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Editorial

Shankar K. Bhagat
Editor-in-chief

The September 2026 issue of Radiographers Journal reflects an exciting phase in the evolution of medical imaging, where technological innovation is increasingly being combined with patient-centred care, quantitative analysis, and professional expertise. The contributions in this issue take us from the human aspects of mammography to advanced MRI, photon-counting technology, artificial intelligence, radiomics, three-dimensional printing, dual-energy CT, and four-dimensional imaging.

We begin with an important reminder that advanced technology must never overshadow the patient experience. The article on the Role of Radiographers in Promoting Patient Comfort During Mammography highlights the contribution of radiographers in reducing anxiety, discomfort, and apprehension during breast imaging. Communication, empathy, appropriate positioning, and attention to individual patient needs can significantly influence the overall examination experience. A positive patient experience is also important in encouraging participation in screening and future examinations.

The role of MRI in neurological imaging is explored through MRI in Multiple Sclerosis. MRI remains central to the detection and monitoring of multiple sclerosis, helping demonstrate disease activity and supporting clinical decision-making. The article emphasizes the importance of appropriate imaging protocols and the radiographer's technical contribution to producing consistent, high-quality examinations.

Moving into the next generation of X-ray technology, Recent Advancements in Photon Counting Detector Technology examines a major development in CT imaging. Photon-counting detectors can provide improved spatial and contrast resolution, spectral information, and greater dose efficiency compared with conventional detector technology. These capabilities are opening new possibilities across a wide range of clinical applications.

The article on Clinical Applications of Diffusion Tensor Imaging (DTI) demonstrates how advanced MRI techniques can provide information about tissue microstructure and white-matter pathways, extending imaging beyond conventional anatomical assessment. Such techniques continue to strengthen the role of MRI in neurological and neurosurgical applications.

Another major theme is the transformation of imaging data into quantitative information. Radiomics and Artificial Intelligence: Biomarkers for Quantitative Imaging explores how large amounts of imaging data can be analysed to identify patterns and potentially generate imaging biomarkers. This represents an important step toward precision medicine, although appropriate validation, standardization, and clinical integration remain essential.

The intersection of imaging and personalized treatment is further demonstrated by 3D-printed patient-specific blocks based on CT for complete knee replacement. By converting patient imaging data into individualized physical solutions, this approach illustrates how diagnostic imaging can contribute directly to treatment planning and customized clinical care.

The changing professional landscape is addressed in The Role of Radiographers in the AI Era of Breast Imaging. As AI-assisted technologies become increasingly integrated into breast imaging, radiographers will remain essential —not simply as operators of technology, but as professionals responsible for patient interaction, technical quality, safety, workflow, and effective integration of new systems into clinical practice.

The issue also examines Dual-Energy CT, an important advancement that enables material differentiation and spectral information beyond conventional CT. Complementing this is the article on 4D Cone-Beam CT in Radiation Therapy, which explores technical developments and clinical applications of imaging that can account for motion and support increasingly precise radiation treatment.

Collectively, these contributions demonstrate that the future of radiography is not defined by technology alone. It is defined by how intelligently technology is applied, how effectively professionals adapt, and how consistently patient needs remain at the centre of care.

I sincerely thank all our contributors for sharing their knowledge and expertise. I hope this issue encourages readers to embrace innovation while continuing to strengthen the human, technical, and professional foundations of radiography.

Happy Reading!

Union Health Ministry Strengthens Allied and Healthcare Education and Professional Standards; UGC Notifies 33 New and Restructures 21 UG & PG Degrees Under NCAHP Regulatory Framework

UGC Notification to Bring Uniformity in Allied and Healthcare Courses Under 'One Nation, One Curriculum' Framework: Dr. Yagna Unmesh Shukla, Chairperson, NCAHP

The Union Ministryof Health and Family Welfareis strengthening the education, training and professional standards of Allied and Healthcare Professions to build a skilled, competent and future-ready healthcare workforce for the country. In a significant step in this direction, the University GrantsCommission (UGC) has notified 33 new and 21 restructured/updated Allied and Healthcare Undergraduate (UG) and Postgraduate (PG) degrees under the regulatory purview of the National Commission for Allied and Healthcare Professions (NCAHP).

The UGC has issued the 5th Amendmentto the Specification of Degreesunder Section 22(3) of the UGC Act, 1956 vide Notification No. F.21-12/2026(CPP-II) – (UIN:3/2026) dated August 27, 2026. The Gazette Notification was published on August 31, 2026. The notification is an importantstep towards bringinggreater uniformity in Allied and Healthcare education across the country and strengthening academic and professional pathways in these criticalhealthcare disciplines.

Appreciating the efforts made by the Ministry of Health and Family Welfare, UGC and NCAHP team, Dr. Yagna Unmesh Shukla, Chairperson, NCAHP said, "This UGC notification will bring uniformity across Allied and Healthcare courses, their duration, degree nomenclature and entry qualification under the 'One Nation, One Curriculum' mandate by the Commission. This notification will provide immense guidance to students who are aiming to pursue their career in Allied and Healthcare Professions scheduled under the NCAHP Act, 2021."

The degrees notified cover disciplines including Physiotherapy, Occupational Therapy, Optometry, Medical Laboratory Sciences, Emergency Medical Technology, Anaesthesia and Operation Theatre Technology, Nutrition and Dietetics, Psychology, Medical and Social Psychiatric Social Work, Medical Radiology, Imaging and Therapeutic Technology, Physician Associate, Respiratory Technology, Dialysis Therapy Technology and Health Information Management, among others. The notification specifies the degree nomenclature, abbreviation, duration and entry qualifications, while course durations have also been revised for select programmes.

The notification further provides for specialisation-specific degrees, with nine specialisations in Master of Occupational Therapy, eight in Master of Physiotherapy, four in Master of Medical Laboratory Sciences, three in Master of Medical Radiology and Imaging Technology and two in Master of Respiratory Technology. This will expand academic opportunities for students and enable universities to offer specialised programmes aligned with the evolving needs of the healthcare sector.

The reform is aimed at establishing institutional parity and uniformnational standards in Allied and Healthcare education while aligning degree nomenclature with globally accepted degree-level qualifications. This is expected to encourage more students to pursue these professions, provide clearer academic and career pathways and facilitate greater mobility and international recognition of Indian Allied and Healthcare professionals.

The initiative fulfilsthe statutory mandateof NCAHP under the NationalCommission for Allied and Healthcare Professions Act, 2021, which provides for the regulation and maintenance of standards of education and professional services across Allied and Healthcare Professions. In line with this mandate, NCAHP has already released 18 competency-based curricula covering 28 professions, with the objective of standardising curricula and degree nomenclature across the country.

The competency-based curricula place particular emphasis on hands-on clinical training through adequate-duration internships at hospitals or associated practising facilities. This approach seeks to ensure that students develop the practical skills, professional competencies and clinical exposure required for effective healthcare delivery.

To ensure seamless adoption of the reforms, NCAHP has already issued directive to all the states, union territories and other relevant stakeholders much before the commencement of the academic year to mandatorily implement the released curricula from 2026-27 academic year, with an option to commence the Diploma in Medical Laboratory Technology (DMLT) course. The Commission is also working towards finalising the remaining competency-based curricula for implementation from the subsequent academic year.

The measures are expected to strengthen the availability of a well-trained and qualified Allied and Healthcare workforce, which forms an essential component of multidisciplinary healthcare delivery. The reforms will also provide greater clarity and consistency for students, educational institutions and healthcare establishments while creating improved opportunities for professional growth and mobility.

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विश्वविद्यालय अनुदान आयोग

(उपाधियों का विनिर्देशन)

अधिसूचना

नई दिल्ली, 27 अगस्त, 2026

सं. एफ. 21-12/2026(सीपीपी-II) – (यूआईएन:3/2026) विश्वविद्यालय अनुदान आयोग अधिनियम, 1956 की धारा 22 की उप-धारा (3) द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए तथा 5 जुलाई, 2014 को जारी उपाधियों के विनिर्देशन पर पूर्ववर्ती राजपत्र अधिसूचना में संशोधन करते हुए, विश्वविद्यालय अनुदान आयोग (यूजीसी) केन्द्रीय सरकार के अनुमोदन से उक्त यूजीसी अधिसूचना (उपाधियों के विनिर्देशन) में पांचवां संशोधन अधिसूचित करता है। यह संशोधन राजपत्र में प्रकाशन की तिथि से प्रभावी होगा।

राष्ट्रीय सहबद्ध और स्वास्थ्य देख-रेख वृत्ति आयोग (एनसीएएचपी) की विनियामक अधिकारिता के अंतर्गत आने वाली निम्नलिखित उपाधियाँ "चिकित्सा एवं शल्य चिकित्सा/ आयुर्वेद/ यूनानी/ होम्योपैथी/ सहबद्ध एवं स्वास्थ्य देख-रेख/ फार्मेसी/ पैरामेडिकल/ नर्सिंग" शीर्षक के अंतर्गत अधिसूचित की जाती हैं।

167.	B.ND	Bachelor of Nutrition and Dietetics (Honours)	BACHELOR'S	4	10+2
168.	M.ND	Master of Nutrition and Dietetics	MASTER'S	2	BACHELOR'S
169.	B.Psy	Bachelor of Psychology	BACHELOR'S	4	10+2
170.	B.MPSW	Bachelor of Medical and Psychiatric Social Work	BACHELOR'S	4	10+2
171.	M.MSW	Master of Medical Social Work	MASTER'S	2	BACHELOR'S
172.	M.PSW	Master of Psychiatric Social Work	MASTER'S	2	BACHELOR'S
173.	B.MRIT	Bachelor of Medical Radiology and Imaging Technology	BACHELOR'S	4	10+2
174.	M.MRIT (C T Imaging Technology)	Master of Medical Radiology and Imaging Technology in C T Imaging Technology	MASTER'S	2	BACHELOR'S
175.	M.MRIT (M R Imaging Technology)	Master of Medical Radiology and Imaging Technology in M R Imaging Technology	MASTER'S	2	BACHELOR'S
176.	M.MRIT (Breast Imaging Tech nology)	Master of Medical Radiology and Imaging Technology in Breast Imaging Technology	MASTER'S	2	BACHELOR'S
177.	B.RTT	Bachelor of Radiation Therapy Technology	BACHELOR'S	4	10+2
178.	M.RTT	Master of Radiation Therapy Technology	MASTER'S	2	BACHELOR'S
179.	B.Sc. (NMT)	Bachelor of Science in Nuclear Medicine Technology	BACHELOR'S	4	10+2
180.	M.Sc. (NMT)	Master of Science in Nuclear Medicine Technology	MASTER'S	3	BACHELOR'S
181.	M.Sc. (Medical Physics)	Master of Science in Medical Physics	MASTER'S	3	BACHELOR'S
182.	B.PA	Bachelor of Physician Associates	BACHELOR'S	4	10+2
183.	M.PA	Master of Physician Associates	MASTER'S	2	BACHELOR'S
184.	B.DTT	Bachelor of Dialysis Therapy Technology	BACHELOR'S	4	10+2
185.	M.DT	Master of Dialysis Therapy	MASTER'S	2	BACHELOR'S
186.	B.RT	Bachelor of Respiratory Technology	BACHELOR'S	4	10+2
187.	M.RT (ARC)	Master of Respiratory Technology in Adult Respiratory Care	MASTER'S	2	BACHELOR'S

Role of Radiographers in Promoting Patient Comfort During Mammography

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Abstract
Mammography is an important imaging method used for the early detection of breast abnormalities and breast cancer. However, some women may experience fear, anxiety, embarrassment, or discomfort during the examination, mainly because of breast compression. The radiographer plays an important role in making the examination more comfortable and less stressful for the patient. Their responsibility is not limited to operating the mammography equipment; it also includes proper communication, patient education, emotional support, correct positioning, and maintaining a comfortable environment. A patient-centered approach can improve cooperation, reduce anxiety, and contribute to obtaining good-quality mammographic images.
Keywords: Mammography, Radiographer, Patient comfort, Communication, Breast imaging

Introduction

Mammography is performed by compressing the breast between two plates to produce clear and diagnostically useful images. Breast compression is necessary because it helps reduce tissue overlap, improve image quality, and minimize radiation exposure. However, the pressure applied during compression can cause discomfort or pain in some patients.

For some women, especially those undergoing mammography for the first time, the procedure may create feelings of fear or embarrassment. Previous unpleasant experiences may also make patients anxious about repeating the examination. Therefore, the radiographer has an important role in preparing the patient, explaining the procedure, and providing reassurance throughout the examination.

A technically good mammogram depends not only on the equipment and exposure factors but also on the patient's cooperation and comfort.

Importance of Patient Comfort During Mammography

Better Image Quality

A relaxed patient is more likely to cooperate during positioning and remain still during exposure. This helps the radiographer achieve proper positioning and obtain good-quality images while reducing the need for repeated exposures.

Encourages Regular Screening

When patients have a positive and comfortable experience, they may be more willing to attend future mammographic examinations. This is important because regular screening can help in the early identification of breast abnormalities.

Reduces Anxiety and Embarrassment

Breast examination can sometimes make patients feel uncomfortable or self-conscious. Maintaining privacy, dignity, and respectful communication can help the patient feel safe and more relaxed during the examination.

Role of the Radiographer in Improving Patient Comfort

Communication and Patient Education

- Before beginning the examination, the radiographer should explain the procedure in simple and understandable language. The patient should know what will happen, why breast compression is required, and approximately how long the compression will last.
- Clear communication helps reduce fear of the unknown. The radiographer should also encourage the patient to ask questions and should respond patiently to their concerns.

For example, saying "The compression will last only for a few seconds" can help the patient understand what to expect and prepare mentally.

Empathy and Emotional Support

- Some patients may feel nervous, embarrassed, or worried about the result of the examination. The radiographer should therefore maintain a calm, respectful, and friendly manner.
- Acknowledging the patient's discomfort rather than ignoring it can make the patient feel understood. Simple reassurance and supportive communication can build trust between the patient and radiographer.

Proper Positioning and Technical Skills

- Patient comfort and image quality are closely related to proper positioning. A skilled radiographer should position the patient carefully while ensuring that the breast is adequately included in the image.
- The height of the mammography unit and compression paddle should be adjusted according to the patient's comfort and body habitus. The radiographer should provide clear instructions regarding posture and breathing.
- Compression should be applied in a controlled and gradual manner rather than suddenly. Good positioning can reduce unnecessary discomfort and also decrease the possibility of repeat imaging.

Creating a Comfortable Examination Environment

- The physical environment can also influence the patient's experience. Privacy should be maintained during the examination, and the room should be kept at a comfortable temperature.

- Where appropriate, allowing a patient to have a support person can provide additional reassurance. A calm atmosphere and friendly interaction may also help reduce nervousness and make the examination easier for the patient.

Managing Common Difficulties During Mammography

- **Discomfort During Compression:** The radiographer should explain why compression is necessary and inform the patient that it will be maintained only for a short period. The patient should be encouraged to communicate if the discomfort becomes difficult to tolerate.
- **Anxiety in First-Time Patients:** Patients having mammography for the first time may not know what to expect. Providing additional information before starting the examination and reassuring the patient can help reduce fear and improve cooperation.

Cultural and Privacy Concerns: Radiographers should respect differences in culture, personal values, and modesty. Proper draping, privacy, respectful communication, and professional behavior are important for maintaining the patient's dignity.

Providing proper information, showing empathy, maintaining privacy, using appropriate positioning techniques, and creating a supportive environment can make mammography more comfortable for patients. Improved patient cooperation can also contribute to better-quality images and fewer repeat examinations.

Therefore, patient-centered care should be considered an important part of mammography practice. A positive experience may also encourage women to participate in future screening, supporting the early detection of breast disease.

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The following readers participated in the Quiz – August 2026 issue.

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Role of MRI in Multiple Sclerosis

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Abstract

Most people with multiple sclerosis (MS) experience transient periods of neurological impairment, which are frequently followed by irreversible clinical disability. To enable early diagnosis and accurately identify MS patients at elevated risk of disease development, precise diagnostic criteria and prognostic markers are essential. The 2017 McDonald diagnostic criteria demonstrate great sensitivity and accuracy for the diagnosis of multiple sclerosis (MS), enabling early diagnosis and treatment, and include magnetic resonance imaging (MRI) as a fundamental paraclinical technique. However, misdiagnosis may become more likely if they are used improperly, particularly when uncommon clinical presentations are involved. Novel imaging indicators are being developed to further enhance the diagnosis process, but before they can be used in clinical practice, thorough validation and standardization are still required. In addition to discussing the current role of MRI in the diagnosis and prognosis of multiple sclerosis, this series article looks at promising MRI markers that may be used as trustworthy indicators of future disease development, thereby improving the care of individual MS patients. We also investigate how new technology, such automated quantification tools and artificial intelligence, might help physicians manage patients. However, it is crucial that standardized brain and spinal cord MRI protocols be used and that qualified (neuro)radiologists in every nation interpret the results in order to guarantee consistency and improvement in the use of MRI in MS diagnosis and patient follow-up.

Introduction

Evidence of a symptomatic demyelinating syndrome with objective neurologic signs, an assessment of clinical and paraclinical findings to show a focal demyelinating pathology affecting at least two different CNS areas (dissemination in space [DIS]) occurring at different times (dissemination in time [DIT]), and the exclusion of alternative diagnoses are all necessary for the diagnosis of multiple sclerosis (MS).

In the 2001 McDonald criteria, magnetic resonance imaging (MRI) was officially added to the diagnostic algorithm for patients who presented with a clinically isolated syndrome (CIS) suggestive of MS.

These criteria, which were updated multiple times throughout the year until the most recent version in 2017, rely on the use of standardized MRI protocols to evaluate the quantity, size, and location of brain and spinal cord lesions indicative of multiple sclerosis, enabling an earlier diagnosis and the initiation of treatment.

Uncommon groups within the MS population have received more attention lately, including radiologically isolated syndrome (RIS), pediatric or late-onset MS, and primary progressive (PP) phenotypes.

Additionally, more prospective MRI features for MS diagnosis and prognosis have been proposed, such as the evaluation of optic nerve involvement and the identification of cortical lesions (CLs), central vein sign (CVS), and chronic active lesions.

In this case paper, we examine the potential use of new MRI markers and technologies while outlining the existing function of MRI in MS diagnosis and prognosis.

Basic principle of MRI Techniques

In order to identify microstructural alterations linked to multiple sclerosis (MS), clinical MRI mainly uses the resonance signal of hydrogen (^1H) in tissue water. While T1-weighted imaging, particularly following gadolinium contrast administration, is useful to detect active lesions by displaying blood–brain barrier disruption, T2-weighted and FLAIR sequences are highly sensitive for recognizing MS lesions, inflammation, edema, demyelination, and axonal loss. While double inversion recovery (DIR) enhances cortical lesion visibility, 3D T1-weighted sequences are crucial for evaluating brain volume and atrophy. Iron accumulation, central vein indicators, and persistent active lesions are identified by susceptibility-based imaging and quantitative susceptibility mapping (QSM). Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) measure water diffusion and white matter microstructural damage, providing quantitative data on demyelination and axonal injury, while magnetization transfer (MT) imaging assesses myelin integrity using the magnetization transfer ratio (MTR).

Diagnostic Criteria of MS

According to the 2017 McDonald MRI criteria, dissemination in time (DIT) is indicated by the presence of CSF-specific oligoclonal bands (OCBs) or new or gadolinium-enhancing lesions, whereas dissemination in space (DIS) is diagnosed by the presence of one or more T2-hyperintense lesions in at least two of four typical CNS regions. In comparison to the 2010 criteria, the 2017 modification reduces long-term disability by increasing sensitivity, enabling earlier diagnosis with fewer MRI scans, and enabling earlier introduction of disease-modifying treatments (DMTs). To prevent misdiagnosis, however, precise MRI interpretation and consistent imaging procedures are crucial. Because diseases including myelin oligodendrocyte glycoprotein-associated disease (MOGAD), neuromyelitis optical spectrum disorder (NMOSD), and small-vessel disease (SVD) might resemble the clinical and MRI characteristics of multiple sclerosis, differential diagnosis is crucial.

Promising MRI measures for MS diagnosis

More unique MRI features, including as CLs, the CVS, and chronic activity lesions, have recently been suggested to increase the specificity and accuracy of the MS diagnostic work-up.

CIs

A very distinctive and clinically significant characteristic of multiple sclerosis (MS), cortical lesions (CLs) are present from the very beginning of the illness and get worse with time. They are crucial in both diagnosing MS and distinguishing it from other demyelinating conditions. However, due to their size and placement, CL detection is technically difficult. While advanced sequences like double inversion recovery (DIR), phase-sensitive inversion recovery (PSIR), magnetization-prepared rapid gradient echo (MPRAGE), magnetization-prepared two rapid acquisition gradient echo (MP2RAGE), and fluid and white matter suppression (FLAWS) enhance in vivo cortical lesion detection, 7.0 T MRI offers higher sensitivity than 3.0 T MRI.

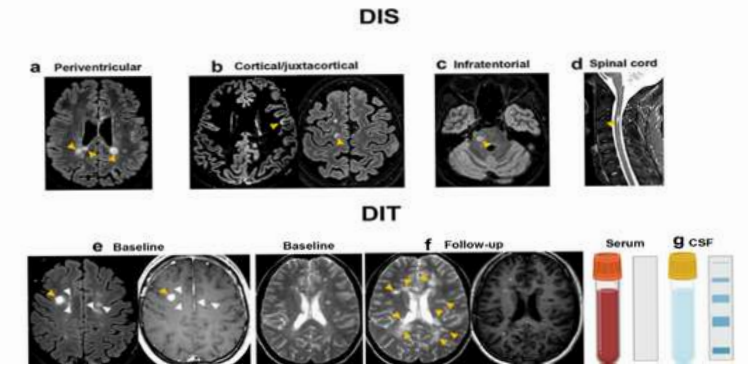

Fig 1. The 2017 McDonald criteria for DIS and DIT manifestation in individuals with a CIS suggestive of MS Typical MRI examples of (a) periventricular, (b) cortical/juxtacortical, (c) infratentorial, and (d) spinal cord MS lesions (orange arrowheads). ≥1T2 hyperintense lesions in ≥2 of the four typical regions of the central nervous system (i.e., periventricular, cortical/juxtacortical, infratentorial, or spinal cord) are indicative of DIS. (e) the simultaneous existence of Gd-enhancing (orange arrowheads) and non-enhancing (white arrowheads) lesions at any time; (f) a new T2-hyperintense and/or Gd-enhancing lesion on a follow-up MRI (orange arrowheads), regardless of when the baseline MRI was performed. The 2017 revision of the McDonald criteria eliminated the distinction between symptomatic and asymptomatic lesions for both DIS and DIT. (g) The demonstration of CSF-specific OCBs, i.e., not present in the serum but only in the CSF, replaces the requirement of fulfilling DIT in patients with a typical CIS suggestive of MS fulfilling DIS criteria and without a better explanation for the clinical presentation, allowing a diagnosis of MS even if the clinical and MRI findings do not meet the criteria for DIT. CIS stands for clinically isolated syndrome; CSF for cerebrospinal fluid; DIS for dissemination in space; DIT for dissemination in time; Gd for gadolinium; MRI for magnetic resonance imaging; and MS for multiple sclerosis.

CVS

One distinctive MRI biomarker of multiple sclerosis (MS) is the central vein sign (CVS), which represents perivenous demyelination, a pathogenic feature of the illness. Susceptibility-based MRI is used to identify it, and gadolinium contrast is administered to increase it. Neuromyelitis optical spectrum disorder (NMOSD), migraine, small-vessel disease (SVD), and myelin oligodendrocyte glycoprotein-associated disease (MOGAD) can all be distinguished from MS with high sensitivity and specificity when there are 35–50% CVS-positive white matter lesions, or at least 3–6 CVS-positive lesions.

Paramagnetic rim lesions

On susceptibility-based MRI and quantitative susceptibility mapping (QSM), paramagnetic rim lesions (PRLs), which are chronic active MS lesions, are detectable due to their iron-rich activated microglia, continuous myelin degradation, and persistent inflammation. PRLs are rarely observed in MS mimics such NMOSD, Susac syndrome, or small-vessel disease (SVD) and are very specific for multiple sclerosis. The presence of at least one PRL enhances the ability to distinguish multiple sclerosis (MS) from other conditions and aids in predicting the transition from clinically isolated syndrome (CIS) to multiple sclerosis, especially when paired with the central vein sign (CVS). When it comes to identifying PRLs, QSM has proven to be more sensitive than traditional susceptibility imaging.

Optic nerve involvement: contribution to diagnosis and prognosis

When assessing multiple sclerosis (MS), optic nerve MRI (ON-MRI) is a useful supplement, especially for patients with optic neuritis. It should be read in conjunction with brain and spinal cord MRI

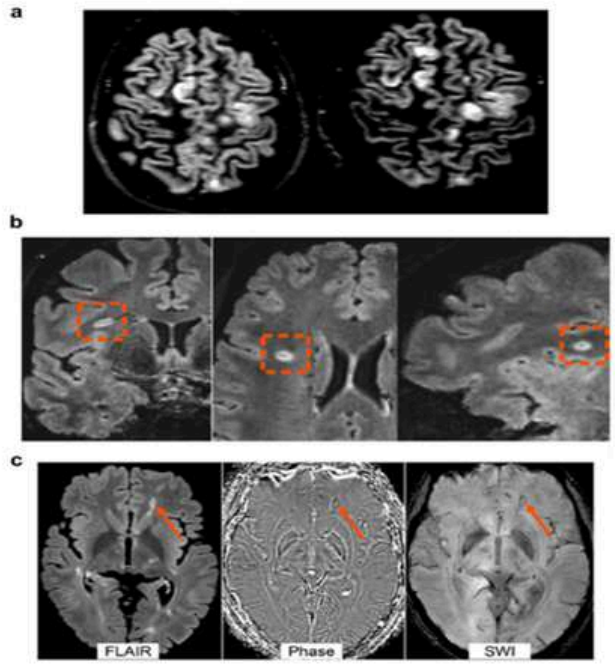

Fig2.Examples of cortical lesions, the central vein sign, and persistent active lesions .(a) A patient with multiple sclerosis has several cortical lesions on a double inversion recovery sequence at 3.0 T. (b) A white matter lesion on the post-contrast T2-FLAIR* sequence at 3.0 T that displays the central vein sign (orange dotted rectangle). (c) One of the T2-hyperintense white matter lesions evident on T2-FLAIR has a hypointense ring on the phase picture and SWI sequence at 3.0 T (orange arrow). FLAIR stands for fluid-attenuated inversion recovery, and SWI is for susceptibility-weighted imaging.

results in order to identify optic nerve lesions and help rule out alternative causes of optic neuropathy. Fat-suppressed T2-weighted/STIR and contrast-enhanced T1-weighted sequences are recommended MRI techniques, while 3D DIR imaging enhances lesion detection, particularly at 3T. Studies indicate that optic nerve assessment using ON-MRI, visual evoked potentials (VEP), or optical coherence tomography (OCT) enhances the sensitivity of the dissemination in space (DIS) criteria, especially in patients presenting with optic neuritis, even though optic nerve involvement is not included in the 2017 McDonald criteria.

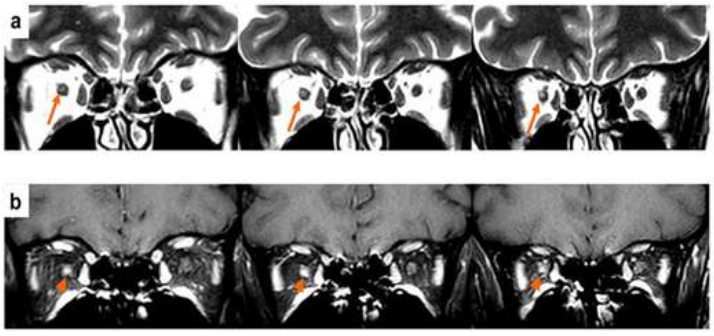

Fig 3. Optic nerve lesions in multiple sclerosis. The posterior endoribital part of the right optic nerve is enlarged and exhibits hyperintensity (orange arrows) on the coronal fat-suppressed T2-weighted sequence. On the post-contrast T1-weighted sequence, there is a focal gadolinium enhancement (orange arrowhead).

Spinal cord involvement: contribution to diagnosis and prognosis

Because cord lesions are highly specific for multiple sclerosis (MS) and offer crucial diagnostic and prognostic information, spinal cord MRI is crucial. Specialized MRI approaches enhance lesion detection despite the technical difficulties of spinal cord

imaging. The diagnosis of dispersal in space (DIS) is aided by MS lesions, which usually affect the peripheral white matter. Relapse risk, disability progression, secondary progressive multiple sclerosis (SPMS), and cord atrophy, especially gray matter atrophy, are all linked to many or new spinal cord lesions. However, routine spinal cord MRI is not advised for tracking treatment response due to technical constraints and reduced sensitivity for identifying new lesions; brain MRI is still the recommended follow-up imaging modality.

Special situations: PPMS, age extremes and RIS

MS can be diagnosed in certain uncommon situations, with their own challenges, which merit discussion.

PPMS

Ten to fifteen percent of MS cases have primary progressive multiple sclerosis (PPMS), which is defined by progressive neurological deterioration from the outset of the disease. MRI results, CSF-specific oligoclonal bands (OCBs), and spinal cord lesions are used to make the diagnosis; the 2017 McDonald criteria demonstrate comparable accuracy to the 2010 criteria. Due to its ambiguous clinical presentation and overlap with other neurological illnesses, PPMS is more challenging to diagnose than relapsing-remitting MS (RRMS). It is linked to microstructural abnormalities in the spinal cord, limited breakdown of the blood–brain barrier, and persistent neurodegeneration. Poorer outcomes are associated with factors including brainstem or spinal cord involvement, more gray matter injury, new T1-hypointense lesions, older age, female sex, and early impairment progression. The majority of individuals attain EDSS 6.0 in 8–10 years, and after reaching EDSS 4.0, disability progression resembles secondary progressive MS.

Pediatric-onset MS (POMS)

Three to five percent of MS cases are pediatric-onset multiple sclerosis (POMS), which is defined as MS that develops before the age of eighteen. The 2017 McDonald criteria can be used for diagnosis; however, due to overlap with monophasic acquired demyelinating syndromes (ADS) and myelin oligodendrocyte glycoprotein-associated disease (MOGAD), care must be taken in children under the age of eleven and those with presentations similar to acute disseminated encephalomyelitis (ADEM). Compared to adult-onset MS, POMS is primarily defined by a relapsing-remitting course with higher relapse rates and earlier accumulation of brain lesions. High-efficacy disease-modifying treatments (DMTs) successfully postpone long-term disability, even if disability usually develops at a younger age.

Late-onset MS (LOMS)

Three to five percent of MS cases are late-onset multiple sclerosis (LOMS), which develops after the age of fifty. LOMS is linked to lower MRI inflammatory activity, fewer relapses, a higher percentage of progressive disease, quicker disability progression, and a worse response to disease-modifying treatments (DMTs) than younger-onset MS. Because its clinical and MRI characteristics may match age-related diseases like small-vessel disease (SVD), diagnosis might be difficult. The 2017 McDonald criteria can be used, although cautious differential diagnosis is necessary, and more research is required to validate these criteria in LOMS.

RIS

The term "radiologically isolated syndrome" (RIS) describes the unintentional finding of MRI lesions that are strongly indicative of multiple sclerosis (MS) in people who do not exhibit the usual clinical symptoms. Approximately half of RIS patients acquire clinical MS within ten years, although the condition being uncommon. Younger age, male sex, CSF-specific oligoclonal bands (OCBs), elevated IgG index, aberrant visual evoked potentials, elevated serum neurofilament light chain levels, and infratentorial, spinal cord, or gadolinium-enhancing lesions are all linked to an increased risk of progression. In order to improve diagnosis and predict progression to multiple sclerosis, the 2017 McDonald criteria and additional risk factors like spinal cord lesions, CSF-specific OCBs, and evidence of dissemination in time (DIT) are incorporated into the most recent recommendations. The original 2009 RIS criteria were based on characteristic asymptomatic white matter lesions.

Early predictors of long-term outcome

Conventional MRI measures

The quantity, position, and activity of T2-hyperintense white matter (WM) lesions, among other conventional MRI findings, are significant indicators of the long-term prognosis in multiple sclerosis (MS). Greater disability progression and a higher chance of secondary progressive multiple sclerosis (SPMS) are linked to a higher lesion burden, especially infratentorial and spinal cord lesions. Poorer physical and cognitive outcomes are also predicted by gadolinium-enhancing lesions and early elevations in T2 lesion load. When brain and spinal cord MRI results are combined, prognosis accuracy is increased and treatment choices are guided. New lesions in both the brain and the spinal cord are more strongly linked to future disability progression than brain lesions alone, despite the fact that the burden of T2 lesions is still rising over time.

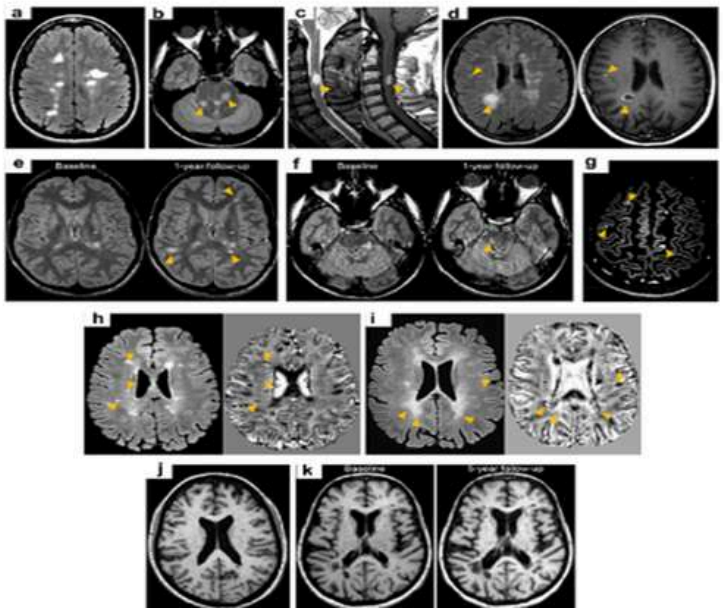

Fig4 The development of multiple sclerosis into secondary progressive multiple sclerosis (SPMS) can be predicted with the aid of early MRI findings. High volumes and numbers of T2-hyperintense lesions, infratentorial and spinal cord lesions, and gadolinium-enhancing lesions at baseline are significant predictors. Disease progression is also linked to a rise in paramagnetic rim lesions, cortical lesions, central vein sign, and T2 lesion burden. Faster brain shrinkage and early brain volume reduction are additional indicators of an increased likelihood of increasing impairment..

Advanced MRI Techniques

In multiple sclerosis (MS), advanced MRI techniques offer useful prognostic information. Increased disability progression, cognitive deterioration, and an earlier conversion to secondary progressive multiple sclerosis (SPMS) are linked to cortical lesions (CLs), paramagnetic rim lesions (PRLs), and slowly

expanding lesions (SELs). A more aggressive course of the disease is indicated by a greater number of these lesions. Long-term physical disability and cognitive impairment are also strongly predicted by early brain microstructural injury and gradual brain and spinal cord atrophy, especially gray matter atrophy. These cutting-edge MRI biomarkers can aid in therapy planning, clinical outcome prediction, and disease progression monitoring.

MRI protocol and report in MS diagnosis

To enhance the diagnosis of multiple sclerosis (MS), the 2021 MAGNIMS–CMSC–NAIMS consensus recommendations suggest uniform MRI techniques and reporting. Using 3D T2-FLAIR, axial T2-weighted, and post-gadolinium T1-weighted sequences, brain MRI should ideally be carried out on a 3.0 T scanner (1.5 T is acceptable). 3D T2-FLAIR is thought to be the primary sequence for identifying white matter lesions. Sagittal T2-weighted, proton density-weighted, or STIR sequences should be used in spinal cord MRIs; contrast-enhanced T1-weighted imaging should be used if needed. Additional details on cortical lesions, central vein sign (CVS), and chronic active lesions are provided by optional sequences such DWI, 3D T1-weighted imaging, DIR/PSIR, and susceptibility-based imaging. Experienced neuroradiologists should interpret MRI results, and standardized reports should record lesion number, size, location, gadolinium enhancement, diagnostic criteria fulfilment, and incidental observations.

Novel technologies: contribution to diagnosis and prognosis

Artificial intelligence

By automating lesion diagnosis, segmentation, and quantification, recent developments in artificial intelligence (AI) have enhanced MRI analysis in multiple sclerosis (MS). Convolutional neural networks (CNNs) and deep learning (DL) reduce manual labor by precisely measuring white matter lesions. Additionally, the central vein sign (CVS), paramagnetic rim lesions (PRLs), cortical lesions, and gadolinium-enhancing lesions can also be identified by AI. Machine learning (ML) aids in the diagnosis of multiple sclerosis (MS), differentiates it from related conditions, and forecasts the course of the illness. Early diagnosis and more precise prognosis are made possible by combining MRI with clinical data.

Automated quantification tools

The time-consuming and unreliable nature of manual MRI lesion and brain volume measurements has led to the development of automated quantification systems. These methods enable quicker assessment of lesion burden and changes in brain volume over time and enhance the precision, sensitivity, and repeatability of MRI analysis. They can aid in the diagnosis of multiple sclerosis, forecast the course of the illness, track its development, and evaluate how well a treatment is working. But further standardization and validation across many datasets are needed, and these technologies should support clinical interpretation by medical professionals rather than take its place.

Conclusions

In order to reduce misdiagnosis and discover multiple sclerosis (MS) early, accurate diagnostic criteria are crucial. Although the 2017 McDonald criteria involve thorough exclusion of other illnesses, they offer excellent sensitivity and accuracy for predicting clinically definite MS, enabling earlier diagnosis and therapy. Although validation and standardization are still required, emerging MRI biomarkers such optic nerve lesions, cortical lesions (CLs), central vein sign (CVS), and chronic active lesions may further increase diagnostic accuracy. Lesion quantity, size, distribution, and advanced imaging features are examples of MRI markers that can be used to forecast the course of a disease and identify patients who can benefit from early, highly effective treatments. Accurate diagnosis and monitoring of multiple sclerosis depend on standardized brain and spinal cord MRI techniques and professional interpretation by neuroradiologists.

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QUIZ to Recapitulate - September 2026

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

1. Which is the primary modality of choice for evaluation of small pleural effusion in Radiology?

2. Why some of pressure injectors in radiology have three syringes?

3. In radiology where we commonly use roadmap technique?

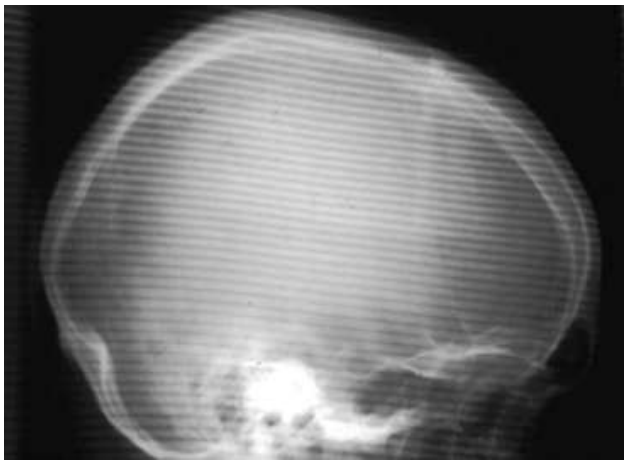
4. What is the recommended concentration of Barium Sulphate suspension for Barium Meal follow-through?

5. What is the thick slice tomography known as?

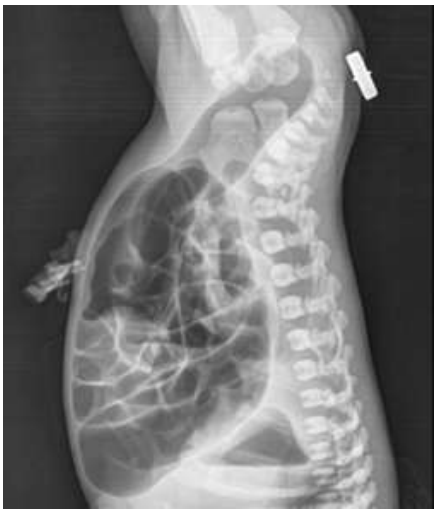
6. Which is preferred reflector material for intensifying screens in Indian context?

7. How much we shall wait for CT scan of the patient for brain tumor after injection of contrast media?

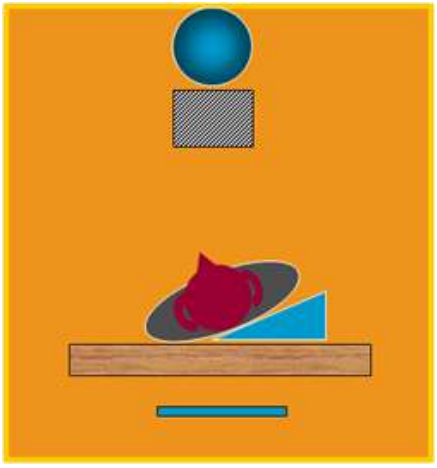
8. Describe the image artifact.



9. Name the View and Purpose.



10. Name the position



- Please send your answers through email on **pkpopli@gmail.com** on or before **30th September 2026.**
- Send your **Name with Hospital/Institution Information** and Passport size **photograph** along with the answers.
- 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 - July 2026 issue

1. CT Scan

2. To hold and deliver contrast media and saline (flush) simultaneously or sequentially.

3. Peripheral Magnetic Resonance Angiography (MRA) and Digital Subtraction Angiography (DSA) of extremities.

4. 4. 0.5% weight/volume (w/v)

5. supine cross-table lateral (dorsal decubitus) view using a horizontal X-ray beam.

6. X-ray exposure of photostimulable phosphor plate, laser scanning in a CR reader and data conversion to digital image.

7. 10-14 days

8. Bronchogram.

9. Artifacts due to dust particles on/in imaging plate (arrows)

10. Lateral Cone View of L5-S1 vertebra.

Recent Advancements in Photon Counting Detector Technology for X-Ray Imaging

Nidhi S, MRIT Student, **Bibin Joseph,** Assistant Professor, MRIT, M S Ramaiah University of Applied Sciences, Bangalore.

Introduction

X-ray imaging has been central to diagnostic radiology since Rontgen's original discovery and for most of that history the detectors capturing the transmitted beam have worked on the same basic principle. So they integrate the energy of every photon striking them over an exposure and producing a single grayscale value per pixel with no record of how many photons contributed or what energy each one carried. This energy integrating approach is efficient and well established but it discards a great deal of physical information and it gives the final image towards lower energy photons which adds disproportionately to patient dose without contributing much diagnostic value. Photon counting detectors work differently. Built from direct conversion semiconductor materials such as cadmium telluride or cadmium zinc telluride they convert each absorbed X-ray photon into a short electrical pulse whose height is roughly proportional to the photon's energy and by comparing that pulse against one or more preset thresholds. The detector sorts incoming photons into discrete energy bins as they are counted rather than averaging them away. This principle gives a detector that suppresses electronic noise which corrects the bias toward low energy photons, and produces genuinely energy resolved data rather than a single averaged signal opening the door to material specific contrast, virtual monochromatic imaging, and dose reduction within the same acquisition.

Over the past decade this technology has moved well beyond early bench top demonstrations and the recent literature reflects that shift on several fronts at once. Clinically comparative studies in full field digital mammography were among the first to establish that photon counting systems could match or exceed the diagnostic performance of conventional digital detectors and population level screening data from Germany later showed this could be achieved while lowering the mean glandular dose delivered to patients. That early clinical footing has since expanded into other modalities. photon counting detectors are now being investigated in panoramic dental radiography where spectral acquisition has been used to decompose images into separate soft tissue and dentin components and simulation based work has suggested that virtual mono energetic reconstructions could improve diagnostic yield here without raising dose further. On the hardware side recent work has focused on overcoming the practical penalties that come with shrinking pixel size particularly charge sharing and the reabsorption of characteristic X-rays near pixel boundaries both of which blur spatial resolution if uncorrected. cascaded systems models have been developed specifically to quantify and design around these effects. However one of the most interesting developments in recent times has been in the detector design whereby the new design using silicon photomultipliers coupled with scintillator arrays is being seen as an indirect option with potential for attaining fine pixel pitch and good energy resolution thereby making direct conversion semiconductors are non essential to clinical photon counting.

On the whole this shows a technology which has progressed from being a niche application for mammography to an imaging platform with wider applications in radiology while the science behind the technology as well as its practical applications are still quite scattered in the literature. In this review we bring these strands together with the aim of examining how photon counting detectors are constructed and how they differ physically from conventional detectors what performance gains and limitations recent studies have reported across mammography, dental, and general radiographic applications and what technical barriers still separate the current generation of devices from wider adoption in routine clinical practice.

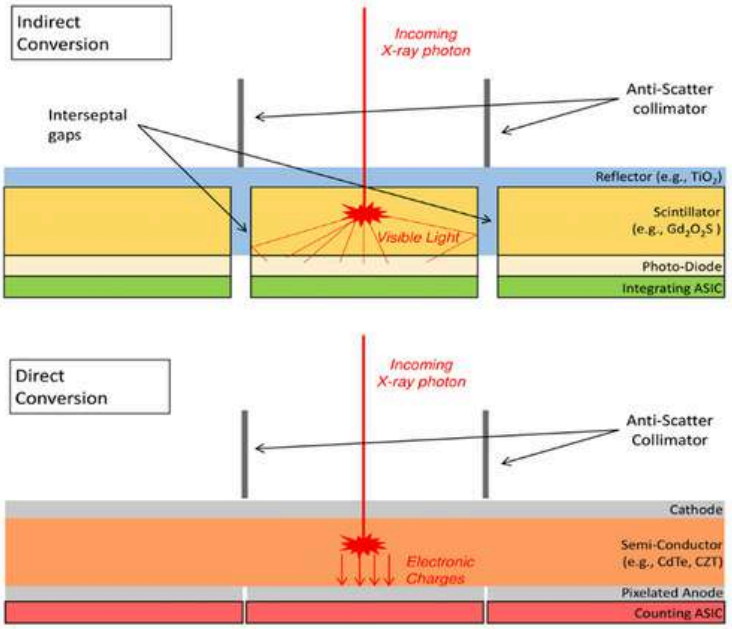


Fig – 01 Difference between direct and indirect photon conversion

Construction:

All photon counting X-ray detectors share the same fundamental principle: the absorption of an X-ray photon produces a burst of charge (or light, in case of an indirect conversion detector), which is proportional to the energy of the photon. The pulse is then processed by a chain of an electronic discriminator counter based on an application specific integrated circuit (ASIC), which counts only photons exceeding a certain threshold. What has been evolving from the papers discussed in this review between approximately 2012 and 2024 is the material of the sensor, the shape of the pixels, and the degree of correction of the electronics for the shortcomings of counting single photons in a high-density pixel matrix.

This earliest detector in the series is the edge-on crystalline silicon strip detector, employed in the Sectra Microdose systems for use in the Cole, Karellas, and Weigel mammography experiments (2012-2014). In this case, the silicon strips are aligned in such a way that the X-rays pass through them in the plane of the wafer, and not through its thickness, ensuring a long absorption distance for each strip even with the relatively low atomic number of silicon. The combination of the pre-collimation and scanning multi-slit geometry, where small detector modules scan the breast tissue, allows for the rejection of much of the scattered radiation prior to reaching the silicon and made the lower doses achieved in these studies possible.

The subsequent advancement solved an issue that couldn't be adequately addressed by the first generation. According to the 2018 cascaded systems theory developed by Tanguay et al. and

based on cadmium telluride (CdTe), it became evident why reducing the size of pixels lowers, rather than increases, resolution for detectors of direct conversion. The charge cloud generated by an absorbed photon can diffuse over the pixel boundary through Coulomb repulsion, and the characteristic X-ray fluorescence generated by the absorption process can get reabsorbed in another pixel, resulting in a split charge for a single photon into two different photons. Thus, it became clear that the anti-charge sharing circuit was needed instead of reduced pixel sizes.

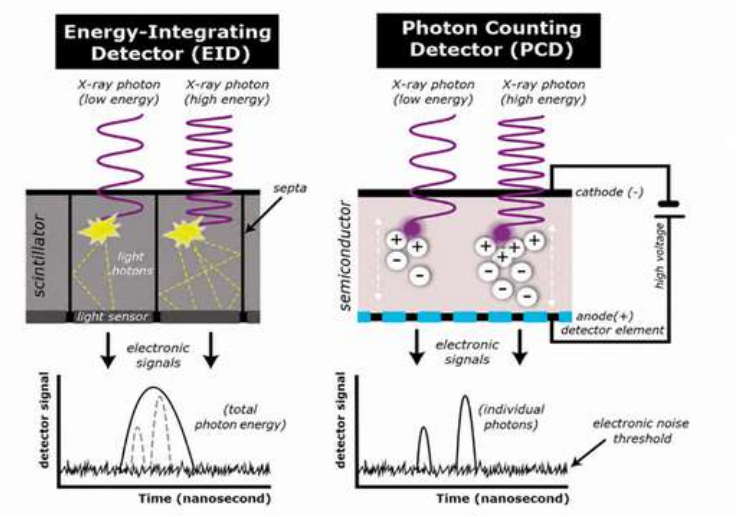


Fig – 02 Construction of EID and PCD

The next generation of detectors can be seen in the 2023 dental panoramic system developed by Somerkivi et al., which featured an off-the-shelf commercial DC-Vela CdTe detector (sensor thickness 0.75 mm) with two separate energy thresholds and integrated charge sharing correction, addressing the issue that Tanguay had modeled. This detector was mounted onto a traditional Panoramic machine, another step forward: photon counting from specialized mammography systems to generic radiographic devices.

This latest detector design by Shimazoe et al., 2024 uses an indirect approach where the silicon photomultiplier array is coupled to the scintillation crystal. This technique no longer relies on the semiconductor for the conversion process. Instead, the X-ray is converted to visible light and is then read out using a silicon photomultiplier array. The detector is made up of pixels with a 250 micrometer pixel pitch and recorded 27% energy resolution at 122 keV and 296 micrometer spatial resolution. This detector successfully inhibits charge sharing.

Results:

In all the mammography studies, photon counting technology maintained its diagnostic superiority but reduced radiation doses. According to Cole et al., a photon-counting mammography device (PCM) was non-inferior to FFDM in terms of AUC, sensitivity, and specificity in a 133 patient cancer-enriched group using the average 40% lower mean glandular dose. In the population screening data by Weigel et al. (13,312 women examined using a photon-counting mammography compared to 993,822 women using conventional systems), there was a higher cancer detection rate in subsequent screenings (0.76% compared to 0.59%, P = .05).

The detector physics issue was revealed by the cascaded systems model of charge sharing by Tanguay et al., which demonstrated that charge sharing causes an artificial increase in the recorded signal while compromising the MTF compared to energy integrating detectors; this effect depended on the energy bin. As a result, the authors concluded that an anti-charge-sharing circuit was required to restore spatial resolution, proving that the mammography advantage listed above relies on hardware correction and not automatic derivation from photon counting.

In terms of novel applications, too, outcomes have been encouraging. Somerkivi et al. were able to perform material decomposition into soft tissue and dentin images on a dental phantom while maintaining tolerable noise levels using regularization. In another reader study conducted on 17 patients undergoing head CT scans, the bone decomposed image performed the best (67.65 out of 75) compared with the traditional panoramic and virtual monoenergetic images (both around 49 out of 75). In addition, Shimazoe et al.'s scintillator-SiPM detector was capable of achieving 27% energy resolution at 122 keV and 296 μm spatial resolution.

Conclusion:

The recent improvements made to the photon-counting detector technology suggest the possibility of significant enhancement of X-ray imaging through providing energy-resolved data, reduced radiation dose, and new applications outside of image formation. As shown by the literature review, the photon-counting technology has already proved its ability to offer diagnostic results equivalent to or better than the energy-integrating detectors' ones in mammography while reducing the dose of radiation. In addition, the photon-counting detector technology has been used for the purposes of dental panoramic imaging with the help of energy discrimination and material decomposition showing promise as a diagnostic technique. On the detector level, such developments as charge-sharing correction have helped to solve such problems as those connected with small pixel sizes and the use of direct conversion CdTe detectors. Recently, an indirect approach using scintillator-based photon-counting detectors with silicon photomultipliers has appeared and can help to overcome certain difficulties of semiconductor detectors. Nevertheless, such problems as charge sharing, fluorescence reabsorption, the complexity of detector design, and the need for more clinical trials are still present. It seems that the photon-counting detector technology is developing from specialized applications such as mammography to becoming applicable for routine X-ray imaging.

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SOCIETY OF Allied Health Professionals (SOAHP)

7th NATIONAL CONFERENCE OF Society of Radiographers & Radiological Technologists (7th NCSORRT) & NATIONAL CONFERENCE OF Student Radiological Technologists

Theme
Innovations in Imaging: Transforming Diagnosis, Enhancing Care

Date: 19th & 20th September 2026
Venue: St.Peters CSI Church Campus
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Organised by
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Dear Colleagues !

We are pleased to announce and cordially invite you to the **7th National Conference of the Society of Radiographers & Radiological Technologists**, along with the **National Level Conference for Student Radiological Technologists**, scheduled to be held at **Kanyakumari on 19th & 20th September 2026.**

This conference promises to be an enriching academic gathering, featuring comprehensive scientific sessions that highlight the latest advancements and rapid innovations in the field of Radiology and Medical Imaging. It will serve as an excellent platform for knowledge exchange, professional development, and collaborative learning among experts, practitioners, and students.

Set in the breathtaking landscape of Kanyakumari—the southernmost tip of India, where the Arabian Sea, the Bay of Bengal, and the Indian Ocean converge—this event offers not only academic excellence but also a unique opportunity to experience nature's splendor. The serene coastline, picturesque hills, and the mesmerizing sunrise and sunset will surely make your visit both memorable and inspiring.

We eagerly anticipate your participation in this prestigious event, where we can come together to share insights, enhance skills, and strengthen professional bonds.

We look forward to welcoming you to Kanyakumari.

With warm regards and best wishes.

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Clinical Applications of Diffusion Tensor Imaging

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Abstract
White matter structure can be examined using diffusion-tensor imaging (DTI), a non-invasive medical imaging technique. Differences in the Brownian motion of the water molecules in brain tissue produce the signal contrast in DTI. There is a great deal of interest in DTI in clinical research because postprocessed DTI scalars can be used to assess changes in the brain tissue brought on by disease, disease progression, and therapy responses. As a relatively novel neuroimaging technique, this review paper sheds light on DTI scalars and its biological foundation. Additionally, it provides an overview of the clinical role of DTI in a number of disease processes, including depression, multiple sclerosis, Parkinson's disease, Alzheimer's dementia, epilepsy, ischemic stroke, stroke with motor or language impairment, traumatic brain injury, and spinal cord injury. Additionally, useful DTI postprocessing methods for clinical research are shown.

Key words: Diffusion tensor imaging, diffusion tensor imaging scalar, postprocessing neurological disorder.

Introduction

By monitoring the mobility of water molecules in tissue, diffusion-tensor imaging (DTI), a relatively recent magnetic resonance imaging (MRI) technology, has mostly been utilized to assess microstructural alterations in the brain. The capacity to identify the orientation and diffusion properties of white matter is the foundation of its imaging capabilities.

It is now feasible to identify pathology-specific features, such as microstructural alterations in the axons and myelin of the brain's white matter, because to recent improvements in DTI resolution. Tracking neural fiber routes in the central nervous system is currently the primary focus of DTI research.

The semiquantitative character of DTI data analysis continues to be a major restriction, despite the fact that DTI has been widely used to a variety of clinical problems.To get more precise quantitative findings, the measurement procedure and picture data processing must be standardized. Clinical treatments and putative alterations in different neural tracts linked to brain damage can now be seen possible by advanced DTI techniques.

Additionally, we provide an overview of the clinical role of DTI in a number of disease processes, such as depression, traumatic brain injury (TBI), multiple sclerosis (MS), Parkinson's disease (PD), Alzheimer's dementia, epilepsy, ischemic stroke, stroke with motor or language impairment, and amyotrophic lateral sclerosis (ALS).

Basic concepts of DTI

A sophisticated MRI method called Diffusion Tensor Imaging (DTI) measures the amount and direction of water diffusion to determine the microstructural integrity of white matter. Fractional anisotropy (FA), axial diffusivity (AD), radial diffusivity (RD), mean diffusivity (MD), and mode of anisotropy (MO) are the main diffusion metrics obtained from DTI. The most widely used DTI parameter, fractional anisotropy (FA), quantifies the extent of directional water diffusion in tissue. FA values are a sensitive indicator of white matter and axonal integrity, ranging from 0 (isotropic diffusion) to 1 (very anisotropic diffusion). The three eigenvalues of the diffusion tensor are λ_1, λ_2, and λ_3. Axial diffusivity (AD, λ_1) is related to axonal integrity and represents diffusion along the major axis of the axon. Radial diffusivity (RD, average of λ_2 and λ_3) represents diffusion perpendicular to the axon and is considered a sign of myelin integrity, with greater RD indicating demyelination. The total amount of water diffusion is represented by mean diffusivity (MD), which is the average of the three eigenvalues and is sensitive to alterations like edema, necrosis, and cellularity. Mode of anisotropy (MO) characterizes the shape of the diffusion tensor and is particularly useful for assessing regions with crossing white matter fibers. FA is not specific to the underlying disease process, despite being extremely sensitive to microstructural defects. As a result, evaluating FA, AD, RD, MD, and MO together offers a more thorough assessment of white matter architecture and enhances the identification and description of neurological diseases. Furthermore, malignancies, cytotoxic edema, bleeding, and inflammatory cell infiltration frequently have lower apparent diffusion coefficient (ADC) values, while vasogenic edema is usually linked to higher ADC.

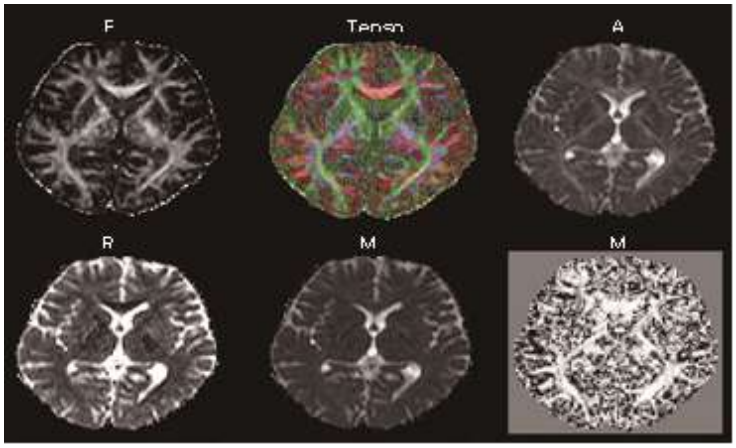

Figure 1. Representative DTI-derived scalar maps illustrating the principal diffusion metrics used in clinical neuroimaging: Fractional Anisotropy (FA), tensor orientation map, Apparent Diffusion Coefficient (ADC), Radial Diffusivity (RD), Mean Diffusivity (MD), and Axial Diffusivity (AD).

DTI Post processing Tools

Diffusion Tensor Imaging (DTI) data can be post-processed and analyzed using a variety of software programs. Tensor reconstruction, fiber tracking, connectometry, and excellent two-dimensional (2D) and three-dimensional (3D) visualization are all offered by DSI Studio. Advanced reconstruction techniques like Q-ball imaging, generalized q-sampling imaging (GQI), diffusion spectrum imaging (DSI), and deterministic fiber tracking are supported.

By computing diffusion metrics such as fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), radial diffusivity (RD), and mode of anisotropy (MO), the Tract-Based Spatial Statistics (TBSS) toolbox within the Functional MRI of the Brain Software Library (FSL) allows voxel-wise analysis of diffusion data. By using voxel-based statistical testing, skeletonization, and image registration, TBSS increases the precision of white matter analysis.

A FreeSurfer program called TRACULA (Tracts Constrained by Underlying Anatomy) uses anatomical data from T1-weighted MRI to automate probabilistic tractography, reconstructing main white matter pathways and measuring diffusion parameters (FA, AD,RD,MD).

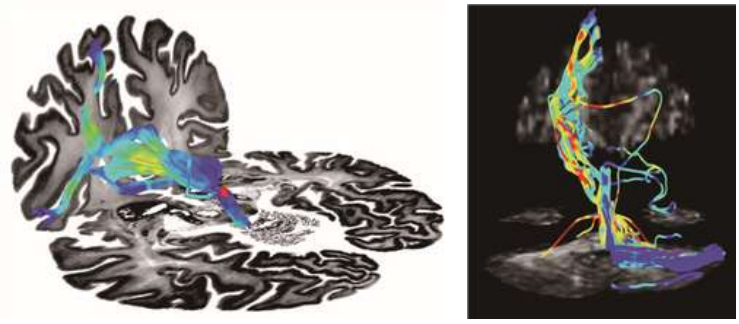

Figure 2. Diffusion tensor tractography (DTT) reconstructed from DTI data, showing color-coded white matter fiber bundles. The images demonstrate the spatial organization and connectivity of major cerebral white matter pathways.

Clinical Applications of DTI

A promising method for assessing white matter deterioration in amyotrophic lateral sclerosis (ALS) is diffusion tensor imaging (DTI). Reduced fractional anisotropy (FA) indicates disruption of white matter integrity and supports the multisystem character of ALS, especially in the corticospinal tract (CST), frontal white matter, cingulate gyrus, internal capsule, brainstem, and hippocampus areas. Although FA is thought to be the most trustworthy DTI biomarker, research has also assessed axial diffusivity (AD), radial diffusivity (RD), and mean diffusivity (MD), with conflicting results about their diagnostic use. While AD and MD may show the course of the disease in certain cases, changes in RD may suggest myelin loss. Even though DTI has a lot of promise for evaluating ALS-related neurodegeneration, more extensive research is needed to confirm its therapeutic value and develop trustworthy imaging biomarkers for diagnosis and disease tracking.

Multiple Sclerosis

A sensitive method for identifying microstructural white matter alterations in multiple sclerosis (MS) is diffusion tensor imaging (DTI). Increased mean diffusivity (MD) and decreased fractional anisotropy (FA) are signs of disease activity and structural damage. Axial diffusivity (AD) indicates axonal degeneration and Wallerian degeneration, whereas radial diffusivity (RD) is closely linked to demyelination and remyelination. DTI is more sensitive than traditional MRI because it may identify anomalies in both white matter that seems normal and apparent MS lesions. Reduced FA, elevated MD, and decreased AD values are linked to optic nerve damage in optic neuritis and may indicate clinical consequences. The evaluation of brain fiber connection has been enhanced by advanced DTI tractography, which also has a strong correlation with MRI lesion burden and clinical impairment.

Parkinson's Disease

DTI is not utilized for routine diagnosis in Parkinson's disease (PD), but rather to assess changes in brain connections linked to motor, cognitive, and behavioral symptoms. Research has shown that executive dysfunction, attention deficiencies, language difficulty, and memory problems are all correlated with anomalies in diffusion parameters.

Alzheimer`s Disease

DTI has demonstrated potential in identifying early white matter degradation in Alzheimer's disease (AD) prior to the development of overt clinical symptoms. As the disease progresses, longitudinal investigations have shown gradual decreases in FA and increases in MD. Additionally, microstructural white matter damage has been linked to higher Tau protein levels in cerebrospinal fluid, indicating that DTI may detect ongoing axonal injury at the preclinical stage.

Epilepsy

A useful method for assessing white matter anomalies in patients with temporal lobe epilepsy, especially those with refractory epilepsy, is diffusion tensor imaging (DTI).Research has shown that sclerotic hippocampus areas had higher mean diffusivity (MD) and lower fractional anisotropy (FA), which are indicative of structural disarray.According to meta-analyses, patients with unilateral hippocampal sclerosis had considerably reduced FA and greater MD in their white matter when compared to healthy controls. The hemisphere with the epileptogenic center showed the most noticeable alterations.

Stroke

By evaluating white matter integrity and forecasting functional consequences, diffusion tensor imaging (DTI) is crucial in the assessment of ischemic stroke. While apparent diffusion coefficient (ADC) values stay high, fractional anisotropy (FA) usually rises during the acute phase but gradually declines in the chronic phase as a result of white matter degeneration. The evaluation of stroke severity and long-term prognosis is improved when FA and ADC are coupled. Additionally, DTI distinguishes between ischemic leukoaraiosis and cerebral infarction by identifying specific microstructural alterations. Additionally, DTI makes it possible to see the corticospinal tract (CST), which makes it possible to evaluate its integrity and forecast motor recovery. While improved functional recovery and ambulation are predicted by intact CST integrity, lower FA levels are linked to worse motor outcomes.

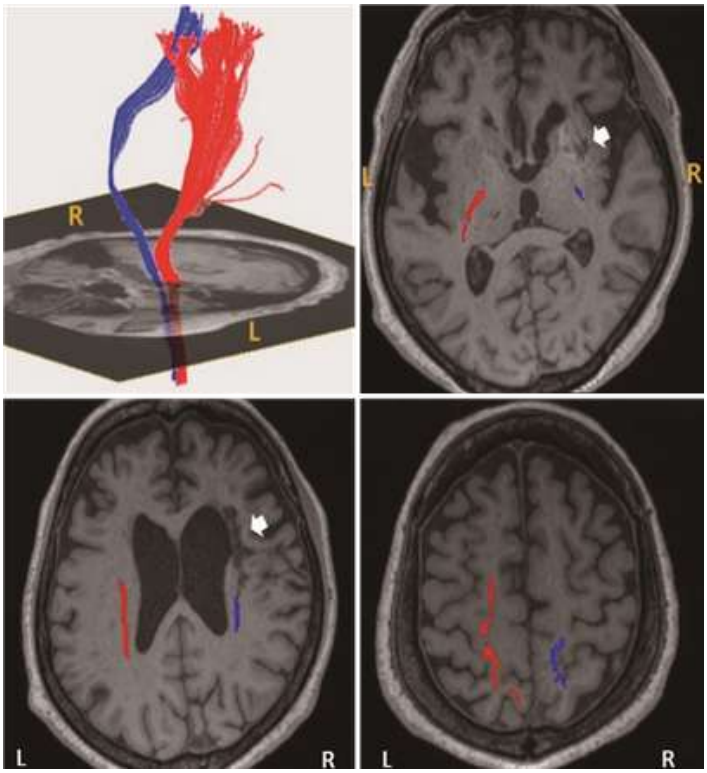

Figure 3. Three-dimensional diffusion tensor tractography (DTT) showing the corticospinal tracts reconstructed from diffusion tensor imaging (DTI). The tractography images are co-registered with T1-weighted MRI to demonstrate the anatomical relationship between white matter pathways and an intracranial lesion (white arrow).

Mild Traumatic Injury

In patients with moderate traumatic brain injury (TBI), diffusion tensor imaging (DTI) is a sensitive imaging method for identifying microscopic traumatic axonal injury that is frequently overlooked on traditional MRI. It permits the diagnosis of minor white matter anomalies in sensitive regions such as the corpus callosum, anterior corona radiata, uncinate fasciculus, and superior longitudinal fasciculus. Additionally, DTI offers important insights into abnormal anatomical connections between and within the brain hemispheres, especially with regard to the prefrontal cortex. Impairments in executive function, attention, and memory have been closely linked to reduced fractional anisotropy (FA) in certain white matter tracts.

Major Dispressive Disorder

A useful technique for examining white matter microstructural abnormalities linked to Major Depressive Disorder (MDD) is Diffusion Tensor Imaging (DTI). Reduced fractional anisotropy (FA) in important white matter pathways, such as the corpus callosum, cingulum, uncinate fasciculus, superior longitudinal fasciculus, internal capsule, and anterior thalamic radiation, has been documented in a number of investigations. These tracts are implicated in reward circuits, affective regulation, and cognitive processing, suggesting that impaired neuronal connection plays a role in the pathogenesis of MDD. Widespread decreases in FA among MDD patients have been repeatedly verified by meta-analyses. Additionally, longer illness duration and higher disease severity have been linked to lower FA values, indicating that DTI-derived metrics may be useful imaging biomarkers for evaluating clinical severity, treatment response, and disease progression in MDD.

Conclusion

DTI is a new neuroimaging technique that can detect microstructural alterations. A number of DTI scalars, including FA, AD, RD, MD, and MO, can be connected with clinical data to identify anomalies linked to neurological conditions.

Sophisticated clinical research needs proper DTI postprocessing technologies in addition to the right DTI scalars. Novel anatomical and structural route knowledge about the brain has been produced by sophisticated resilient postprocessing approaches. The use of DTI in clinical research and even as a diagnostic tool will be ensured by advancements in DTI acquisition techniques, such as shorter scanning times (to lessen the effects of head motion), high spatial and gradient-direction resolutions, higher signal-to-noise ratios, and standardization of postprocessing techniques.

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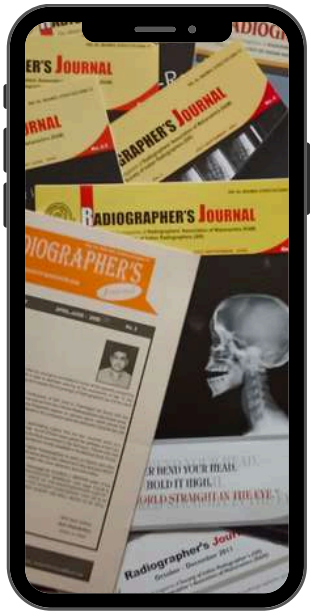

Radiomics and Artificial Intelligence: Biomarkers for Quantitative Imaging

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Abstract

In order to offer objective information regarding tissue properties, lesion heterogeneity, and disease biology, radiomics is an emerging quantitative imaging approach that extracts high-dimensional features from standard medical pictures. In contrast to traditional qualitative image interpretation, radiomics assesses quantifiable characteristics that might not be immediately apparent to the human eye, such as intensity, form, texture, and higher-order patterns. The radiomics workflow has been improved by the incorporation of Artificial Intelligence (AI), namely Machine Learning (ML) and Deep Learning (DL), which support picture normalization, noise reduction, segmentation, feature extraction, feature selection, and predictive model creation. Quantitative imaging biomarkers with potential uses in early illness detection, diagnosis, prognosis, treatment-response evaluation, risk stratification, and personalized healthcare are made possible by AI-driven radiomics. These methods have shown promise in the fields of neurology, cardiology, cancer, lung, liver, and musculoskeletal imaging. Clinician confidence and model transparency can be further enhanced by explainable AI techniques like SHAP and LIME.Nevertheless, there are still significant issues with image acquisition variability, scanner variations, segmentation techniques, small datasets, overfitting, and lack of standardization. Clinical translation could be strengthened by upcoming advancements in radiogenomics, federated learning, multimodal AI, foundation models, and massive language models. Therefore, generating trustworthy quantitative imaging biomarkers and improving precision medicine can be achieved using AI-integrated radiomics.

1. Introduction

Medical imaging has improved significantly over the last century, from traditional X-ray imaging to highly advanced modalities including computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and hybrid imaging systems. Technological advancements have greatly enhanced disease detection, diagnosis, therapy planning, and patient monitoring. (1), (2). Historically, radiologists depended on qualitative visual examination of medical images. However, qualitative interpretation is generally subjective and may miss minor imaging signals linked with underlying tissue heterogeneity and disease biology. (3). As a result, there is a rising demand for quantitative imaging methods that give objective, reproducible, and measurable information (4).

Radiomics has developed as a viable quantitative imaging technology for obtaining a large number of high-dimensional characteristics from regular medical images. These quantitative imaging indicators characterise lesion intensity, shape, texture, and geographic heterogeneity, giving information that is not visible to the human eye (5) (2). Radiomics, which converts medical images into readable data, allows for a more thorough study of disease features (3).

Artificial intelligence (AI), namely machine learning (ML) and deep learning (DL), has improved radiomics by automating image preprocessing, lesion segmentation, feature extraction, feature selection, and prediction model creation (4). The combination of AI with radiomics enhances accuracy, repeatability, and efficiency while allowing for the analysis of complicated imaging datasets (6). AI-driven radiomics contributes to precision medicine by enabling early diagnosis, risk stratification, prognosis prediction, treatment response evaluation, and guided therapeutic decision-making (3).

List of Abbreviation

AI-vArtificial Intelligence
ML-vMachine Learning
DL- Deep Learning
ROI- Region of Interest
VOI- Volume of Interest
CT- Computed Tomography
MRI- Magnetic Resonance Imaging
PET- Positron Emission Tomography
CNN- Convolutional Neural Network
U-Net- U-shaped Convolutional Neural Network
V-Net- Volumetric Neural Network
SVM- Support Vector Machine
XGBoost - Extreme Gradient Boosting
LASSO- Least Absolute Shrinkage and Selection Operator
RFE- Recursive Feature Elimination
SHAP- SHapley Additive exPlanations
LIME- Local Interpretable Model-agnostic Explanations
XAI- Explainable Artificial Intelligence
LLM- Large Language Model
CT/MRI- Computed Tomography / Magnetic Resonance Imaging
ML/DL- Machine Learning / Deep Learning
GLCM- Gray-Level Co-occurrence Matrix
GLRLM - Gray-Level Run Length Matrix
GLSZM - Gray-Level Size Zone Matrix
GLDM - Gray-Level Dependence Matrix
NGTDM - Neighborhood Gray-Tone Difference Matrix
ILD- Interstitial Lung Disease
HCC - Hepatocellular Carcinoma

2. Fundamentals of Radiomics

2.1 Definition of Radiomics

Radiomics is a quantitative imaging technique that extracts multiple quantitative aspects from regions or volumes of interest (ROIs/VOIs), transforming medical pictures into high-dimensional data (Majumder et al., 2024; Volpe et al., 2023). These properties objectively define image intensity, shape, texture, and tissue heterogeneity, exposing information that cannot be seen (3), (4). The resultant imaging phenotype is used as a non-invasive biomarker for illness diagnosis, prognosis, and therapy response prediction. Precision medicine and personalised healthcare are supported by the integration of radiomics with AI, machine learning (ML), and clinical or genetic data (4), (1).

2.2 AI driven Radiomics Workflow

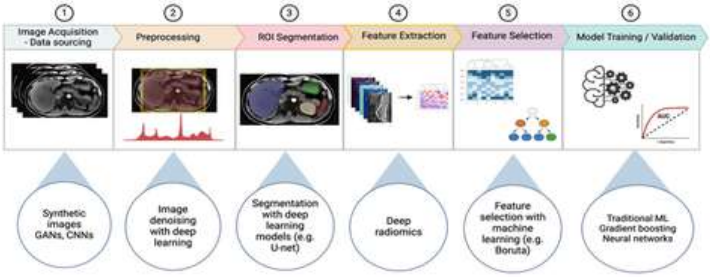

Figure 1: AI supports every step of the radiomics pipeline, from image acquisition to model validation. (4)

2.3 Types of Radiomic Features

2.3.1 First-order Features:

First-order features explain the distribution of voxel intensity values inside the ROI without taking into account spatial connections. They comprise statistical metrics like as mean, median, minimum, maximum, variance, skewness, kurtosis, entropy, and energy, which describe the overall intensity properties of tissues (2), (3).

2.3.2 Shape Features:

Shape characteristics describe the geometric qualities of a lesion or anatomical structure. Volume, surface area, compactness, sphericity, elongation, maximum diameter, and irregularity are some of the parameters used to distinguish between benign and malignant tumours (2), (4)

2.3.3 Texture Features:

Texture characteristics assess the spatial order and relationships between neighbouring pixel or voxel intensities. They use matrices like GLCM, GLRLM, GLSZM, NGTDM, and GLDM to assess tissue heterogeneity, which provides useful information regarding tumour complexity and biological behaviour (2), (6), (3).

2.3.4 Higher-order Features:

Higher-order features are created by using mathematical filters or image transformations such as wavelet, Laplacian of Gaussian, Gabor filters, or Fourier transforms. These approaches bring out subtle image patterns and enhance hidden tissue properties that are not obvious in the original images (4), (4)(6).

2.3.5 Deep Features:

Deep learning models, particularly convolutional neural networks (CNNs), learn deep features from medical images automatically, eliminating the need for manual feature engineering. They record complicated and hierarchical imaging patterns, which frequently aid in disease categorisation, segmentation, prognosis, and predictive modelling (4), (6).

3. Artificial Intelligence in Radiomics

3.1 Artificial Intelligence:

Artificial Intelligence (AI) allows computers to accomplish activities that would ordinarily need human intelligence. Machine Learning (ML) is a subset of AI that learns patterns from data, whereas Deep Learning (DL) employs deep neural networks to learn complicated characteristics from big datasets, particularly medical images.

Difference between AI, Machine Learning, and Deep Learning (1), (2)

Feature	Artificial Intelligence (AI)	Machine Learning (ML)	Deep Learning (DL)
Definition	Mimics human intelligence	Learns from data	Learns using deep neural
Feature Extraction	Rule- Based or ML- based	Handcrafted Features	Automatic feature learning
Data Requirement	Low to moderate	Moderate	Large dataset
Common Algorithms	Expert syatem	SVM, Random Forest	CNN, U-Net, Vision
Radiomics Application	Decision Support	Feature Selection &	Automated Segmentation,

3.2 AI in Image Acquisition

3.2.1. Image standardization:

AI increases image standardisation by eliminating the variances produced by various scanners, imaging methods, and acquisition settings. This maintains constant image quality and increases the repeatability of radiomic characteristics across various imaging datasets (2), (4).

3.2.2. Noise reduction:

AI-powered denoising methods eliminate undesired image noise while keeping key anatomical information. Improved images improve radiomic feature extraction accuracy while also reducing quantitative image analysis mistakes (6), (4).

3.2.3. Harmonization:

AI aids in image harmonization by reducing disparities between images obtained from various scanners and organisations. Harmonised datasets enhance multicenter research, boost model dependability, and aid in the discovery of strong quantitative imaging biomarkers (3), (2).

3.3 AI in Segmentation

3.3.1 Manual Segmentation:

Manual segmentation entails an expert delineation of the area of interest (ROI). It is accurate, but time-consuming and subject to observer fluctuation (2), (3).

3.3.2 Semi-automatic Segmentation

Semi-automatic segmentation blends user supervision with AI algorithms to increase efficiency, uniformity, and repeatability while decreasing manual effort (2).

3.3.3. Automatic Segmentation

Automatic segmentation use artificial intelligence to detect and delineate anatomical features without requiring human interaction, allowing for rapid, accurate, and reproducible image analysis (1), (4).

3.3.4. Convolutional Neural Network (CNN)

CNN is a deep learning model that learns image characteristics for effective segmentation, classification, and disease detection in medical imaging (6), (4).

3.3.5. U-Net

U-Net is a CNN-based architecture built for biomedical image segmentation, capable of precise localisation and accurate segmentation even with minimal annotated datasets (4), (6).

3.3.6 V-Net

V-Net is a deep learning architecture designed for three-dimensional medical image segmentation that provides reliable analysis of volumetric CT and MRI data. (4), (6)

3.4 AI in Feature Extraction

Handcrafted Features vs Deep Features (4), (6)

Feature	Handcrafted Feature	Deep Features
Feature Generation	Manually extracted using predefined mathematical algorithms.	Automatically learned by deep learning models from images
Human Involvement	Requires manual feature selection and engineering	Minimal human intervention is required.
Complexity	Captures basic intensity, shape, and texture information	Learns complex, hierarchical imaging patterns.
Data Requirement	Perform well with relatively smaller datasets	Requires large annotated datasets for optimal performance.
Clinical Application	Used for Diagnosis, Prognosis, and radiomics based prediction	Used for automated detection, segmentation, classification, and prediction medicine

3.5 Feature Selection:

Feature selection is an important stage in radiomics because it finds the most significant characteristics while deleting duplicated data, hence boosting model performance and decreasing overfitting. LASSO chooses significant variables by reducing insignificant coefficients. Boruta uses the Random Forest method to identify all essential characteristics. Random Forest ranks features according to their relevance, whereas Recursive Feature Elimination (RFE) progressively removes less important characteristics to get the best feature subset (4), (2), (6).

3.6 Model Development

Model creation in AI-driven radiomics include training algorithms to identify illnesses, forecast outcomes, and aid clinical decision-making. Support Vector Machine (SVM) is good for high-dimensional radiomic data, but Random Forest enhances prediction by combining many decision trees. XGBoost improves accuracy through gradient boosting and efficient feature optimisation. Deep learning methods, such as Convolutional Neural Networks (CNNs), automatically learn complicated imaging characteristics, whereas Transformers capture long-range correlations in medical images, allowing for enhanced image analysis and increased prediction accuracy. (4), (6), (1).

3.7 Explainable AI

Explainable Artificial Intelligence (XAI) increases the transparency and interpretability of AI models in radiomics. SHAP (Shapley Additive Explanations) quantifies each feature's contribution to model predictions, whereas LIME (Local Interpretable Model-agnostic Explanations) explains individual predictions by approximating complicated models locally. These strategies improve model transparency, which increases clinician trust, dependability, and AI adoption in medical imaging (6), (4), (3).

4. Quantitative Imaging Biomarkers

Definition: Quantitative imaging biomarkers are quantifiable imaging properties derived from medical images that objectively describe tissue structure, function, and disease biology (3), (2).

Characteristics: These biomarkers are non-invasive, quantifiable, repeatable, and can represent tissue heterogeneity, making them useful for disease detection and monitoring (3).

Importance: Quantitative imaging biomarkers help in early diagnosis, prognosis, treatment planning, and personalised medicine by providing objective clinical information that goes beyond visual image interpretation (1), (2).

Clinical Applications

Oncology

Tumour characterisation, prognosis, survival prediction, therapy response evaluation, and radiogenomics are all applications (4), (3).

Neurology: Alzheimer's disease, brain tumour characterisation, and stroke diagnosis have all been used to enhance illness detection and prediction (3), (1).

Cardiology: Assists in determining myocardial fibrosis and coronary plaque analysis for better cardiovascular risk assessment. (4).

Lung Diseases: Assesses COVID-19 severity, evaluates interstitial lung disease (ILD), and characterises pulmonary nodules (2), (3).

Liver Diseases: Used to predict hepatocellular carcinoma (HCC), measure liver fibrosis, and quantify hepatic fat (4), (2).

Musculoskeletal Imaging: Assesses osteoporosis and characterises bone tumours to aid in proper diagnosis and therapy planning (2), (3)

Table: Clinical Applications of Quantitative Imaging Biomarkers

Imaging Modelity	Biomarker Type	AI method	Clinical application
CT/MRI	Tumor heterogeneity	ML/DL	Oncology
MRI	Brain texture	CNN	Alzheimer’s disease, Brain tumors, Stroke
CT/MRI	Myocardial tissue	ML	Myocardial fibrosis, coronary plaque
CT	Lung texture	CNN	Covid-19, ILD, Pulmonary nodules
CT/MRI	Liver texture	ML/DL	HCC Prediction, Fibrosis, Fat quantification
X- ray/CT/MRI	Bone texture	CNN	Osteoporosis, Bone tumors

5. Challenges

- Image acquisition variability caused by different imaging techniques may have an impact on radiomic feature consistency (2)
- Scanner heterogeneity across manufacturers and imaging systems can impair the repeatability of AI-radiomics models (3).
- Variability in segmentation due to various observers or methods might have an impact on feature extraction and model performance (4).
- Small datasets restrict model training, weaken robustness, and raise the possibility of biased predictions. (2).
- Overfitting is when a model performs well on training data but poorly on independent datasets (4).

6. Future Directions

- Foundation models will increase radiomics' accuracy and efficiency across a wide range of imaging activities (4).
- Large Language Models (LLMs) will enable automated reporting and clinical decision-making.
- Federated learning allows for secure AI model building across several centers while maintaining patient privacy (3).
- Multimodal AI will combine imaging, clinical, and genetic data to provide a thorough illness evaluation. (2), (4).
- Radiogenomics will connect imaging biomarkers to genetic data for precision oncology (3).

Conclusion

Radiomics has developed as a potent quantitative imaging technique for identifying hidden imaging biomarkers to aid in disease characterisation and clinical decision-making. The incorporation of Artificial Intelligence (AI) enhances the whole radiomics process, including images capture, segmentation, feature extraction, feature selection, and predictive modeling (4), (2). AI-driven radiomics has demonstrated substantial promise in illness diagnosis, prognosis, therapy response evaluation, and precision medicine across a variety of clinical specialisations (3), (1). Despite challenges such as standardization, reproducibility, and clinical validation, ongoing advancements in AI technologies are expected to accelerate the development of dependable quantitative imaging biomarkers and support the future of personalized healthcare (6), (4).

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3D produced patient-specific blocks based on computed CT for complete knee replacement

Faisal Ahmed Khan, Niyati Aswal, Ajay Gurjar, Msc Research Fellows,
Saniya Zehra, Assistant Professor, Department of Radiology, NIMS University, Jaipur

Introduction

For patients undergoing total knee replacement (TKR), patient-specific blocks (PSB) have been used as a personalized instrument choice. These can be produced using the pictures acquired from specific lower limb sequencing using either Computed Tomography (CT) scanning or Magnetic Resonance Imaging (MRI). 3D printing is used to manufacture these personalized blocks.

Production of blocks tailored to each patient through 3D printing

"Additive manufacturing" is used to create the 3D printed patient-specific jigs for TKR. Additive manufacturing is a process that uses computer-aided design to construct a model by depositing a powder layer by layer. Depending on the necessity, a variety of materials, including nylon, polymers, and metals, can be utilized to make the models. Although there are several methods for additive manufacturing, the fundamental production process is the same. In orthopaedics, additive manufacturing is utilized to create intricate anatomical models that aid in the study of pathology.

In special situations, it can also aid in the production of jigs and implants tailored to each patient.1 Improving bone development in implants (such as Stryker's Titanium implants) is another benefit of the AM method.

These implants have unique 3D architectures because of the application of AM, which has improved implant survival and longevity and demonstrated superior implant absorption into parent bone. They play a part in teaching in addition to surgical planning, patient-specific implant and jig manufacture, and increasing implant longevity. These models can aid in students' education and improve their comprehension of anatomy. Additionally, they help the patient and their family better comprehend the pathology and the scheduled surgery through education and counseling.

In the production process, photos are taken, formatted appropriately, and fed into a computer. A CAD (computer-aided design) is produced utilizing this.

After this CAD is further transformed into a suitable format that the printer can read, the model is eventually produced. In the example of Stryker's CT-based patient-specific jigs (PreplanTM), the component was created using CAD and the images were obtained as CT scans, which were then translated to DICOM (Digital Imaging and Communications in Medicine).

The 3D printer used additive manufacturing to create the jigs once the design was transformed into an STL file.

The biocompatible materials used to make the jigs had particular qualities.

These jigs do not abrade when they come into touch with bone saws . Additionally, the material can be utilized during the procedure because it is compatible with autoclaving. These jigs are "negatives" of the anterior proximal tibial and anterior distal femoral anatomy, and they lie comfortably on the surface at a certain distance from the articular surface as determined by the surgeon. The traditional distal femoral and proximal tibial jigs, which are used to make the final cuts, are then pinned using these.

TKR's patient-specific blocks have been examined for a number of clinical factors. The advantages and disadvantages of these blocks for these indications will be covered here:

Prediction of the femoral valgus angle

One important indicator of a total knee replacement's (TKR) long-term survival is the mechanical axis restoration. The femoral valgus angle (FVA), which varies from patient to patient, requires the distal femoral cut because the mechanical and anatomical axes on the femoral side do not align. Traditionally, the femoral valgus angle has been fixed for everyone when making cuts. However, changes in the neck-shaft angle, femoral bowing, and other aspects of femoral anatomy may exist.

Theoretically, the femoral valgus angle and the femoral offset are positively correlated. Males typically have larger femoral valgus angles due to their greater hip offset. Changes in the femoral valgus angles would also have an impact on the total mechanical axis.

Predicting the overall mechanical and anatomical axis of the limb can be aided by the femoral and tibial jigs' CT-based 3D printing .

Prediction of component size in TKR

By anticipating the size of the femur and tibia's components, preoperative templating can reduce the amount of equipment and trial trays used in the operating room (OR).

Preoperative templating can assist the surgeon in determining whether any atypical femoral or tibial component sizes are required in a low volume replacement setup. The expenses related to transporting and storing sizes that are significantly different from the anticipated sizes might be reduced with an understanding of the anticipated sizes. For the knee to regain proper biomechanics, the right size insertion is also essential. A

shift in the femoral component influences the flexion gap in the knee.

Both an undersized and a large component have negative consequences. While a smaller component might rest on only cancellous bone and increase stress over a tiny bone-cement contact, an enormous component might cause soft tissue impingement.

Utilizing patient-specific blocks in TKR while keeping hardware

The replacement surgeon faces particular challenges when dealing with retained hardware in an osteoarthritic knee. Retained hardware and callus-induced canal sclerosis can both impede the medullary canal. An extra-articular deformity could be present.. In some situations, it can make it impossible to employ intra-medullary rods for alignment. Hardware removal is a possibility, however there is a chance of intraoperative fracture if it is done in one session.

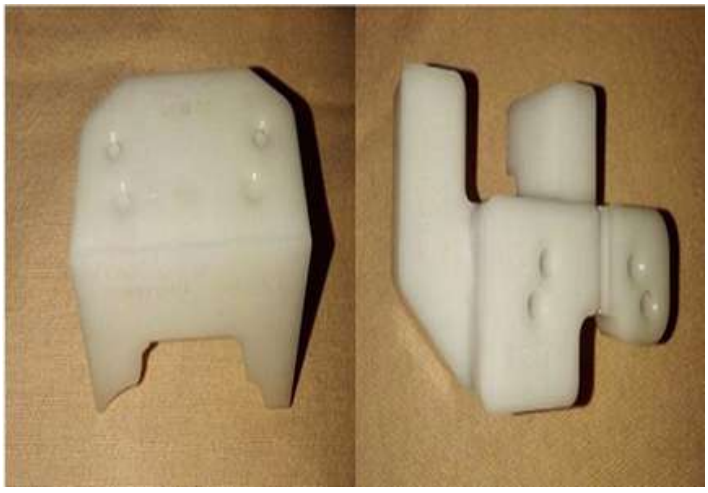

Fig 1. The 3D printed jigs used for complete knee replacement are based on computed tomography. The tibial jigs on the right side correspond to the proximal anterior tibial anatomy, while the femoral jig on the left corresponds to the anterior distal femoral anatomy

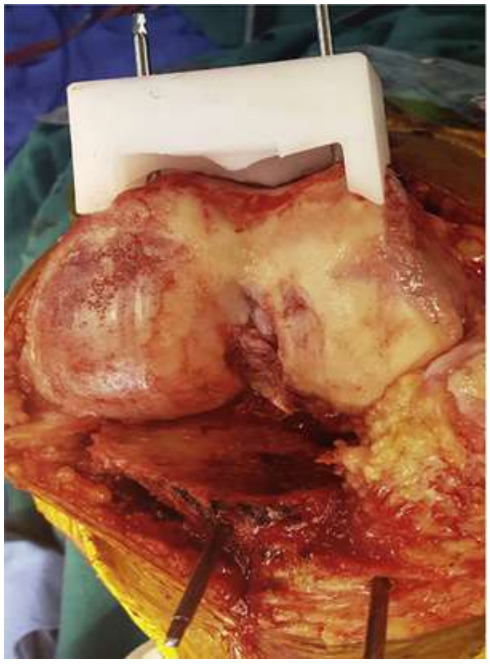

Fig 2. The femoral patient-specific jig showed how to fit snugly on the anterior femoral cortex and match the distal anterior femoral anatomy intraoperatively.

The precision of alignment with patient-specific blocks

The long-term results of total knee replacement have been demonstrated to be significantly impacted by the postoperative alignment attained. When employing the IM femoral jig, the patient's femoral valgus angle must be predicted or assumed in order to determine the lower limb's overall alignment. The EM jig's connection to the shaft, tibial tuberosity, and ankle joint all affect the tibia's alignment on the tibial side. Each of these variables may differ from surgeon to surgeon and lead to the existence of "outliers."

Lower limb alignment can be improved with the use of patient-specific 3D printed jigs that match the proximal tibial and anterior femoral anatomy. Using the virtual incisions created on the 3D reconstruction of the lower limb anatomy, the surgeon may forecast the postoperative limb alignment. Planning the proximal tibial and distal femoral cuts can be aided by it.

For complicated primary total knee replacement, 3D printed patient-specific jigs show promise. Long-term and mid-term outcomes are anticipated, and their role in routine TKR is currently being refined. This technology has potential for the future as information and follow-ups increase. Furthermore, this method has been pushed by the growing interest in 3D printing technology and its application in orthopaedics. As previously indicated, the jigs' price and waiting time have greatly decreased, and this will continue to do so as 3D printing technology becomes more widely available.

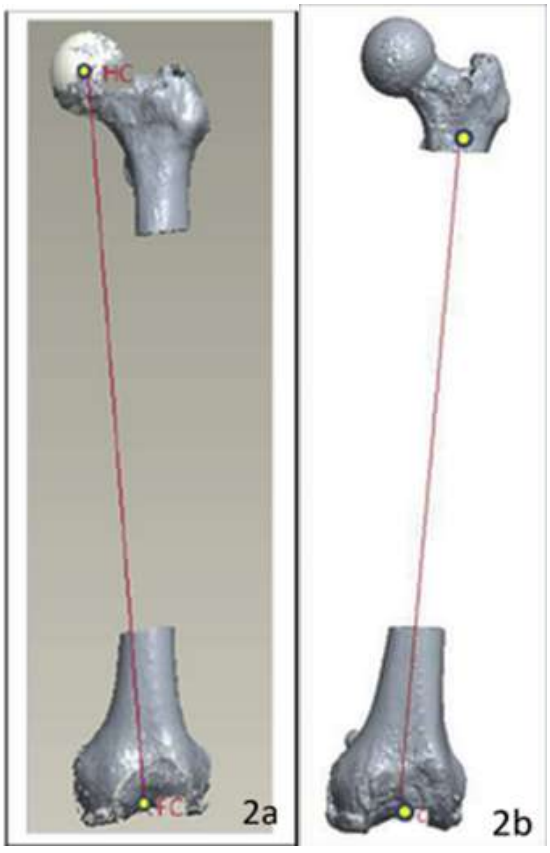

Fig 3. 2a , 2b . virtual 3D representation of the patient's femur showing the computation of the mechanical axis, anatomical axis, and femoral valgus angle

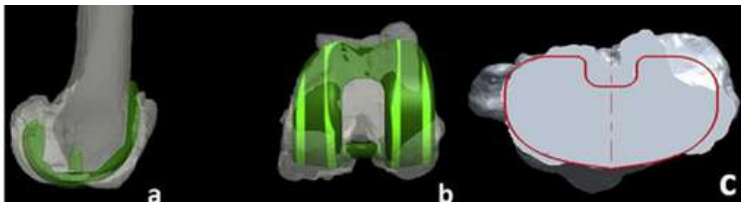

Fig 4. The size of the tibial and femoral components on the 3D reconstructed model of the bones is shown in an example.

Conclusion

The use of 3D printing technology in total knee replacement is a fascinating prospect. Additive manufacturing is employed in orthopaedics 3D printing, which can be utilized for planning and teaching. To anticipate component sizes for total knee replacement, 3D printed patient-specific jigs can be used, which can improve OR efficiency and reduce the amount of equipment needed. Its function in predicting patient-specific distal femoral valgus angles has also been investigated, and the findings are positive. They have a clear and substantial advantage in retained hardware. It has been demonstrated that 3D printed patient-specific jigs can enhance mechanical alignment following complete knee replacement. Their use is still in its infancy, and further research involving more patients and longer follow-ups will be necessary to determine their place in total knee replacement.

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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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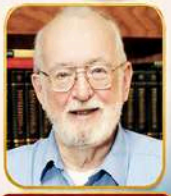
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The Role of Radiographers in the AI Era of Breast Imaging

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Regional Institute of Paramedical and Nursing Sciences (RIPANS), Aizawl, Mizoram

Abstract

Artificial intelligence (AI) is transforming breast imaging, from mammography triage to lesion detection and workflow prioritisation. While much of the discussion centres on radiologists, the professional who performs the imaging, patient positioning, and is often the first point of clinical contact -the radiographers occupy an equally critical, though under-discussed, position in this transformation. This review examines the evolving role of radiographers as AI becomes embedded in breast imaging pathways, covering image quality, AI-assisted quality control, integration of workflow, communication with patient, and the trained radiographers must develop to remain central to safe, effective breast lesion diagnosis.

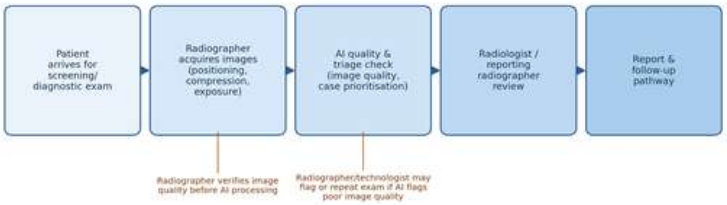
Introduction

The mammography, has long depended on the technical skill of the radiographer. Accuracy of patient Positioning, compression technique, exposure parameters directly determine diagnostic image quality, and discreet acquisition errors can give doubtful pathology or give false diagnosis. Over the past decade, deep-learning–based computer-aided detection tools have consistently outperformed traditional CAD systems in lesion detection accuracy, and AI applications for mammography now span interpretive tasks such as lesion detection, triage and density assessment, as well as non-interpretive tasks including image-quality control and acquisition support (1,2). This shift raises an important question for the profession: as machines take on more interpretive and quality-assurance tasks, what happens to the radiographer's role? rather than diminishing the radiographer's importance, AI is redefining it, shifting significance from purely technical execution toward image-quality control, AI-output verification, and patient-centred communication.

AI and Image Acquisition: A New Responsibility

Historically, image quality assessment relied on the radiographer's trained eye and adherence to positioning protocols. A growing body of literature notes that AI's effect on image acquisition and radiographer workflow itself remains comparatively underexplored relative to its diagnostic applications, even as AI-powered tools are increasingly used to support lesion identification, triage and real-time quality assessment in imaging departments (3). Where such tools are deployed, radiographers must learn to interpret AI-generated quality feedback, understand its limitations, and decide when to repeat an exposure rather than accept an algorithmic verdict at face value. This needs a hybrid competency: technical mammography skill combined with basic AI literacy, so radiographers can distinguish genuine quality flags from algorithmic false positives.

Figure 1. The radiographer's position in an AI-assisted breast imaging pathway



The Radiographer as First Filter: AI in Triage and Workflow

Several large studies now support AI's use as a second or supporting reader in mammography screening. A Danish population-based screening programme found that full implementation of an AI system considerably reduced radiologist workload while improving screening performance, with roughly two-thirds of post-implementation screenings read singly and the remainder double-read with AI assistance (4). A South Korean prospective multicentre study similarly found that AI-based computer-aided detection significantly improved radiologists' cancer detection rates in a single-read setting (5), while a Japanese single-centre study evaluating AI as a substitute second reader found performance broadly comparable with routine double reading (6). In this environment, radiographers increasingly act as the human checkpoint between acquisition and algorithmic analysis: because AI performance depends heavily on image quality, radiographers are becoming de facto data-quality custodians for AI systems, ensuring that only technically adequate images enter the triage pipeline — a role rarely reflected in current job descriptions but essential to algorithmic reliability.

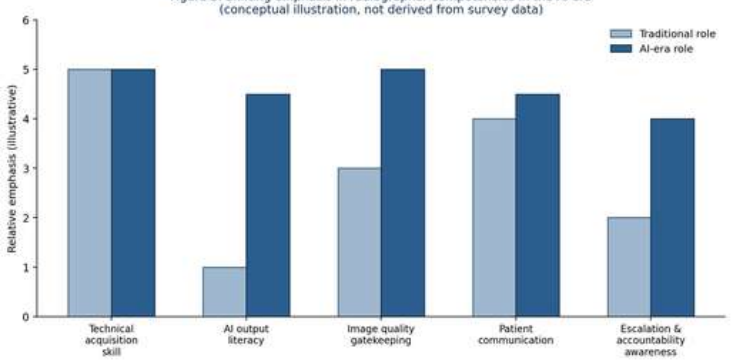
Radiographer-Led Reporting and Advanced Practice

The reduced availability of radiologists in many health systems has accelerated interest in advanced-practice and reporting radiographer roles. A UK national survey of diagnostic imaging departments found that mammogram reporting was among the most prevalent forms of radiographer advanced clinical practice, present in roughly two-thirds of responding NHS trusts, alongside protectional radiograph reporting (7). Earlier work in Mexico's national screening programme likewise demonstrated that trained radiographers could support radiologists in interpreting screening mammograms as a viable response to radiologist shortages (8). Taken together with the workforce pressures documented across breast imaging services, these findings suggest that AI-supported triage and radiographer-led reporting are converging as complementary strategies rather than competing ones, provided appropriate training, credentialing, and governance frameworks are in place.

The Human Element: Communication with patient

AI cannot replace the interpersonal skill required to support anxious patients through a breast screening or diagnostic pathway. Qualitative work comparing radiologists' and radiographers' responses to AI adoption in NHS breast units found that radiographers often have less direct exposure to AI development and industry information than radiologists, relying more on local training and hands-on experience to build their understanding (9). This gap matters clinically: as algorithmic tools become more visible in the imaging suite, patients often have questions about "the computer reading my scan," and radiographers are uniquely positioned to explain, in accessible terms, how AI is used and to reassure patients that human oversight remains central. This human-centred function is likely to grow in importance precisely because AI cannot replicate it.

Figure 2. Shifting emphasis in radiographer competencies in the AI era (conceptual illustration, not derived from survey data)



Challenges and Considerations

Several challenges accompany this evolving role. A large European survey of radiographers on the perceived impact of AI on professional identity found mixed views: while many respondents saw AI as a tool that could support their work, concerns persisted around deskilling, role erosion, and inadequate preparation through existing training pathways (10). Reviews of AI in breast cancer detection consistently flag unresolved questions around cost of implementation, algorithmic bias, and legal and ethical accountability when AI-assisted decisions contribute to a missed or delayed diagnosis (2,11). Automation bias is a further risk: over-reliance on AI quality or triage outputs could erode independent clinical judgement over time if not actively guarded against. Finally, most pre-registration and continuing professional development curricula have not yet caught up with the pace of AI deployment, leaving many radiographers to build AI-interaction skills informally rather than through structured education (3,9).

Future Directions

Looking ahead, breast imaging departments are likely to see closer integration of AI into daily radiographer workflow, including automated positioning guidance, real-time compression feedback, and AI-assisted risk stratification informing scheduling and follow-up. Radiographer training programmes will need formal AI modules covering algorithm basics, output interpretation, bias awareness, and escalation protocols, informed by the survey evidence that radiographers currently receive less structured AI education than their radiologist colleagues (9,10). Professional societies should continue developing scope-of-practice guidance for AI-supported and advanced-practice roles, building on existing evidence for radiographer-led reporting (7,8), so that radiographers are positioned as active stakeholders in AI implementation rather than end-users of tools designed without their input.

Conclusion

The AI era does not lessen the radiographer's role in breast imaging; it transforms it from technical image acquisition to AI-output verification, quality assurance, and patient communication, radiographers remain central to the safe and effective delivery of breast cancer screening and diagnosis. Realising this potential will require investment in targeted training, clear governance around accountability, and active professional advocacy to ensure radiographers help shape — rather than simply adapt to — the AI-enabled future of breast imaging.

Keywords

Radiographer; artificial intelligence; breast imaging; mammography; workflow; advanced practice; screening

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Dual-Energy CT: The Next Big Thing in Medical Imaging

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Introduction

Dual-energy CT has remained neglected during the last ten years, probably due to current technical limitations and a tedious workflow problem. The possible clinical advantages of dual-energy CT over single-energy CT should be explained to clinical radiologists. The fundamental idea, existing acquisition techniques with benefits and drawbacks, and different material-specific imaging techniques as clinical applications of dual-energy CT should all be thoroughly discussed in order to achieve this goal. Dual tubes with or without beam filtration, fast voltage switching, dual-layer detectors, split filter techniques, and sequential scanning are some of the current dual-energy CT acquisition techniques.

By employing two distinct X-ray energy bands, dual-energy CT, which was first launched as a dual-source CT system in 2006, can enhance material discrimination. The idea of dual-energy CT was first presented in 1973, and with the latest advancements in CT technology, it has reappeared in the field of clinical radiology. The technical varieties and clinical applications of dual-energy CT are continuously expanding.

The Dual-Energy CT Technical Options Available Today

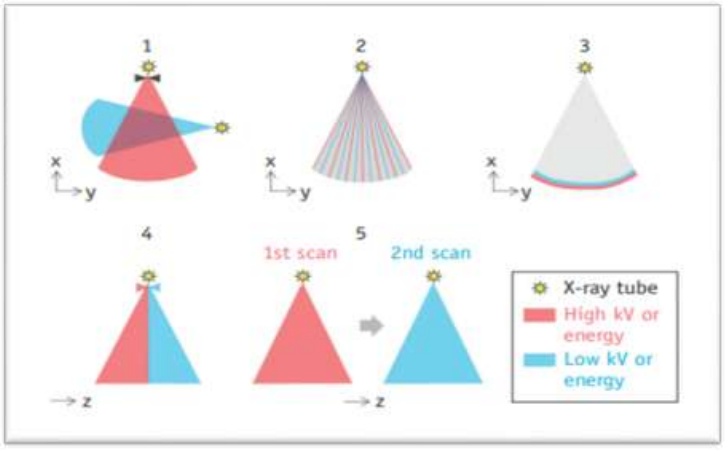

Fig. 1. Illustration of five different methods of dual-energy CT data acquisition. 1 = dual tubes with or without beam filtration, 2 = rapid voltage switching with single tube, 3 = dual-layer detector with single tube, 4 = single tube with split filter, 5 = single tube with sequential dual scans

We define the technical principles underlying the currently available dual-energy techniques to facilitate ease of understanding and avoid conceptual confusion.

Dual Tubes with or without Beam Filtration

A dual-source CT system is needed for this technique, where each X-ray tube generates a distinct X-ray energy spectrum. The most notable benefit of this approach is that, depending on the patient's body size and diagnostic goal, the tube voltage, tube current, and filter can be changed to optimize dual-energy spectral contrast and radiation dose efficiency.

The dual-source CT system currently offers the maximum dual energy spectral contrast and appears to be especially helpful for assessing small body sections, like children's entire bodies and adults' and children's extremities. Since the larger detector data is available for single-energy image reconstruction, the anatomy outside the dual-energy FOV can be assessed even though the target organ or structure is often within the FOV.

Rapid Voltage Switching with Single Tube

The two projection data sets are gathered independently for use in a projection-based dual-energy reconstruction algorithm after the tube voltage is quickly adjusted between 80 and 140 kVp. The quality of two voltage-specific projection data is limited by the rise and fall periods needed for voltage modulation, and dual-energy CT scanning requires a slower gantry rotation speed (0.5 seconds or more). The slight temporal discrepancy (0.5 ms) between the two X-ray energy spectra is negated by the significant motion artifacts caused by slow gantry rotation. Another significant issue with this technique is the difference in photon output between high and low voltages, which results in excessive radiation exposure to make up for the lower image quality.

Dual-Layer Detector with Single Tube

This technique acquires dual-energy data using a special dual-layer energy-resolving detector. Unlike other techniques that use two distinct tube voltages, dual-energy scans are carried out at a single fixed-tube voltage, typically 120 kVp, because polychromatic X-ray photons are produced by a single tube. Low-energy photons are preferentially absorbed by the inner thin layer made of yttrium-based scintillator, while high-energy photons are absorbed by the outer thick layer made of Gd2O2S2. There is hardly any temporal difference in the dual-energy data. However, due to significant overlap in the sensitivity profiles of the scintillator materials between the two layers, the dual-energy spectrum contrast is lower than that of dual tubes with beam filtration.

Single Tube with Split Filter

This technique limits dual-energy spectrum contrast to values lower than those attained by combining 80 and 140 kVp by applying a split filter to a single X-ray tube at 120 kVp to produce two distinct but overlapped X-ray energy spectra (the so-called twin beam).

The split filter is made up of a 0.6-mm thick tin filter to raise X-ray photon energy and a 0.05-mm thick gold filter to lower it. By minimizing the temporal difference between the two X-ray energy spectra comparable to a single gantry rotation time, this method allows dual-energy evaluation of enhanced or moving structures, in

contrast to the sequential dual data acquisition method. In order to preserve gapless imaging volume, the pitch factor is restricted to 0.5. Since the prefiltration absorbs around two-thirds of the radiation, a higher X-ray output is required even if the radiation dosage is nearly neutral to single-energy CT.

Single Tube with Sequential Dual Scans

This technique simply acquires dual-energy CT data with spiral or sequential scanning twice in succession using two distinct tube voltages, typically 80 and 140 kVp. One advantage is that sophisticated CT equipment is not needed. However, many dual-energy evaluations including contrast enhancement and moving body parts are not possible due to the method's significant limitations caused by the largest time gap between the two X-ray energy bands. Because of this, its clinical use is limited to unenhanced studies like gout, kidney stone differentiation, and metal artifact reduction in metal implants. An image-based dual-energy reconstruction algorithm is used in this method, and radiation-lowering techniques such tube current modulation can be applied.

Dual-Energy Applications

The investigation of material-specific and material-nonspecific energy-dependent data can be broadly classified as dual-energy CT applications.

1.Differentiation of Urinary Stones

Because uric acid-containing stones include components with substantially lower atomic numbers than calcium-containing stones, dual-energy CT can be used to accurately discriminate between the two types of stones in nephrolithiasis (25). Additionally, distinct kinds of non-uric acid calculi can be distinguished using dual-energy CT.

2.Gout Imaging

Dual-energy CT scan discriminates monosodium urate crystals from calcium-containing substances within joints and periarticular soft tissues such as tendons in a meta-analysis. Dual-energy CT is very helpful in gout cases with odd placements, negative or inconclusive arthrocentesis, and other concurrent arthropathies. It can also be used to assess the overall burden of gout and the effectiveness of treatment. For full examination, the use of a standardized 4-limb dual-energy CT is indicated.

3.Dual-Energy Bone Removal

Spectral information collected with dual-energy CT can be used to differentiate iodine from bone in CT angiography. For whole-body CT angiography, dual energy automatic bone removal gives much less errors in bone segmentation than threshold-based single-energy technique at equivalent radiation exposure and postprocessing time. The modest inaccuracies in dual-energy bone removal can be decreased with greater spectral separation or higher dual energy ratio of dual-energy CT data. Nevertheless, the quality of dual-energy bone removal is generally lower to that of subtraction procedure employing pre- and post-contrast images.

4.Lung Vessels Analysis

Regardless of the vessel diameter, the lung vasculature analysis tool can be used to differentiate between enhanced and unenhanced lung vessels based on the difference slopes between the two on the dual energy plot. Consequently, the diagnosis of minor peripheral pulmonary embolism is enhanced by dual-energy lung vessel studies. However, inadequate pulmonary arterial enhancement may make it more difficult to accurately diagnose peripheral pulmonary embolism.

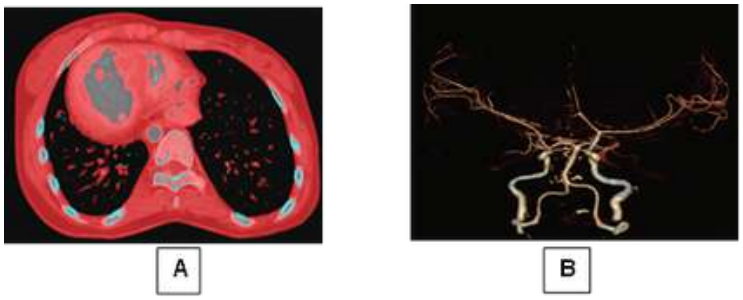

Fig. 2. A= In patient with dextrocardia, pulmonary atresia, ventricular septal defect, right aortic arch, and Eisenmenger syndrome, unobstructed pulmonary vessels in both lungs are red, secondary to very slow pulmonary circulation. B=Three-dimensional dual-energy angiographic image after detailed manual bone removal improves quality of head angiography but is time-consuming.

Conclusion

By boosting the iodine contrast-to-noise ratio, reducing metal or beam-hardening artifacts, and offering material-specific information, dual-energy CT improves the diagnostic performance and confidence of CT. Additionally, by eliminating real unenhanced CT and reducing the amount of contrast agent needed, patient safety is improved. The many clinical advantages of dual-energy CT, a new medical imaging method, should be investigated by radiologists.

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Compliance Test and Quality Assurance of Medical Diagnostic Installations

Quality Assurance of diagnostic x-ray equipment means systematic actions necessary to provide adequate confidence that diagnostic x-ray equipment will perform satisfactorily in compliance with safety standards specified by the **Atomic Energy Regulatory Board (AERB).**

The AERB has published the National Safety Code on Medical Diagnostic X-ray Equipment and Installations, **Safety code # AERB/SC/MED-2 (Rev-1), dated : 05/10/2001**

The implementation of the provisions of the safety code ensures the protection from radiation of occupational workers, patients, and the public.

WHY QUALITY ASSURANCE OF DIAGNOSTIC MACHINES IS REQUIRED?

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  - Accuracy and Consistency of Radiation Equipment
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  - Evaluation of potential exposure levels at various locations arising from the operations of the equipment
- **It helps :-**
  - Reduces the down time of the machine
  - Accurate & Timely diagnosis
  - Minimize radiation dose levels tc patients, technicians & general public
  - Cost effective
  - Complies to regulatory requirements
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- **Compulsory Requirements as per :-**
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Quality Assurance & Area Surveillance tests is compulsory requirements to register / renew your diagnostic equipment with AERB.

- **Diagnostic Installations, include:-**
  - X-Ray with fluoroscopy (Fixed and Mobile)
  - CT Scan
  - Mammography
  - C Arm Machines
  - Cath Lab
  - Dental X rays
  - Orthopentogram (OPG)
  - Cone beam CT (CBCT)
  - Bone Densitometry (BMD)
- **Quality Assurance Tests to be performed Include:-**
  - Congruence of radiation and optical field
  - Central beam alignment
  - Focal spot size & Timer check
  - Accelerating voltage reproducibility
  - Linearity of Timer and mA station
  - Output consistency
  - Total Filtration of the X-ray machine
  - Tube housing leakage
  - Table top dose rate at 45 cm from focus
  - Area Surveillance

Technical Advances and Clinical Applications of 4D Cone-beam CT in Radiation Therapy

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Abstract

In radiation therapy, cone-beam CT (CBCT) is the most popular onboard imaging method for target localisation. Conventional 3D CBCT creates 3D images of the patient in the treatment room by projecting x-ray cone beams around the patient at different angles. However, 3D CBCT's capacity to scan disease areas impacted by respiratory motions or other dynamic changes inside the body is restricted due to the lack of time-resolved information. In order to get over this restriction, 4D-CBCT was created, which includes a time dimension in the imaging to take the patient's motion into consideration during the acquisitions. Respiration-correlated 4D-CBCT, for instance, divides breathing cycles into discrete phase bins and then reconstructs 3D images for each phase bin to produce a complete collection of 4D images. 4D-CBCT significantly improves tumour localisation in the thoracic and abdominal areas, where respiratory movements affect localisation accuracy.This is especially important for hypo fractionated stereotactic body radiation therapy (SBRT), which delivers far higher fractional doses in fewer fractions than conventional fractionated treatments. However, 4D-CBCT has a number of disadvantages, including long scanning times, large imaging doses, and poor image quality, since it necessitates capturing sufficient x-ray projections for each respiratory phase.

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

Introduction

Since its creation in the late 1990s, cone beam computed tomography (CBCT) has been a cornerstone of image-guided radiation therapy. To image the object from multiple projection angles and reconstruct 3D or 4D images (3D images at different breathing phases), the system uses either a megavoltage radiation beam delivered by the linear accelerator (linac) or a kilovoltage beam created using an additional x-ray tube mounted on the radiation delivery unit. The generated images offer accurate and comprehensive information on the patient's anatomy, which is utilised to see the tumour and surrounding healthy tissues in three dimensions to verify the patient's position and ensure that the therapy is given where it should be. 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) Compared to a conventional 3D-CBCT scan, which takes one minute to gather, this results in a longer collection 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 greater imaging dosage. Additionally, streaking errors, under sampling, and intra-phase movements can be caused by long cycles and irregular breathing. In order to improve tumour management and lessen detrimental effects on healthy tissues, 4D-CBCT is crucial for greatly improving radiation therapy accuracy. Numerous methods, such as pre-processing, reconstruction, acquisition, sorting, and post-processing, have been developed to improve 4D-CBCT efficiency and image quality at different stages. (2) **Fig.1**

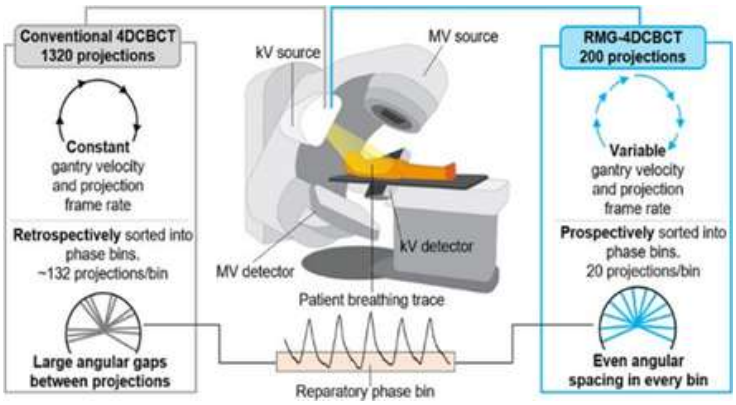

Figure:1 Radiation delivery unit to create 3D or 4D photographs (3D images at various breathing phases) by imaging the object from several projection angles

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. Motion-compensated reconstruction methods, such Simultaneous Motion Estimation and Image Reconstruction (SMEIR), have been developed to reduce motion artefacts. 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**

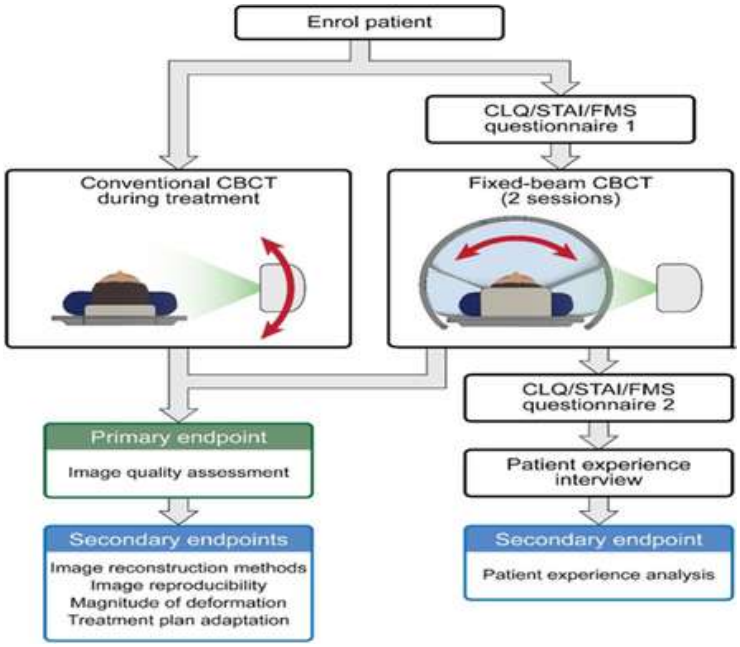

Figure:2 These methods provide more accurate depictions of anatomical structures by combining geometric and biomechanical models to account for organ motion during image reconstruction.

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

Pre-processing pictures is a crucial step to optimise input data for medical imaging technologies like 4D cone-beam computed tomography (4D-CBCT).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.

2. Iterative Reconstruction (IR): This method reduces discrepancies by iteratively comparing acquired data to picture estimates. Iterative techniques such as simultaneous algebraic reconstruction technique (SART) and algebraic reconstruction technique (ART) offer superior image quality and noise management in comparison to FBP.

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)

Post-processing of the image reconstruction

Post-processing of reconstructed images is crucial for enhancing image quality, reducing artefacts, and ensuring that the pictures are ready for clinical interpretation or treatment planning in 4D cone-beam computed tomography (4D-CBCT). Enhancing the accuracy and utility of the rebuilt data is the aim of this phase.

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 use of 4D-CBCT extends beyond lung imaging to additional anatomical sites affected by respiration-induced motion. It's interesting to note that 4D-CBCT has been employed for liver imaging, however there are some challenges. The most significant challenge is the poor x-ray contrast between liver tumours and healthy tissue. Iodinated contrast agents are commonly used in liver 4D-CT to enhance tumour visualisation, however their application in 4D-CBCT is difficult due to logistical constraints and concerns over contrast toxicity. 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 fact that current 4D-CBCT produces images of poor quality and requires a significantly longer scanning duration and imaging dosage than 3D-CBCT severely restricts its clinical applicability. Although many techniques have been developed to reduce imaging dosages, speed up 4D-CBCT acquisition, and greatly improve image quality, further research and implementation are needed before these ground-breaking developments may be applied in clinical settings. The efficiency, imaging dosage, and quality of 4D-CBCT must be optimised in accordance with the therapeutic task in order to enhance the usage of this helpful imaging technology in radiation treatment. Another drawback of 4D-CBCT is its temporal resolution. 4D-CBCT divides the breathing cycle into a limited number of bins and produces 3D images for each respiratory bin. Thus, the temporal precision of 4DCBCT is limited by the number of bins required for sorting and reconstruction. Increasing the number of categories may improve the temporal resolution, but the more severe undersampling in each bin will worsen the image quality. Ten bins are most commonly used in phase-resolved 4D-CBCT imaging, and the temporal resolution of each bin is around one tenth of the breathing cycle. The motion information within each bin cannot be recorded by 4D-CBCT, and thus is vulnerable to intra-bin motion artefacts.

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

4D-CBCT is necessary for localising moving targets, such as lung and liver malignancies. This is especially important in the era of stereotactic radiation therapy, because massive radiation doses are given in each fraction and extremely precise target localisation is needed. The 4D-CBCT is currently the most used tool for 4D patient imaging in clinics because of improvements in linear accelerator hardware. To improve 4D-CBCT efficiency and image quality at different stages, several techniques have been developed, including acquisition, sorting, pre-processing, reconstruction, and post-processing. Recent advances in 4D-CBCT imaging have been made possible by the development of artificial intelligence (AI) and deep learning, which have the potential to greatly and effectively improve 4D-CBCT image quality. The limitations of conventional 4D-CBCT approaches may be overcome by these new technologies, which have the potential to greatly expand the usage of 4D-CBCT from target localisation to outcome prediction and adaptive therapy. In the future, rapid, low-dose, high-quality 4D-CBCT can be developed to record different patient motions and integrate with other imaging modalities to provide a wide range of applications in radiation oncology and radiology.

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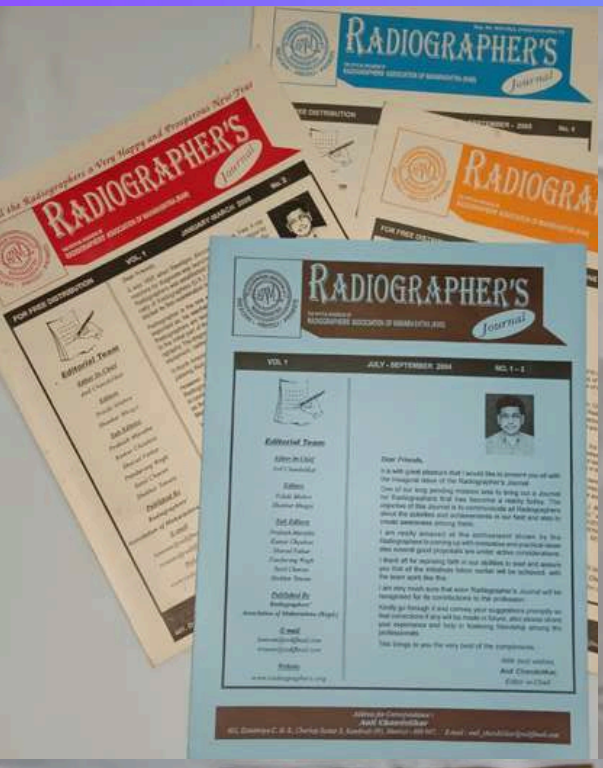

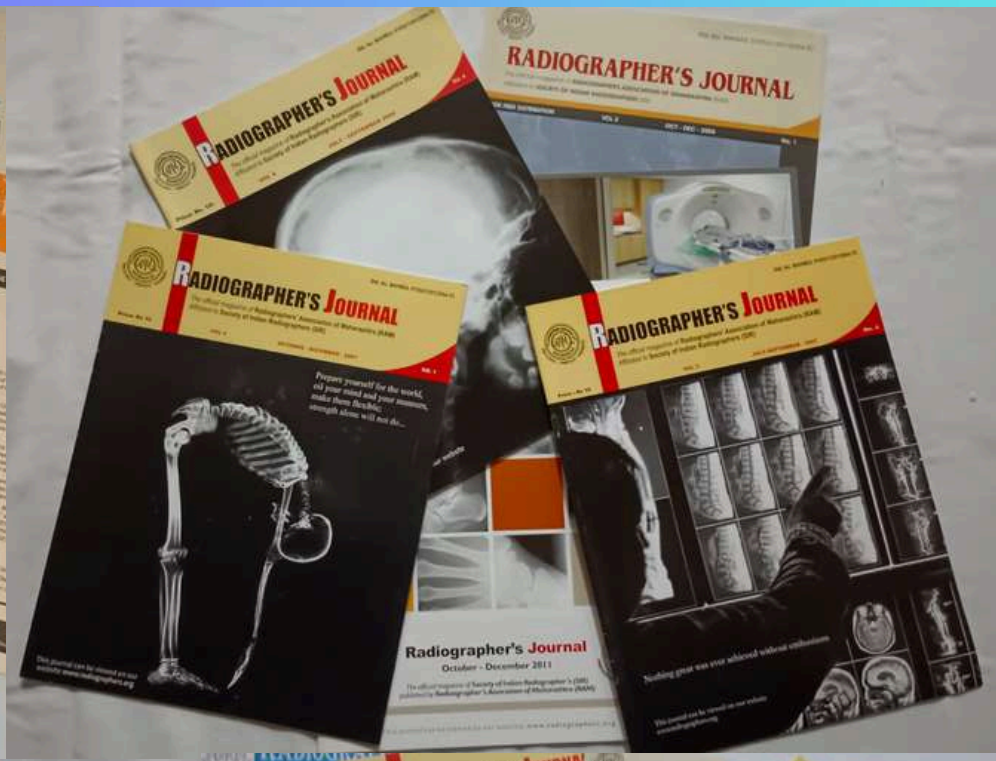

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