performance metrics were compiled, and where available, confidence intervals and validation results (internal or external) were included to assess model reliability.

The systematic extraction and detailed analysis of imaging modality, tumor type, radiomic feature categories, and diagnostic performance provided a multidimensional understanding of the capabilities and limitations of radiomics. This approach enabled a robust comparison across studies, highlighting the most effective imaging strategies, feature types, and diagnostic metrics for distinguishing benign from malignant tumors.

Results and Discussion

Imaging Modalities and Feature Categories

Radiomics utilizes features such as:

Shape features: Compactness, sphericity (useful in identifying irregular malignant lesions)
First-order statistics: Mean, skewness, entropy(malignant tumors often show higher entropy)
Texture features: GLCM and GLRLM descriptors (malignancy correlates with heterogeneity)

Diagnostic Performance

Most studies report high performance:
Lung CT radiomics: AUC > 0.90
Brain MRI radiomics: Accuracy 85–89%
Breast MRI radiomics: Sensitivity > 90%

Integration with Machine Learning

SVMs, Random Forests, and Deep Neural Networks have been widely used. Ensemble models often outperform single classifiers.

Example: A CNN model trained on breast MRI features reached 92% diagnostic accuracy compared to radiologist-based evaluation at 85%.

Radiogenomics

Radiogenomic studies are correlating imaging features with mutations like EGFR (lung cancer), IDH1 (gliomas), and BRCA1 (breast cancer). This fusion enhances biological understanding and predictive modeling.

Challenges and Limitations

Standardization: Variations in imagingprotocols affect reproducibility.
Data sharing: Regulatory constraints hinder multicenter data collection.
Segmentation bias: Manual segmentation can introduce variability.
Interpretability: ―Black-box‖ AI models lack clinical explainability.
Clinical Translation: Few radiomics models are FDA-approved for routine use.

Conclusion

Radiomics represents a paradigm shift in medical imaging by enabling the extraction of hidden tumor characteristics that assist in differentiating benign from malignant tumors. Its integration with AI and radiogenomics enhances diagnostic precision and personalizes cancer care. While challenges remain —particularly in standardization, data sharing, and validation— the future of radiomics is promising with increasing interest from both the academic and clinical communities. Standardized protocols, robust multicenter trials, and regulatory frameworks are crucial for translating radiomics into clinical practice.

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Advancements in Medical Radiology through Multimodal Machine Learning

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Abstract

This is particularly true for radiography, which has long been a crucial area for machine learning in the medical field due to its high data density, accessibility, and interpretive power. Future developments in computer-assisted in the same way that physicians look at multiple sources when diagnosing patients, diagnostic systems need to be clever enough to interpret multiple data at once. Advanced identification techniques called multimodal learning can be used to extract novel characteristics from a variety of medical data sources. This allows algorithms to assess data from several sources without requiring training for each modality. This method incorporates a variety of data to increase the algorithms' flexibility.

Keywords

Multimodal Machine Learning, Radiology, Medical Image, Fusion, Translation, Representation Learning

Introduction

Globally, the rapid advancement of science and technology is transforming people's lives. Scientific research in the twenty-first century has been greatly impacted by several innovative developments.

Machine learning (ML) techniques are the most well-known and widely applied of all these innovations. Since machine learning integrates statistics and computation, it is not a new technique. The increasing availability of information from numerous sectors has created opportunities for the extensive use of ML in education, banking, economics, smart cities, and healthcare.

Furthermore, swarm intelligence methods are widely applied and used to solve different machine learning (ML) optimization problems. Machine learning is a comprehensive scientific method that encompasses multiple kinds of methodologies. It could be instructed and enhanced to produce accurate forecasts based on the information and data in its surroundings; these predictions can be retrained and applied as data sources and application settings alter.

In clinical settings, patient information is provided by a variety of data types from various sources. This includes nuclear medicine, molecular imaging, CT, MRI, ultrasound, X-ray, and other radiographic pictures. A significant amount of non-imaging information associated with every patient are also collected, such as lab tests, radiological reports, ECG and EEG data, etc. Furthermore, non-clinical information including a patient's demographics, genetic information, and medical history may be connected to them. In the medical context, “multimodal data” refers to data 3 of 39 beyond simply the imaging modality. **(Figure1)**

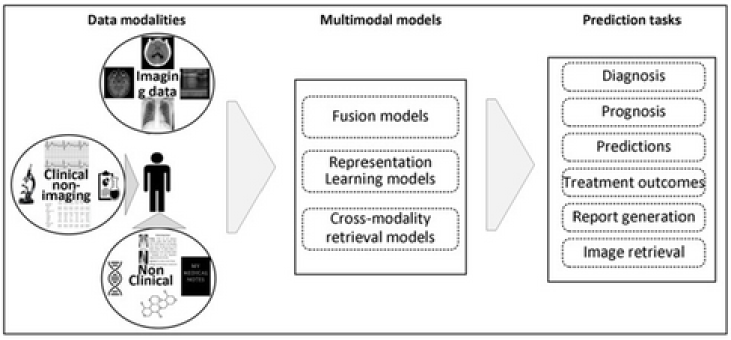

Figure 1 - The radiology conceptual pipeline of MMML. To serve a range of clinical prediction tasks, this figure shows how various clinical and non-clinical input modalities are handled using certain fusion and learning algorithms. It gives this review's narrative structure.

Multimodal machine learning (MMML) is the name of the branch of machine learning that focuses on evaluating data from several sources. As a subfield of computer vision and machine learning, it has grown significantly. MMML functions similarly to how people interpret physiological inputs, such as sound and vision. Autonomous driving (using a sequence of images, radar, lidar, and other sensors), conditioned image creation (using an image and text), audio–visual speech identification (using a sequence of audio clips and images), visual question answering (using an image and text), and other fields are among the many applications for it. In these cases, the goal is to aggregate the data from all input sources into a feature representation.

According to recent data, there will be a notable increase in multimodal AI research between 2019 and 2024, particularly in the fields of radiology and healthcare **(Figure 2A)**. This sharp rise demonstrates the increased interest in enhancing healthcare through multimodal approaches. The most common pairings in these studies, according to a study of the data modalities, are radiography and text, followed by omics and pathology (**Figure 2B)**. This pattern shows that MMML is becoming more widely recognized as a ground-breaking approach in medical research.

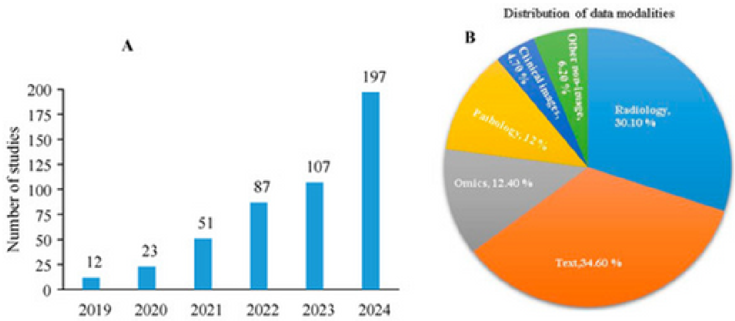

Figure 2 - Summary of data modalities utilized in the reviewed articles. (A) Bar chart illustrating the exponential growth in the number of studies published annually from 2019 to 2024. (B) Pie chart depicting the distribution of various modality groups and the corresponding data modalities employed in the studies.

Data Modalities

Medical Image Data

Usually, medical imaging data in medical practice are saved in DICOM format as 2D slices. This encompasses clients' metadata, the specifics of the imaging technique, the data on the instrument utilized for the image, and the parameters of the imaging procedure.

Several 2D slices with predetermined dimensions are frequently used to construct clinical 3D volume imagery, which shows a specific body part of concern. To identify important features, each slice can be analysed and processed separately (2D) or collectively (3D).

The DICOM format is either converted into commonly used imaging types (JPEG, PNG) or into the Neuroimaging Informatics Technology Initiative (NifTi) format, a specialized medical image processing plan that preserves important metadata alongside the image in the file's header, when medical imaging data is being prepared for machine learning.

Medical X-Ray: X-ray imaging is a readily accessible and cost-effective two-dimensional imaging modality. In 2022, over 50% of the 43.3 million diagnostic examinations conducted in the UK were X-ray scans, establishing X-ray as the predominant medical diagnosis tool. It is based on the idea of differential retardation in X-rays when they pass through different kinds of bodily tissues.

Computed Tomography: Complex cross-sectional scans of various body sections are possible with computed tomography (CT). The scans combine many consecutive two-dimensional slices from radiography pictures taken from different angles to create three-dimensional image volumes. The Hounsfield CT scan units (HU) and the signal attenuation caused by tissue density in relation to water are closely connected.

Magnetic Resonance Imaging (MRI): In contrast to the earlier-mentioned imaging methods, MRI is a non-ionizing technology. The individual is positioned inside a strong magnetic field, which causes the body protons' magnetic moments to align with the field. Radiation from short radio frequency bursts causes the protons to re-align with the magnetic field. MRI quantifies magnetization in transversal and longitudinal directions, allowing for tissue-specific reconstructions. MRI preserves a higher SNR and offers a comprehensive envision.

Nuclear Medicine Imaging: Single-Photon Emission CT (SPECT) and Positron Emission Tomography (PET) are nuclear medicine imaging (NMI) procedures that detect gamma photons from radioactive tracers, providing insights into blood flow/function and metabolic activity. In every scan, these approaches produce several 2D slices, ranging from dozens to hundreds.

Ultrasonography: Ultrasound imaging employs sound radiation at over 20 kHz to detect anatomical features. The data generally include a sequence of 2D frames, although current developments also allow for 3D and 4D scans. Transducer frequency affects image quality, lower frequencies provide deeper depths at the cost of visibility, and higher frequencies offer higher quality but reduced penetration, making them ideal for surface structures.

Non-Imaging Data

The understanding of imaging data can be improved by the Supplementary Information and important context provided by non-imaging data. A range of data kinds are included in non-imaging data, such as text data (unorganized data) such as patient histories and clinical reports, time ECG, EEG, blood pressure, oximetry, and other series data are examples of organized data, as are lab results, genetic data, and demographic information.

Preliminaries

Data Modalities-Based Classification

Non-imaging consists of various data types, i.e., text data like clinical reports and patient histories, as well as structured data such as time series and discrete data. This leads to two sets of modalities: imaging with text data and imaging with structure data.

Methodology-Based Classification

Modality fusion, cross-modality retrieval, and representation learning are the three main ideas that make up the categorization of MMML in radiology. To fully appreciate the complexities of MMML, it is essential to comprehend these ideas. Based on approach, the published papers were categorized. This is based on the "sections" of the neural network that link each modality, as seen in Figure 3. To help researchers identify a convenient place to start, a thorough collection of public ally available datasets in each modality category is also included.

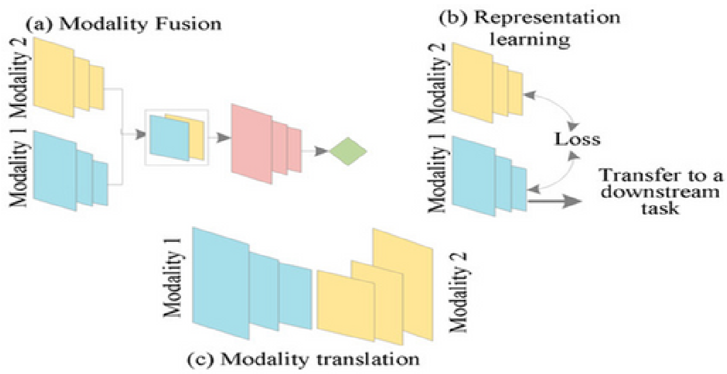

Figure 3. Classification of approaches using multiple modalities. Each approach is evaluated according to its utilization of modality combinations: (a) fusing the features of different modalities, (b) learning-based enhanced representation of different data types, and (c) translation of one type of data into another. (b) learning-based enhanced representation of different data types, and (c) translation of one type of data into another.

Multimodal Machine Learning in Radiology

This study solely concentrates on multimodal machine learning (MMML) in radiology, in contrast to many other reviews that arrange multimodal medical AI research by disease domain. It makes use of a classification paradigm that is methodology-driven and modality-based. The framework of radiological data processes is represented by this technique, which frequently combines imaging with other non-imaging data types for a variety of activities, including vital signs, laboratory results, and clinical reports. Figure 1 offers a simplified design that uses fusion, representation learning, and cross-modality conversion techniques to connect integrated data modalities to clinical objectives (such as diagnosis, prognosis, and report generation). This framework guarantees that the clinical foundation and wide audience accessibility of MMML models are maintained while maintaining their technical sophistication.

Conclusions

- To improve medical judgments, the discipline of radiology is putting more and more emphasis on MMDL, which entails integrating information from several sources other than medical imaging.
- More thorough and accurate diagnoses have resulted from the integration of multiple data modalities. opening the door for individualized medical treatment.
- The importance of MMDL is found in its capacity to combine intricate information and provide insights that were previously unachievable.
- The main features of MMDL in radiology have been emphasized in this review, demonstrating how it has the potential to revolutionize medical diagnostics.
- To sum up, multimodal deep learning is not only an adjunct to conventional imaging techniques but also a crucial step in developing radiology and enhancing patient outcomes.
- This assessment offers a solid basis for upcoming research, providing information about the state of the art now and opening the door for the upcoming developments in multimodal machine learning in the medical field.

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