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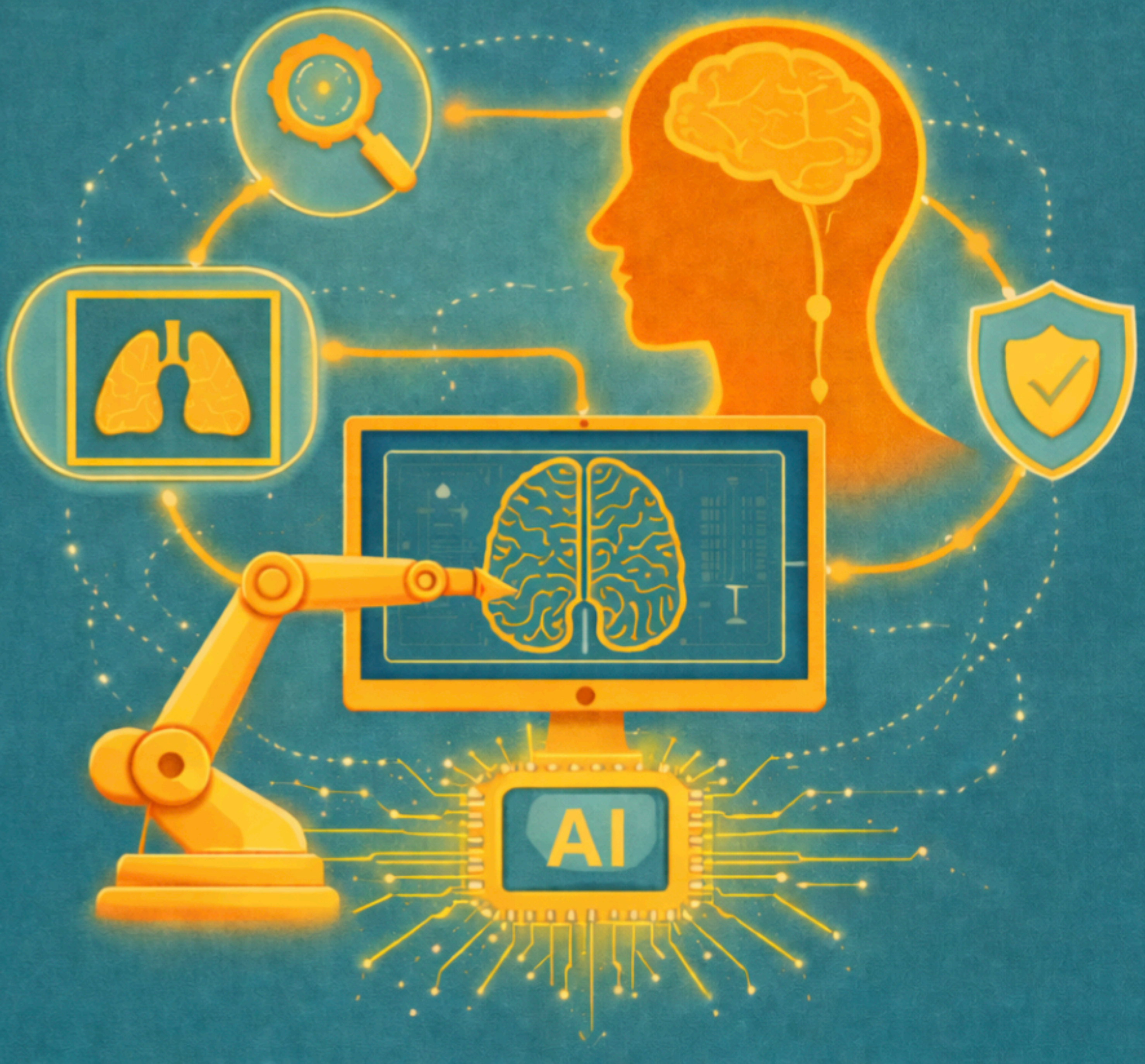

ARTIFICIAL INTELLIGENCE IN RADIOLOGY

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Human and Artificial Intelligence in Radiology: Current Status, Evidence, Regulation, and Future Perspectives

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Abstract

Artificial intelligence (AI) has rapidly evolved into a transformative force in radiology, complementing human intelligence across the entire imaging workflow. Current applications range from image acquisition and reconstruction to automated detection, quantification, triage, and clinical decision support. Evidence to date demonstrates that AI systems can match or exceed human performance in narrowly defined tasks, particularly in pattern recognition and workflow optimization. However, robust prospective validation, demonstration of clinical impact, and proof of generalizability across institutions and populations remain limited.

Human intelligence continues to play a central role in contextual interpretation, integration of clinical information, ethical judgment, and responsibility for patient care. Rather than replacing radiologists, AI is increasingly viewed as an augmentative tool that enhances diagnostic accuracy, efficiency, and consistency when appropriately implemented.
Regulatory frameworks are evolving in response to these developments. In Europe, the Medical Device Regulation (MDR) and the forthcoming AI Act introduce stricter requirements for transparency, risk classification, post-market surveillance, and human oversight. Comparable regulatory efforts are underway globally, aiming to balance innovation with patient safety, data protection, and accountability. Nonetheless, regulatory heterogeneity and the dynamic nature of adaptive AI systems pose ongoing challenges.

Looking ahead, the future of radiology will be shaped by closer human–AI collaboration, increased emphasis on explainability, continuous learning systems under regulatory control, and higher-quality clinical evidence. Education and training of radiologists in AI literacy will be essential. Ultimately, the successful integration of artificial intelligence into radiology will depend not only on technological progress, but also on evidence-based implementation, clear regulation, and sustained human expertise.

Keywords: artificial intelligence, transparency, radiology

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1. Introduction

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2. Methods and Sources

The present article is based on a curated, critical analysis of recent high-quality literature addressing the role of artificial intelligence (AI) in radiology. The purpose of this chapter is not to provide a systematic review in the strict methodological sense, but rather to transparently describe the sources used and to analyze how contemporary publications conceptualize, evaluate, and contextualize AI within clinical radiology. Emphasis is placed on methodological rigor, evidence generation, human–AI interaction, and regulatory framing.

The selected time frame (2022–2025) captures a period that followed an initial phase of considerable enthusiasm surrounding AI in radiology. During the years preceding this interval, AI was frequently portrayed as a disruptive technology with the potential to fundamentally transform diagnostic imaging, often accompanied by claims of near-human or superhuman performance. More recent publications, however, reflect a noticeable shift toward a more cautious and sober assessment. This phase is characterized by increased attention to real-world performance, unintended consequences of AI deployment, limitations of retrospective evidence, and the growing influence of regulatory requirements (11).

Against this background, the present analysis aims to examine how leading journals and expert groups currently approach AI in radiology, how evidence is generated and reported, and where persistent gaps and inconsistencies remain. The overarching perspective is radiological and clinical, with patient safety, accountability, and feasibility of implementation taking precedence over technological optimism.

2.1 Literature identification and selection strategy

The literature corpus consists of twelve peer-reviewed publications published between 2022 and 2025. Sources were selected from internationally recognized journals with high relevance for clinical radiology, medical imaging research, digital medicine, and health technology assessment. These include Nature Medicine, Radiology, The Lancet Digital Health, European Radiology, npj Digital Medicine, Insights into Imaging, The British Journal of Radiology, and Value in Health (1–12).

Selection criteria focused on publications that met at least one of the following conditions:
(a) presentation of original clinical or reader-based evidence on AI performance in radiology,
(b) methodological or reporting frameworks for clinical evaluation of AI systems,
(c) health-economic evaluation standards applicable to AI-based interventions, or
(d) regulatory and legal analyses with direct relevance to radiological practice.

Purely technical machine-learning papers without clinical validation, as well as non–peer-reviewed industry reports, were deliberately excluded.

The final selection reflects four thematic clusters: clinical evidence and human–AI interaction (7, 8, 10, 12), methodological and reporting standards (4 – 6), regulatory and governance perspectives (7 – 10, 12), and critical commentaries offering a meta-level appraisal of the current state of AI in radiology (11). This approach allows a balanced view across the AI life cycle, from development and evaluation to implementation and oversight.

2.2 Types of publications and study designs

The analyzed literature demonstrates substantial heterogeneity with regard to publication type and study design. Original clinical evidence is predominantly derived from retrospective cohort studies and reader studies, often using enriched or curated datasets. A representative example is the large retrospective screening study evaluating AI as an independent or assisting reader in breast cancer screening, which relies on historical mammography data with long-term follow-up (2). Similarly, real-world validation studies in specific disease contexts, such as multiple sclerosis MRI monitoring, remain largely retrospective and context-specific (3).

Reader studies assessing human–AI interaction frequently employ simulated reading environments or controlled experimental designs. While these approaches allow detailed analysis of performance metrics and behavioral effects, they inherently differ from routine clinical conditions (1). Prospective randomized trials remain rare, and when present, are often limited to narrow use cases or specific screening settings.

A substantial portion of the literature consists of methodological guidance documents and reporting standards, including frameworks for clinical evaluation (4), early-stage decision support assessment (5), and health-economic reporting (6). These publications are normative in nature and aim to raise the methodological bar for future studies rather than to provide empirical performance data.

Regulatory and legal analyses form another important category. These papers interpret evolving regulatory frameworks, particularly within the European context, and translate legal requirements into practical implications for radiologists and healthcare institutions (7, 10, 12). Finally, critical commentaries synthesize existing evidence and explicitly challenge prevailing assumptions about efficiency gains, economic benefits, and the transformative impact of AI in routine radiology (11).

2.3 Conceptualization of artificial intelligence in the literature

Across the analyzed publications, AI is consistently conceptualized as a task-specific tool rather than a general or autonomous diagnostic entity. Most studies focus on narrowly defined applications such as lesion detection, triage, quantification, or second-reader support. This reflects both technical realities and regulatory constraints, as fully autonomous diagnostic systems remain neither legally permissible nor clinically validated.

Definitions of AI vary in specificity, ranging from broad descriptions encompassing machine learning and deep learning to more explicit distinctions between conventional algorithms, deep neural networks, and, more recently, large language models (LLMs) (9). However, even when LLMs are discussed, they are framed as adjunctive tools for reporting, documentation, or workflow support rather than primary diagnostic decision-makers.

Functionally, AI systems are most commonly positioned as assistive technologies. The second-reader paradigm, particularly in screening contexts, represents a recurring theme and is often cited as a realistic and regulatorily acceptable use case (2, 11). Workflow-oriented applications, such as protocoling, image reconstruction, or administrative automation, are acknowledged as potentially impactful but remain underrepresented in empirical studies.

Importantly, none of the analyzed sources advocate for the removal of the radiologist from the diagnostic process. On the contrary, explicit emphasis is placed on human oversight, contextual interpretation, and accountability, reinforcing the notion of AI as an augmentative rather than substitutive technology.

2.4 Evaluation methodology and evidence standards

Performance evaluation in the reviewed literature relies heavily on conventional diagnostic metrics, including area under the receiver operating characteristic curve, sensitivity, specificity, and recall rates. While these measures are well established, their clinical relevance is often limited when used in isolation. Improvements in such metrics do not necessarily translate into better patient outcomes, reduced morbidity, or meaningful efficiency gains (18, 19).

Comparisons between human readers and AI systems, or between unassisted and AI-assisted radiologists, reveal heterogeneous effects. A large-scale reader study demonstrated substantial inter-individual variability in the impact of AI assistance, with some radiologists experiencing performance improvements and others showing deterioration, particularly in the presence of AI errors (1). These findings challenge the assumption that AI uniformly benefits less experienced readers or consistently improves overall performance.

External validation remains a major weakness. Many studies rely on single-center datasets or vendor-specific systems, limiting generalizability across institutions, populations, and imaging protocols. Dataset shift and hidden stratification are rarely addressed in a systematic manner.
Methodological guidance documents attempt to address these shortcomings. The DECIDE-AI framework provides structured recommendations for early-stage clinical evaluation of AI-based decision support systems, emphasizing transparency, contextual description, and staged evidence generation (5). Similarly, CHEERS-AI extends established health-economic reporting standards to AI interventions, highlighting the need to explicitly account for algorithm behavior, learning effects, and implementation costs (6). Despite their availability, adherence to these frameworks in empirical studies remains inconsistent.

2.5 Human–AI interaction and the role of the radiologist

The analyzed literature consistently assigns a central role to the radiologist within AI-augmented workflows. Radiologists are portrayed as integrators of imaging findings, clinical context, and patient-specific considerations, functions that remain beyond the capabilities of current AI systems.
Human–AI interaction studies reveal both potential benefits and risks. While AI may support decision-making in specific tasks, it can also introduce automation bias, authority bias, and overreliance, particularly when AI outputs are presented without adequate uncertainty information or calibration (1, 11). Empirical evidence indicates that incorrect AI suggestions can negatively influence radiologist performance, increasing error rates compared with unassisted reading (1).
Concerns regarding deskilling are acknowledged but not uniformly supported by evidence. Rather than a loss of expertise, the literature suggests a redistribution of cognitive effort, with radiologists shifting from pure detection tasks toward supervision, validation, and consultation. However, this shift has implications for training, work-load, and professional responsibility that are only partially addressed in current studies.

2.6 Regulatory and governance perspectives

Regulatory considerations occupy a prominent position in recent literature. In the European context, AI systems used in radiology are consistently classified as high-risk medical devices, subject to stringent requirements under the Medical Device Regulation and the forthcoming AI Act (7, 8, 10, 12). Core principles include risk management throughout the life cycle, robust data governance, transparency, and mandatory human oversight.

Several publications emphasize that regulatory compliance is not merely a legal obligation but a determinant of study design and implementation strategy. Adaptive systems, continuous learning, and post-market performance monitoring pose particular challenges, as they conflict with traditional static approval models (7, 9).

Legal analyses further highlight issues of liability and accountability. Radiologists retain ultimate responsibility for diagnostic decisions, even when AI systems are involved, reinforcing the need for clear protocols defining the scope and limits of AI use (12). Similar regulatory trends are observed globally, suggesting increasing convergence toward risk-based oversight rather than permissive innovation.

2.7 Methodological and structural limitations across the literature

Despite notable progress, several structural limitations persist across the analyzed sources. Publication bias toward positive results remains likely, as negative or neutral findings are under-represented. Many studies address narrowly defined tasks that may not reflect the complexity of routine radiological practice.

Economic evidence is particularly limited. Claims of efficiency gains and cost reduction are often speculative and rarely supported by comprehensive economic modeling or prospective evaluation (6, 11). This gap undermines the business case for widespread AI adoption and contributes to the growing sense of disillusionment following earlier hype.

Moreover, the fragmentation of evidence across clinical, technical, and regulatory domains hampers integrated assessment. Few studies simultaneously address performance, workflow impact, economic implications, and legal feasibility.

2.8 Rationale for integrating these sources

The selected literature provides a coherent snapshot of the current state of AI in radiology, characterized by a transition from enthusiasm to methodological realism. Together, these sources illustrate how AI is increasingly framed as a supportive technology whose value depends on rigorous evaluation, thoughtful implementation, and robust governance.

By integrating clinical studies, methodological frameworks, regulatory analyses, and critical commentaries, this chapter establishes the foundation for subsequent discussion. It highlights both the tangible progress achieved and the substantial work that remains necessary to ensure that AI contributes meaningfully and safely to radiological practice.

3. Radiology Today: Clinical Role and Value Contribution

3.1 Radiology as a clinical discipline in a value-driven era

Radiology has long been central to modern healthcare, yet its clinical role has not always been visible in proportion to its impact. Over the last decades, imaging has moved from a supportive diagnostic tool to a cornerstone of patient pathways, influencing diagnosis, staging, treatment planning, monitoring, and increasingly prognostication. At the same time, radiology has been affected by pressures that are now familiar across many health systems: rising demand, workforce shortages, cost containment, and the shift toward value-based healthcare models. These developments have triggered an important reappraisal of what radiology contributes—beyond throughput, report volume, and technical excellence—and how that contribution should be articulated and measured.

Value-based healthcare is often described as maximizing patient outcomes relative to cost.

In this context, radiology's value is not merely determined by the accuracy of image interpretation, but by its measurable influence on clinical decision-making, patient experience, and down-stream outcomes. A multisociety perspective has emphasized that radiology must be viewed as a clinical discipline whose value extends beyond the production of diagnostic reports and includes consultative expertise, stewardship of appropriate imaging, and quality improvement across the care continuum. (14, 15, 22) Similar arguments have been expressed in broader medical discourse, underscoring that imaging is embedded in clinical decision systems and should be evaluated accordingly. (19)

While European radiology has produced several structured frameworks on value and professional identity, the underlying themes are not uniquely European. Rather, they reflect global challenges: maintaining quality and access under increasing demand, demonstrating relevance within multidisciplinary care, and ensuring that radiology remains clinically integrated rather than commoditized. (18, 19) In this chapter, the contemporary clinical role of radiology is analyzed through the lens of value contribution, focusing on three interconnected domains: clinical impact on decision-making, radiologists as consultants and integrators, and patient-centered value including communication and experience. In parallel, the chapter addresses how value can be measured and where limitations in current evidence and practice remain.

3.2 Clinical impact: radiology as a driver of diagnosis and management

Radiology's most direct contribution to value lies in its influence on diagnostic accuracy and clinical management. Imaging findings frequently determine whether a patient is admitted or discharged, treated conservatively or invasively, and whether a malignancy is staged as resectable or metastatic. In acute care, radiology is pivotal in time-critical decisions such as stroke treatment, trauma triage, and suspected pulmonary embolism. In oncology, imaging guides diagnosis, staging, therapy response assessment, and surveillance. These roles are widely accepted in clinical practice; however, the challenge is that radiology's impact is often diffuse and distributed across multiple decisions, making it difficult to quantify using single metrics.

A value-based framing therefore requires moving beyond "test performance" and considering radiology's effect on downstream outcomes. The multisociety perspective in Radiology emphasizes that radiology creates value through appropriate imaging selection, accurate and timely diagnosis, and the reduction of diagnostic uncertainty. (14, 15, 22) In practice, radiology can shorten time to diagnosis, prevent unnecessary procedures, and improve patient stratification. Yet these benefits may not be captured by traditional departmental key performance indicators such as report turn-around time or scanner utilization.

Moreover, radiology is increasingly intertwined with clinical pathways and guidelines. Imaging appropriateness, radiation safety, and protocol optimization represent value contributions that occur before interpretation even begins. These elements are especially relevant in global healthcare settings where access to imaging is unequal, resources are limited, and the balance between benefit and cost is particularly delicate. A mature value narrative must therefore include not only high resource settings with advanced imaging infrastructure, but also low- and middle-income contexts where radiology may have a different role—sometimes more focused on basic access and diagnostic availability.

In multidisciplinary care, radiology's value becomes more visible. Imaging is a shared language between specialties, and radiologists provide interpretive expertise that can prevent miscommunication and ensure that imaging findings are translated into actionable decisions. A summary of the ESR International Forum highlights that radiology's role in multidisciplinary approaches is not optional but fundamental, and that visibility and integration are essential if radiology is to contribute optimally to patient care. (17) While this discussion emerges from a European forum, the same logic applies globally: the radiologist's clinical role is strongest when radiology is embedded in teams rather than operating as an isolated reporting service.

3.3 The radiologist as consultant and integrator: beyond the report

One of the clearest contemporary shifts in radiology is the reemphasis on the radiologist as a clinical consultant. This role is sometimes under-appreciated because it is difficult to measure and often not formally reimbursed. Yet consultative work is a major mechanism through which radiologists create value: recommending the most appropriate imaging, advising on protocol selection, clarifying findings for referring clinicians, and contributing to complex decision-making in multidisciplinary conferences.

A recent analysis in the Journal of the American College of Radiology addresses the value of radiology consultation in terms of effort allocation, clinical impact, and *"untapped opportunities."* (14, 15, 22) The authors frame consultation as a meaningful and underutilized component of radiology practice. This is important for value-based radiology because it challenges a narrow view in which radiology's output is reduced to a written report. Consultation can prevent unnecessary imaging, avoid repeated examinations, improve interpretation accuracy through clinical context, and support decision-making where imaging findings are ambiguous or unexpected.
The consultative role also strengthens radiology's identity as a clinical specialty. The ESR white paper on the changing world of healthcare highlights that radiologists must maintain clinical visibility, participate actively in patient pathways, and engage in communication that demonstrates value to both clinicians and patients. (18, 19) Although this white paper is European in origin, its relevance is global: in many health systems, radiology is vulnerable to commoditization when radiologists are perceived as "report producers" rather than clinical experts.

However, the consultative role is not uniformly implemented worldwide. In some regions, radiologists are physically colocated with clinical teams and participate in ward rounds, tumor boards, and clinical conferences. In other settings, radiology is increasingly remote, with outsourcing, teleradiology, and distributed reporting models. These models may improve access and efficiency, but they risk weakening clinical integration if consultation is not explicitly preserved. Value-based radiology therefore requires intentional structures that enable consultation, such as dedicated clinician communication channels, protected time for multidisciplinary meetings, and recognition of consultation as a measurable service.

3.4 Patient-centered value: communication, understanding, and trust

Radiology's value is not limited to clinicians and health systems; it also extends directly to patients. Historically, radiology has often been a "hidden" specialty, with limited patient contact and little visibility in patient experience narratives. Yet patients increasingly access their imaging reports through electronic health records, and expectations of transparency and communication have risen across healthcare. This shift has implications for radiology's role, responsibilities, and potential value contribution.

Direct communication between radiologists and patients has been studied as a mechanism for improving report quality. A study in European Radiology reported that direct communication can improve the quality of imaging reports. (18, 19) While the precise pathways of this effect can be debated—ranging from improved clinical context to increased accountability—the broader implication is that patient-facing radiology is not merely a "soft skill" but may influence diagnostic clarity and relevance. Communication can also reduce anxiety, correct misunderstandings, and strengthen trust in imaging-based decisions.

Patient perceptions of radiology value have also been explored through surveys. The ESR value-based radiology subcommittee reported results from a patient survey addressing how value is perceived in relation to radiology. (14, 15, 22) Such work is important because value-based healthcare is, at least in principle, patient-centered. If radiology is to demonstrate value, it must understand what patients consider valuable: timely access, clear explanations, respectful interaction, safety, and the sense that imaging contributes meaningfully to care rather than being a routine or redundant step.

Importantly, patient-centered value varies internationally. In some health systems, patients may have direct access to radiologists and structured opportunities for consultation; in others, radiologists remain largely invisible. Cultural expectations also differ: some patients prefer detailed explanations, while others may defer to clinicians. A balanced international perspective therefore avoids prescribing a single model and instead recognizes that patient-centered radiology must be adapted to local norms and infrastructure.

Nonetheless, the general direction is clear: radiology's value proposition is strengthened when radiologists engage with patients as stake-holders. This does not imply that every radiologist must become a front-line communicator in all settings, but it does suggest that radiology departments should develop strategies for patient communication, report clarity, and accessibility.

3.5 Frameworks for value: defining, measuring, and improving radiology's contribution

The concept of "value" risks becoming rhetorical unless it is linked to measurable and actionable frameworks. Radiology has increasingly adopted value-based language, but implementation requires concrete metrics and quality improvement mechanisms. The ESR has provided structured perspectives on value-based radiology, including discussions on what radiology societies are doing and what future directions should be pursued. (14, 15, 22) These frameworks emphasize that value is multidimensional, involving clinical outcomes, safety, patient experience, appropriateness, efficiency, and professional engagement.

A central challenge is that radiology's value is often indirect. For example, an accurate report may prevent unnecessary surgery, but the avoided harm may not be captured as a radiology metric. Similarly, imaging stewardship may reduce unnecessary examinations, but the "success" is the absence of imaging rather than increased volume. This creates tension with traditional productivity metrics that reward throughput rather than appropriateness.

Feedback mechanisms represent one practical route to value improvement. A recent paper on feedback in radiology describes feedback as an essential tool for improving user experience and delivering value-based care. (14, 15, 22) Feedback can be directed toward multiple stakeholders: referring clinicians, radiologists, technologists, and patients. It can address diagnostic accuracy, report clarity, communication, turnaround time, and appropriateness. Importantly, feedback systems can convert abstract value concepts into operational quality improvement processes.

The multisociety perspective on value-based radiology also emphasizes that radiology must demonstrate its impact through evidence and quality measurement rather than relying on assumptions of importance. (14, 15, 22) In practice, this may involve adopting metrics such as:

- appropriateness and guideline adherence,
- clinically actionable report elements,
- discrepancy tracking and learning systems,
- patient satisfaction and understanding,
- participation in multidisciplinary decision-making,
- time-to-treatment or pathway efficiency measures.

From an international standpoint, the choice of metrics should reflect local priorities. In resource-limited settings, value may be measured through improved access and reduced diagnostic delay. In high-resource systems, value may be measured through appropriateness, cost-effectiveness, and avoidance of unnecessary downstream interventions.

3.6 Radiology identity and professional visibility: maintaining relevance in modern healthcare

The identity of radiology as a clinical specialty is closely linked to value contribution. A survey among ESR full radiologist members explored professional identity and role perception, offering insight into how radiologists view their position in healthcare. (20) While such surveys reflect a specific membership population, they highlight broader professional concerns: maintaining clinical relevance, avoiding commoditization, and ensuring that radiologists are recognized as physicians with interpretive and consultative expertise.

The ESR white paper further elaborates on the radiologist's role in a changing healthcare environment, emphasizing that radiologists must remain clinically engaged, participate in decision-making, and adapt to evolving expectations. (13) These perspectives align with global concerns about workforce shortages, increasing imaging demand, and the need for radiology to maintain both quality and accessibility.

Radiology's identity is also shaped by how it is organized. Departmental integration with clinical services, training structures, and institutional culture all influence whether radiologists are visible as clinical partners. In systems where radiology is primarily service-oriented and remote, radiologists may be less involved in direct clinical dialogue. In contrast, in systems with strong multi-disciplinary integration, radiologists may be perceived as indispensable contributors to patient care.

A key point is that radiology's value is not self-evident to all stakeholders. Hospital administrators may focus on cost and throughput, clinicians may focus on availability and report clarity, and patients may focus on understanding and reassurance. Value-based radiology therefore requires active communication of radiology's contributions, supported by evidence and quality improvement.

3.7 Challenges and limitations: evidence gaps, measurement problems, and implementation barriers

While the value narrative is compelling, it must be tempered by realism. Several limitations persist in how radiology value is currently conceptualized and measured.

First, evidence linking radiology interventions to patient outcomes is often indirect. While it is intuitive that accurate imaging improves care, rigorous studies demonstrating downstream outcomes are difficult to conduct. Imaging is embedded within complex clinical pathways, and isolating radiology's independent effect can be methodologically challenging. As a result, many value arguments rely on plausibility and expert consensus rather than definitive outcome trials.

Second, economic evaluation is frequently underdeveloped. Value-based healthcare is inherently tied to cost-effectiveness, yet radiology economics can be complex. Costs are distributed across equipment, staffing, maintenance, and downstream interventions. Moreover, imaging can both increase and decrease costs: it may reduce unnecessary procedures, but it may also detect incidental findings that generate additional testing. A mature value framework must acknowledge these complexities rather than assuming that imaging always reduces cost.

Third, measurement systems may incentivize the wrong behaviors. If radiology departments are evaluated primarily by throughput and turnaround time, radiologists may have limited incentive or time for consultation, multidisciplinary engagement, and patient communication. Yet these are precisely the activities that strengthen radiology's value contribution. Aligning incentives with value therefore requires institutional commitment and structural support.

Fourth, international variability complicates generalization. Health systems differ in reimbursement, referral patterns, imaging access, and professional roles. A strategy that improves value in one system may not translate directly to another. For example, patient-facing radiology communication may be feasible in some contexts but not in high-volume settings with severe work-force shortages. Similarly, consultation models depend on institutional culture and clinical workflow.

Finally, the shift toward value-based radiology may encounter resistance if it is perceived as an administrative burden rather than a clinical opportunity. The success of value-based initiatives depends on radiologists seeing them as tools for improving care and strengthening professional identity, not merely as reporting requirements.

3.8 Radiology's value proposition today

Radiology today is best understood as a clinical discipline that contributes value across the patient pathway. Its impact extends from accurate diagnosis and management guidance to consultation, multidisciplinary integration, patient communication, and stewardship of appropriate imaging. The transition toward value-based health-care provides both a challenge and an opportunity: radiology must demonstrate its contribution in measurable terms, but it can also strengthen its clinical identity by emphasizing roles that go beyond report production.

Internationally, radiology's value contribution is shaped by local healthcare structures, workforce realities, and cultural expectations. Nonetheless, the core elements of value appear consistent: clinical relevance, integration, communication, safety, and outcome-oriented practice. Frame-works and professional guidance support this shift, but further work is needed to build robust measurement systems, generate outcome-linked evidence, and align incentives with value. (11 – 15)

Ultimately, radiology's future role will depend on its ability to remain clinically visible, evidence-driven, and patient-centered—ensuring that imaging continues to serve not only diagnostic accuracy, but meaningful improvement in patient care.

4. Radiation Protection as Culture (Technology, Behavior, Organization)

Radiation protection in radiology is increasingly recognized not merely as a collection of technical rules, but as a comprehensive culture that integrates technology, human behavior, and organizational structures. This cultural perspective connects the classical principles of radiation protection—justification, optimization (including the ALARA principle), and dose limitation—with routine clinical practice, clinical decision-making, and leadership within radiology departments. (24) Such an approach reflects the understanding that radiation safety is shaped by everyday professional actions and institutional priorities rather than by technology alone.

This perspective is consistent with international recommendations, which emphasize justification, optimization, and dose limitation as the foundational principles of radiation protection practice. The International Commission on Radiological Protection (ICRP) explicitly frames these principles within a system that requires professional responsibility, education, and organizational support to be effective in clinical settings. (13, 25)

4.1 Technology: Optimization, Automation, and Monitoring

From a technological standpoint, radiation protection relies on optimized imaging protocols and effective dose management systems. Advances in computed tomography and other imaging modalities have introduced automatic exposure control, iterative reconstruction algorithms, and protocol standardization strategies aimed at preserving diagnostic image quality while minimizing patient exposure. However, large-scale studies demonstrate substantial variability in radiation doses between institutions, often attributable to protocol selection, parameter settings, and workflow differences rather than inherent equipment limitations. (26) This variability highlights both the potential and the limitations of purely technical dose-reduction strategies.

Dose monitoring systems, supported by digital imaging and hospital information infrastructures, enable systematic collection and analysis of radiation exposure data. These platforms facilitate benchmarking against diagnostic reference levels (DRLs), identification of outliers, and implementation of corrective actions. When combined with education and structured quality improvement processes, dose monitoring and audit-and-feedback mechanisms have been shown to reduce radiation exposure without compromising diagnostic performance. (27) International organizations, including the International Atomic Energy Agency (IAEA), recommend such systematic approaches as essential components of medical radiation protection programs. (28)

4.2 Behavior: Awareness, Training, and Professional Responsibility

Technology alone cannot ensure radiation safety without informed and deliberate human action. Persistent variability in radiation doses for similar CT examinations across institutions underscores the central role of user-dependent decisions, such as protocol selection and parameter adjustment, in determining patient exposure. (26) These findings indicate that suboptimal practices are often driven by gaps in training, awareness, or routine habits rather than by technical constraints.

A robust radiation protection culture therefore requires continuous education and professional development for radiologists, radiologic technologists, and medical physicists. Professional and international organizations emphasize that radiation protection is an ethical obligation and an integral part of high-quality clinical care. Educational initiatives should address radiation risk communication, evidence-based modality selection, and the application of appropriateness criteria. Behavioral interventions, including structured audits, feedback systems, and collaborative quality improvement initiatives, have demonstrated measurable reductions in unnecessary radiation exposure while maintaining clinical effectiveness. (27)

4.3 Organization: Governance, Processes, and Safety Culture

At the organizational level, embedding radiation protection into governance structures and standard operating procedures promotes consistency, accountability, and sustainability. Designated radiation protection officers, medical physics experts, and multidisciplinary committees play a key role in protocol harmonization, incident reporting, and performance monitoring. Such formal structures support a just and learning safety culture, in which staff are encouraged to report near-miss events and quality concerns without fear of punitive consequences.

International safety standards and regulatory frameworks further reinforce the need to integrate radiation protection into broader health care quality management systems rather than treating it as an isolated compliance requirement. The IAEA safety guidance on medical uses of ionizing radiation provides a comprehensive framework for implementing coordinated technical, educational, and managerial measures to protect patients, workers, and the public. (28)

4.4 Synthesis: Radiation Protection as Culture

Radiation protection in radiology represents a complex socio-technical system. Technology supplies the tools for dose optimization and monitoring; professional behavior translates knowledge into daily practice; and organizational structures ensure reliability, accountability, and continuous learning. When these elements are aligned and supported by international standards and evidence-based governance, radiation protection evolves beyond regulatory compliance into a pervasive culture of safety that enhances patient care and professional integrity in radiology.

5. AI in Radiology: Application Areas and Evidence

Artificial intelligence (AI) has progressed in radiology from experimental prototypes to clinically deployed systems across multiple application domains. Current implementations already demonstrate measurable efficiency gains and task-specific performance improvements, while simultaneously highlighting the necessity of contextual evaluation, continuous monitoring, and sustained human oversight (29, 30)

5.1 Image Interpretation and Diagnostic Support

The most mature and widely studied AI applications in radiology focus on image interpretation, particularly in high-volume examinations such as chest radiography, mammography, and CT. Deep learning algorithms have demonstrated diagnostic performance comparable to expert radiologists in specific, well-defined tasks.

In mammography, a large retrospective study by McKinney et al. showed that a deep learning system reduced both false-positive and false-negative rates compared with human readers across datasets from the United States and the United Kingdom (31). Importantly, the study emphasized that AI performance varied across populations and imaging settings, reinforcing the need for local validation before clinical deployment (31).

For chest X-ray interpretation, commercially deployed systems such as those developed by Annalise.ai are based on multi-label deep learning models trained to detect dozens of radiographic findings simultaneously. Clinical validation studies have demonstrated improved sensitivity for certain pathologies when AI is used as a second reader, particularly in emergency and high-throughput settings (32, 33). However, these gains are task-specific and depend strongly on prevalence, case mix, and reader experience.

5.2 Workflow Automation and Reporting Efficiency

Beyond diagnosis, AI has shown significant impact in workflow automation and reporting efficiency. Natural language processing (NLP) and generative AI techniques are increasingly used for report structuring, auto-completion, and clinical summarization. Studies conducted in academic radiology departments demonstrate that AI-assisted reporting can reduce reporting times while maintaining diagnostic accuracy, particularly for standardized examinations such as trauma CT or chest imaging (34).

Nevertheless, evidence also indicates that unchecked automation may introduce new risks, including propagation of template errors and reduced critical reflection. Consequently, professional societies emphasize that AI-generated text must remain assistive rather than autonomous, with final responsibility residing unequivocally with the radiologist (29).

5.3 Radiotherapy Planning and Image Segmentation

One of the most robust application areas for AI lies in image segmentation and radiotherapy planning. Deep learning–based autocontouring systems have consistently demonstrated substantial reductions in planning time while achieving contour accuracy comparable to expert manual delineations. Multi-institutional studies report time savings of up to 50–70% for organs-at-risk and target volumes, particularly in head-and-neck and prostate cancer workflows (35).

Commercial implementations, including systems integrated into clinical radiotherapy platforms and cloud-based solutions (e.g., Microsoft-supported research collaborations), illustrate how AI can shift professional effort from repetitive manual tasks toward quality assurance and clinical decision-making. Nonetheless, contouring errors - especially in anatomically complex or postoperative cases - remain clinically relevant, underscoring the continued need for expert review (36).

5.4 Evidence Quality, Limitations, and Generalizability

Despite promising results, the current evidence base for AI in radiology remains heterogeneous. Many studies are retrospective, single-center, or enriched with high disease prevalence, limiting external validity. Systematic reviews highlight frequent shortcomings in study design, including limited reporting on failure modes, insufficient subgroup analysis, and lack of prospective outcome data. (37)

Moreover, performance degradation after deployment—due to dataset shift, protocol changes, or evolving disease patterns—has been documented, emphasizing that AI systems require continuous monitoring and recalibration rather than one-time approval. (30)

5.5 Human Oversight and Clinical Integration

Across all application domains, a consistent conclusion emerges: AI systems deliver the greatest benefit when deployed as decision-support tools embedded within clinical workflows, not as replacements for human expertise. Human–AI collaboration has been shown to outperform either alone in multiple diagnostic tasks, particularly when AI outputs are presented transparently and radiologists are trained to interpret algorithmic confidence and limitations. (38)

Accordingly, regulatory authorities and professional societies converge on the principle that accountability remains with the physician, and that AI systems must be auditable, explainable to an appropriate degree, and aligned with clinical responsibility frameworks (29, 39).

5.6 Summary

AI applications in radiology already demonstrate tangible gains in efficiency, standardization, and task-specific diagnostic performance. Radiotherapy planning, chest X-ray interpretation, and reporting support represent particularly mature use cases. However, current evidence also highlights limitations related to generalizability, dataset bias, and long-term performance stability. Sustainable clinical value therefore depends not only on algorithmic accuracy but on context-aware implementation, continuous evaluation, and robust human oversight.

6. Generative AI: Support Rather Than Replacement

For several years, the discourse surrounding artificial intelligence in radiology was dominated by predictions of professional displacement. This narrative was epitomized by Geoffrey Hinton's widely cited statement in 2016 suggesting that "we should stop training radiologists," reflecting the belief that image recognition tasks would soon be fully automated by deep learning systems. Nearly a decade later, empirical evidence and clinical experience have demonstrated the opposite: radiologists are not being replaced but are increasingly integrating AI - particularly generative AI - into their workflows as a supportive technology.

6.1 From Automation Anxiety to Augmentation Reality

Early concerns about replacement were largely driven by narrow task-based benchmarks in image classification, where AI systems matched or exceeded human performance under controlled conditions. However, real-world radiology encompasses far more than image recognition, including clinical reasoning, contextual interpretation, communication, quality assurance, and interdisciplinary coordination. Subsequent analyses have emphasized that these broader competencies are not amenable to full automation and instead benefit from human – AI collaboration (30, 34).

Generative AI systems—based on large language models (LLMs) and multimodal architectures—mark a conceptual shift from diagnostic automation toward cognitive and administrative support. Rather than issuing autonomous diagnoses, these systems assist with report drafting, clinical summarization, protocol suggestions, and information retrieval, thereby reducing cognitive load and time spent on non-interpretative tasks (29).

6.2 Generative AI in Reporting and Documentation

One of the most immediate applications of generative AI in radiology is report generation and structuring. LLM-based systems can draft preliminary reports from structured inputs, prior examinations, and clinical context, which are then reviewed, edited, and finalized by radiologists.
Early studies indicate that such tools can reduce reporting time and improve consistency, particularly for standardized examinations, while maintaining physician oversight as a safeguard against errors and hallucinations. (34, 40)

Crucially, professional guidance consistently frames generative AI as an assistive technology. The ESR explicitly states that AI-generated text must not replace clinical judgment and that radiologists remain fully accountable for report content and diagnostic conclusions (29). This positioning reflects broader concerns regarding automation bias and underscores the importance of maintaining human responsibility.

6.3 Evidence from Early Clinical Evaluations

Emerging evaluations of generative AI tools in medical documentation suggest that their value lies in workflow efficiency rather than diagnostic autonomy. In a study assessing the use of ChatGPT-like models for radiology-related tasks, performance was found to be variable and highly dependent on prompt structure, task complexity, and clinical supervision, reinforcing that such systems are not reliable as standalone clinical decision-makers. (41)
These findings align with broader healthcare AI literature demonstrating that productivity gains are most pronounced when AI offloads clerical and repetitive tasks, allowing clinicians to reallocate time toward patient interaction, complex decision-making, and quality assurance. (42)

6.4 Professional Roles and Responsibility

The reframing of AI from replacement to support has important implications for professional identity and training. Rather than diminishing the role of radiologists, generative AI amplifies the need for domain expertise, critical oversight, and system literacy. Radiologists must understand AI limitations, recognize erroneous outputs, and contextualize algorithmic suggestions within the clinical picture—skills that cannot be delegated to machines. (30)
Regulatory authorities reinforce this view. The U.S. Food and Drug Administration explicitly emphasizes that AI systems in medicine function as decision-support tools and that accountability remains with the healthcare professional, particularly for adaptive and generative models whose outputs may vary over time. (39)

6.5 Synthesis

Nearly a decade after early predictions of obsolescence, radiology offers a clear example of augmentation rather than replacement. Generative AI is increasingly used to streamline documentation, reporting, and information management, reducing administrative burden while preserving - and in some cases enhancing - clinical quality. The evidence to date supports a model in which generative AI serves as a supportive layer within radiological workflows, contingent on transparency, validation, and continuous human oversight.

7. Regulation, Governance, and Quality Assurance

The rapid expansion of artificial intelligence (AI) in radiology has shifted the discussion from whether AI can perform specific tasks to how such systems can be deployed safely, responsibly, and sustainably in clinical environments. Regulation, governance, and quality assurance (QA) are therefore not administrative add-ons but prerequisites for clinical adoption. Recent literature increasingly emphasizes that the key challenge is lifecycle control of systems that may behave differently across institutions, populations, and time. (7, 8, 10, 12)

7.1 Regulatory frameworks: from permissive innovation to risk-based control

Globally, regulatory approaches to AI in medical imaging are converging toward risk-based models that prioritize patient safety, transparency, and accountability. In Europe, radiology-relevant AI tools are typically considered high-risk systems because they influence diagnostic and therapeutic decisions. The European Society of Radiology (ESR) has emphasized that the upcoming EU AI Act will likely strengthen obligations for human oversight, documentation, transparency, and post-market responsibilities. (18, 19) In parallel, AI products intended for clinical use remain subject to medical device regulations, meaning that radiology departments cannot treat AI as a "software add-on" but must consider it a regulated medical technology.

From a practical standpoint, this regulatory evolution matters because it influences what counts as acceptable evidence. Traditional performance metrics derived from retrospective datasets are increasingly insufficient as a sole basis for adoption, particularly when a system is expected to operate in heterogeneous real-world environments. The regulatory landscape described in the British Journal of Radiology highlights that compliance requirements will continue to expand, not least because AI systems raise unique challenges such as continuous updating, unclear failure modes, and the need for traceable decision pathways. (8)

A further complication arises with the emergence of large language models (LLMs) and generative AI. These systems do not fit neatly into conventional *"locked algorithm"* paradigms. Regulatory approval processes for LLM-based medical devices require additional considerations beyond classical AI, including issues of non-deterministic outputs, susceptibility to hallucinations, and the difficulty of defining stable performance characteristics. (18, 19) For radiology, this is particularly relevant because LLMs may increasingly be used for reporting support, protocol guidance, or clinical summarization —functions that can still affect patient care even if they are not framed as diagnostic classification tools.

7.2 Governance: defining responsibility and preventing accountability gaps

Regulation defines external requirements, but governance determines how an institution operationalizes them. Governance in radiology AI must address three core questions:

- *Who owns the system clinically?*
- *Who is accountable when the system fails?*
- *How is ongoing performance ensured?*

A consistent message across recent sources is that the radiologist remains responsible for the final diagnostic output, even when AI is integrated into the workflow. (7, 8, 10, 12) This principle is not merely a legal formality; it has practical implications. If AI output is treated as authoritative or is integrated in a way that subtly nudges decision-making, then responsibility without control becomes an unsafe model. Therefore, governance must ensure that radiologists retain meaningful oversight and the ability to challenge or disregard AI suggestions.

The need for structured governance is further reinforced by evidence that AI assistance does not benefit all radiologists equally and can sometimes worsen performance when AI is wrong. (7, 8, 10, 12) Such findings undermine simplistic assumptions that AI is uniformly "helpful" and highlight the importance of implementation strategies that explicitly manage human factors, training, and error exposure. Governance must therefore include human–AI interaction considerations, not only technical validation.

A realistic governance model typically requires a multidisciplinary structure. In many institutions, this includes radiology leadership, medical physics, IT and cybersecurity, data protection officers, legal counsel, and clinical stakeholders from high-impact pathways (e.g., emergency medicine, oncology). Governance should define decision rights for procurement, evaluation, deployment, monitoring, and decommissioning. Without such structures, AI adoption risks becoming fragmented, vendor-driven, or dependent on local enthusiasm rather than evidence and oversight.

7.3 Quality assurance as a life-cycle obligation, not a one-time test

A recurring limitation in the AI radiology literature is the mismatch between how AI systems are validated and how they are used. Many AI tools demonstrate performance in retrospective datasets but are deployed into workflows with different prevalence, imaging protocols, patient populations, and operational constraints. The *"emperor has few clothes"* critique captures this gap sharply: AI systems may appear impressive in controlled settings, yet evidence for efficiency gains and robust real-world impact remains limited. (18, 19) This critique is not anti-technology; it is a reminder that clinical value depends on implementation and sustained performance.

Quality assurance for radiology AI must therefore be conceptualized as continuous. Testing processes described in the medical physics literature emphasize that evaluation should cover not only algorithm performance but also integration, failure handling, and reproducibility. (7, 8, 10) In practice, QA needs at least three layers:

1. Pre-deployment validation (local acceptance testing)

Before routine use, AI systems should be tested on local data that reflect the institution's scanners, protocols, patient mix, and clinical prevalence. This step helps identify dataset shift early. It also provides baseline metrics against which future drift can be detected. A crucial governance decision is whether the system is used as a second reader, triage tool, or quantification aid—each use case implies different risk profiles and QA requirements.

2. Deployment monitoring (performance surveillance)

- Post-market surveillance is frequently mentioned as essential, partly because prospective randomized trials are often too resource-intensive and too slow for rapidly evolving software. (11) Monitoring should include:

- basic performance indicators (e.g., sensitivity proxies, false-positive rates where measurable)
- workflow metrics (time-to-report, case prioritization effects)
- discrepancy and incident tracking
- user feedback (radiologist trust, perceived failure modes)
- importantly, monitoring should not rely solely on vendor dashboards. Institutions need independent capacity to detect unexpected behavior, particularly in high-risk pathways.

3. Periodic re-evaluation and controlled updating

- AI systems may degrade over time due to changes in scanners, reconstruction algorithms, patient demographics, or clinical practice. Additionally, software updates may change performance characteristics. Governance must ensure that updates are treated as clinically relevant events requiring revalidation. This becomes more complex with adaptive AI systems and even more so with LLM-based components, where outputs may vary and *"version stability"* can be difficult to define. (18, 19)

7.4 Managing risk: from technical errors to socio-technical failure modes

Traditional medical device QA often focuses on technical accuracy and hardware reliability. AI introduces new categories of risk, including sociotechnical failures where harm results from the interaction between humans, software, and workflow.

One prominent example is automation bias—overreliance on automated suggestions. Evidence indicates that incorrect AI predictions can adversely affect radiologist performance on aggregate and for specific tasks. (7, 8, 10, 12) This suggests that AI errors are not merely additive but can propagate through human decision-making. A governance and QA system must therefore consider not only *"how often AI is wrong,"* but also *"what happens when AI is wrong."*

Risk management must also address the possibility of miscalibration, particularly when AI is deployed in populations with different disease prevalence. A system trained in one setting may produce misleading probability estimates in another, affecting both radiologist interpretation and clinical decision-making. (11) This supports the argument that local validation and calibration checks are not optional extras but essential safety steps.

7.5 Documentation, transparency, and auditability

From a regulatory and clinical governance perspective, documentation is a practical necessity. Radiology departments must be able to answer basic questions:
- *What does the AI do?*
- *On which data was it trained?*
- *How is it intended to be used?*
- *What are known limitations?*
- *What performance has been demonstrated locally?*
- *What happens when the AI output conflicts with radiologist judgment?*

In Europe, the move toward stronger regulatory oversight will likely increase expectations for documentation, audit trails, and transparency. (7, 8, 10) Legal analyses also emphasize that unclear documentation and undefined responsibility boundaries create liability risks. (12, 13) For quality assurance, documentation supports reproducibility and learning: when an AI-related incident occurs, it must be possible to reconstruct what the system output was, how it was displayed, and how the clinician responded.

7.6 A pragmatic synthesis: what "good governance" looks like in radiology

Taken together, recent evidence and expert guidance suggest that successful AI deployment in radiology depends less on single performance numbers and more on robust governance and QA. Regulation sets minimum standards, but departments must translate them into operational practice. Testing must be local and life-cycle oriented, monitoring must be continuous, and human oversight must be meaningful rather than symbolic. (7, 8, 10, 12)

A conservative and realistic conclusion is that AI in radiology is best treated as a high-impact clinical technology that requires the same discipline as any other medical device—while acknowledging that its risks are often less visible and more workflow-dependent. Radiology departments that invest early in governance structures, QA processes, and post-deployment monitoring are more likely to realize sustainable benefits and less likely to experience harmful surprises. The central goal should not be rapid adoption, but safe and accountable integration into clinical care.

8. Limit of Current Systems: "Common Sense" and Explainability

Despite measurable progress in narrow radiological tasks, current AI systems remain fundamentally limited in ways that are clinically relevant and often underestimated in implementation discussions. These limitations are not primarily about raw pattern recognition, where deep learning has demonstrated strong performance in many settings, but about robustness, contextual reasoning, and the ability to behave safely when confronted with uncertainty, atypical presentations, or shifting clinical environments. In other words, contemporary AI may appear competent within well-defined test conditions, yet still lack the "common sense" required for reliable operation in real-world radiology.

8.1 "Common sense" in radiology: more than image classification

Radiological interpretation is not simply a matter of detecting abnormalities. It is an integrative cognitive process that combines imaging findings with clinical context, prior examinations, pre-test probability, and downstream consequences. Radiologists routinely perform tasks that are difficult to formalize: weighing differential diagnoses, recognizing when an image is technically inadequate, identifying incidental findings that matter (and those that do not), and tailoring recommendations to patient-specific circumstances.
Current AI systems typically do not possess this form of contextual reasoning. They excel at specific tasks under predefined conditions but struggle when the clinical question

changes, when imaging protocols differ, or when unexpected confounders occur. This limitation is particularly important because radiology is full of “edge cases”: post-operative anatomy, mixed pathologies, rare diseases, artifacts, and incomplete clinical information. A model that performs well on average may still fail in precisely the cases where radiologists add the most value.

The gap between narrow task performance and real-world clinical utility contributes to a broader sense of “post-hype realism.” A critical appraisal has argued that many AI tools currently add complexity without proportionate efficiency gains, particularly when they are layered onto existing workflows rather than replacing clearly defined tasks. (11) In such scenarios, radiologists still must read the entire case, verify AI outputs, and manage exceptions—meaning that the AI does not remove work but can create additional cognitive load.

8.2 Robustness and generalizability: the persistent problem of dataset shift

A central technical and clinical limitation is generalizability. Many AI systems are trained and validated on datasets that do not represent the full heterogeneity of clinical practice. Differences in scanners, reconstruction algorithms, acquisition parameters, patient demographics, disease prevalence, and institutional workflows can produce dataset shift that degrades performance.

In radiology, such shifts are not rare; they are routine. A system validated in a tertiary academic center may behave differently in a community hospital. A model trained on one vendor’s imaging data may fail silently on another. Even within the same institution, protocol updates or software upgrades can change image appearance enough to influence model outputs. These effects are difficult to predict from retrospective validation alone, reinforcing the need for ongoing monitoring and post-market surveillance. (7, 10, 11)

A related concern is that performance metrics reported in studies often mask clinically relevant failure modes. High AUC values can coexist with systematic errors in subgroups or with poor calibration in real-world prevalence settings. The clinical risk is not only that the AI is imperfect, but that its errors may not be obvious to users—particularly when the system presents confident outputs without reliable uncertainty information.

8.3 Human factors: why AI errors are not neutral

In radiology, AI errors are not necessarily independent of human performance. Reader studies have shown that AI assistance can have heterogeneous effects across radiologists, and that incorrect AI predictions can adversely influence radiologist performance on aggregated tasks and on specific pathologies. (1) This is a crucial point: AI is not merely an additional opinion, but a cognitive input that can bias interpretation.

Such effects align with well-known human factors phenomena, including automation bias and authority bias. When AI is presented as *“smart”* or *“validated”*, users may overweight its suggestions, especially under time pressure or in ambiguous cases. The practical implication is that the safety profile of AI is not determined solely by its standalone accuracy, but by the interaction between AI outputs, human decision-making, and workflow design. This makes explainability, calibration, and appropriate user training more than academic concerns; they become patient safety issues.

A conservative interpretation is therefore warranted: even high-performing AI systems can reduce overall diagnostic quality if they are integrated in a way that increases over-reliance or disrupts radiologists’ normal verification strategies. The goal of implementation should not be to maximize AI visibility, but to ensure that AI outputs are presented in ways that support sound clinical judgment.

8.4 Explainability: promises, limits, and practical relevance

Explainability is frequently proposed as a solution to trust and safety concerns. In principle, explainable AI should allow users to understand why a system produced a given output, identify when it is likely to be wrong, and maintain meaningful oversight. In practice, however, explainability remains limited and sometimes misunderstood.

Many commonly used explainability methods in imaging (e.g., saliency maps or heatmaps) can provide visually appealing overlays but do not necessarily correspond to clinically meaningful reasoning. They may highlight regions correlated with model predictions without proving causal understanding. Furthermore, explanations can create a false sense of security: users may interpret an explanation as evidence of correctness, even when the model is wrong.

From a clinical perspective, the most useful "explainability" may not be a visual overlay, but robust transparency about model scope, limitations, and uncertainty.
This includes:
- *what the model was trained on,*
- *which populations and scanners were represented,*
- *what kinds of errors are common,*
- *and how performance changes with prevalence.*

These elements align closely with governance and quality assurance requirements, including documentation, auditability, and monitoring. (7, 8, 10, 12)

8.5 LLMs and generative systems: a new category of limitations

Large language models introduce additional constraints beyond conventional diagnostic AI. While LLMs can support radiology through report drafting, summarization, protocol guidance, or structured reporting, they are prone to hallucinations, non-deterministic outputs, and sensitivity to prompt wording.
These characteristics make stable validation difficult and raise questions about how such systems can be regulated as me-dical devices. (9)

The regulatory and methodological challenges of LLMs are not theoretical. If an LLM generates a plausible but incorrect statement in a report draft, the error may be difficult to detect—particularly in high-volume settings. Moreover, the output may appear confident and fluent, increasing the risk of overtrust.

A realistic approach is therefore to treat generative AI as a supportive layer that requires strict governance, constrained use cases, and careful QA, rather than as an autonomous clinical agent. (7, 8, 10, 12)

8.6 Summary: why limitations matter for safe clinical adoption

The limitations of current AI systems in radiology are not best described as "AI is not good enough," but rather as "AI is good at some things, yet unreliable in ways that matter clinically." The gap between narrow performance and real-world robustness, the absence of common-sense contextual reasoning, the challenges of dataset shift, and the complexities of human–AI interaction all argue for a cautious approach.

Explainability may contribute to safer deployment, but it should not be treated as a universal remedy. Instead, safe adoption requires a combination of conservative use-case selection, strong governance, local validation, continuous monitoring, and training that addresses human factors. (7, 8, 10, 12) In this framing, radiologists remain central—not because AI is ineffective, but because current systems lack the broader clinical reasoning and responsibility that define radiological practice.

9. Outlook: Agentive Systems and Division of Labor

The near-term future of AI in radiology is unlikely to be defined by autonomous *"replacement"* of radiologists, but rather by a gradual restructuring of workflows and responsibilities. As AI tools become more capable and increasingly integrated into clinical systems, the central question shifts from *"Can AI interpret images?"* to *"Which parts of radiological work should be delegated to machines, and under what governance conditions?"* This outlook requires a pragmatic concept of division of labor: assigning tasks to AI where it is demonstrably reliable, measurable, and safe, while preserving human responsibility for synthesis, context, and final decision-making. (7, 8, 10, 12)

9.1 From isolated tools to orchestrated work-flows

Most current radiology AI systems are narrow applications—detection algorithms, quantification tools, or triage aids. These tools often operate as add-ons to existing workflows. A consistent critique is that such add-on deployment may increase complexity without delivering proportional efficiency gains, because radiologists must still perform full reads and maintain oversight. (11) The next stage of development is therefore expected to focus less on adding more "point solutions" and more on integrating AI into coordinated workflows that remove clearly defined burdens from radiologists.

This evolution is sometimes described as a shift toward "agentive systems": software components that can execute multi-step processes across systems rather than providing a single prediction. In radiology, an agentive workflow might automatically retrieve priors, align follow-up studies, compare measurements longitudinally, detect discrepancies, draft structured summaries, and surface cases that require urgent attention. While this vision is technologically plausible, it raises immediate governance questions. If an agent coordinates multiple tasks, errors may propagate through the workflow, and accountability can become diffuse unless responsibility boundaries are explicitly defined. (7, 8, 10, 12)

A conservative outlook therefore recognizes that the future is not merely *"more AI,"* but *"more interconnected AI,"* which increases both potential benefits and potential failure modes.

9.2 A realistic division of labor: what AI can do well

A practical division of labor should prioritize tasks that are (a) repetitive, (b) time-consuming, (c) measurable, and (d) less dependent on nuanced clinical context. In radiology, this often includes:

a) Image quality and protocol support: identifying incomplete acquisitions, suggesting repeat sequences, and flagging technical limitations.
b) Quantification and measurement: volumetry, lesion segmentation, and longitudinal change tracking—particularly where manual measurement is inconsistent or burdensome.
c) Prior comparison and follow-up tracking: automatically aligning prior studies, highlighting interval changes, and ensuring relevant comparisons are not missed.
d) Workflow triage: flagging potentially urgent findings to reduce time-to-action in high-risk pathways.
e) Structured reporting assistance: populating templates, ensuring completeness, and reducing clerical burden.
f) Administrative automation: coding support, worklist management, and report distribution tasks.

These areas align with the broader argument that radiology's sustainability depends not only on marginal gains in diagnostic accuracy, but on meaningful reductions in workload and improved system efficiency. (11) Importantly, such applications also tend to be easier to validate and monitor than complex "end-to-end diagnostic reasoning" systems.

9.3 What remains distinctly human: synthesis, accountability, and clinical judgement

Even as AI takes on a larger share of measurable tasks, several responsibilities remain inherently human, at least for the foreseeable future:

a) Clinical synthesis and prioritization
Radiologists interpret imaging in the context of incomplete information, competing differentials, and variable clinical relevance. This includes deciding what matters, what can be ignored, and what requires immediate escalation.

b) Handling ambiguity and rare events
Radiology is characterized by exceptions, artifacts, and unusual combinations of findings. AI may perform well on common patterns but is less reliable in atypical situations, particularly under dataset shift. (11)

c) Ethical and professional accountability
Clinical responsibility cannot be delegated to a model. Legal analyses emphasize that accountability remains with the medical professional and the institution, even when AI is involved. (12)

d) Communication and consultation
Discussing findings with clinicians and patients, resolving contradictions, and translating imaging into actionable recommendations remain core radiologist functions. This consultative role is difficult to automate safely.
This division of labor reflects a broader principle: radiology is not only image interpretation but a clinical service embedded in

patient pathways. AI can support this service, but cannot replace its professional responsibility structure.

9.4 Agentive systems and governance: avoiding accountability gaps

As AI becomes more agent-like—executing sequences of actions rather than producing isolated outputs—governance must evolve accordingly. Traditional approval and QA models assume relatively static systems with predictable behavior. Agentive workflows may involve dynamic interactions between multiple software components, increasing complexity and reducing transparency.

This creates a risk of "accountability gaps", where no individual can fully explain why a certain workflow produced a given output. The regulatory and governance literature increasingly emphasizes life-cycle control, documentation, human oversight, and monitoring as safeguards against such gaps. (7, 8, 10, 12) The challenge is to ensure that oversight remains meaningful. *"Human-in-the-loop"* must not become a symbolic phrase that simply transfers responsibility to radiologists without giving them control or visibility into system behavior.

In practice, safe governance of agentive workflows likely requires:
a) clear definition of AI scope and intended use,
b) audit trails for key decisions and outputs,
c) controlled updates and revalidation,
d) incident reporting and corrective action processes,
e) and explicit fallback strategies when AI outputs are unavailable or inconsistent.

These elements mirror medical device safety principles but must be adapted to software that may change more rapidly and interact more broadly with clinical systems. (7, 10)

9.5 A conservative outlook: incremental transformation rather than disruption

A realistic future for radiology is one of incremental transformation rather than sudden disruption. AI will likely be adopted where it solves concrete problems—reducing repetitive workload, improving consistency of quantification, and supporting workflow prioritization—while radiologists remain responsible for interpretation, integration, and patient-centered decision-making.

The most successful implementations will likely be those that treat AI not as a replacement technology, but as a workforce multiplier under strict governance. This approach aligns with the post-hype phase of radiology AI, where the emphasis shifts from performance claims to evidence, safety, and sustainable value creation. (7, 8, 10, 12) In this framing, agentive systems may become valuable tools, but only if their integration is guided by conservative governance and rigorous QA rather than by technological enthusiasm alone. (7, 10, 12)

10. Practical Checklist: Governance & Safe Implementation

Successful implementation of AI in radiology depends less on "algorithmic performance in principle" and more on disciplined governance, local validation, and continuous quality assurance. Recent literature consistently highlights that real-world adoption is constrained by regulatory obligations, human factors, workflow complexity, and limited economic evidence. (7, 8, 10, 12) In this setting, a pragmatic checklist can support departments in moving from interest-driven adoption to safe, auditable, and clinically meaningful deployment.

The following checklist is designed for radiology departments planning to introduce AI systems for clinical use. It focuses on high-risk decision support tools but is applicable to most AI applications, including workflow and reporting support. It reflects core principles of staged clinical evaluation (5), health-economic transparency (6), regulatory alignment (7, 8, 12), and practical testing processes in radiology environments. (10)

10.1 Governance and accountability

a) Define the clinical owner (*"responsible physician"*)

b) Named radiologist accountable for clinical oversight and intended use.

c) Define decision rights and escalation pathways

d) Who can approve deployment, pause use, or decommission the system?

e) Clarify responsibility boundaries

f) AI output is advisory; final responsibility remains with clinicians. (12)

g) Establish a multidisciplinary oversight group

h) Radiology leadership, IT/security, medical physics, legal/compliance, data protection, key referrers.

10.2 Use-case definition and risk classification

a) Specify the intended use precisely

b) Detection, triage, quantification, second reader, reporting support, etc.

c) Define patient population and clinical pathway

d) Emergency, screening, oncology follow-up, MS monitoring, etc.

e) Identify failure modes with clinical risk assessment

f) False negatives vs false positives; consequences and mitigation.

g) Confirm regulatory status and labeling

h) CE marking / regulatory clearance for the intended use. (7, 8)

10.3 Data governance, privacy, and cybersecurity

a) Confirm legal basis for data processing

b) Local privacy laws, institutional approvals, contracts.

c) Ensure secure integration

d) Network segmentation, authentication, logging, vulnerability management.

e) Clarify data flows

f) What leaves the hospital? Cloud processing? Storage duration? (12)

g) Vendor transparency requirements

h) Training data description, versioning, update policies, audit support. (7, 8)

10.4 Local validation before deployment (“acceptance testing”)

a) Test on local representative cases

b) Scanner types, protocols, prevalence, demographics.

c) Define performance metrics and thresholds upfront

d) Sensitivity/specificity proxies, false-positive burden, time impact.

e) Compare against current standard of care

f) Ensure AI adds measurable value rather than complexity overhead. (11)

g) Validate workflow behavior

h) Where AI output appears, how it is displayed, how it is acted upon. (10)

10.5 Workflow integration and human factors

a) Define when and how radiologists see AI results

b) Early triage vs after initial read; avoid overanchoring.

c) Train users (radiologists, technologists, clinicians)

d) Intended use, limitations, known failure modes, escalation rules. (5)

e) Address automation bias explicitly

f) Encourage independent verification, especially in ambiguous cases. (1, 11)

g) Provide a clear “AI off” fallback mode

h) Ensure continuity of care if AI fails or is paused.

10.6 Post-deployment monitoring and quality assurance

a) Establish continuous performance monitoring

b) Drift detection, subgroup issues, unexpected false positives/negatives. (7, 10)

c) Implement incident reporting and review

d) Near misses, discrepancies, adverse events linked to AI output.

e) Monitor workflow impact

f) Turnaround time, prioritization effects, radiologist workload.

g) Revalidate after major changes

h) Scanner upgrades, protocol changes, software updates, vendor model updates. (7, 10)

10.7 Economic and operational evaluation

a) Document implementation costs

b) Licenses, infrastructure, staff time, training, integration.

c) Define expected value outcomes

d) Efficiency gains, reduced rereads, improved quantification consistency.

e) Perform transparent health-economic assessment where feasible

f) Use CHEERS-AI principles for reporting and interpretation. (6)

10.8 Documentation and auditability

a) Maintain an AI system dossier

b) Intended use, validation results, version history, known limitations.

c) Ensure audit trails for AI outputs

d) Output storage, timestamps, user interaction logs where possible. (7, 8)
e) Define review cycles

f) Quarterly/annual governance review; decision to continue, adjust, or stop.

10.9 Checklist summary

AI implementation in radiology should be treated as a controlled clinical intervention rather than a plug-in technology. A conservative governance model emphasizes clear accountability, precise use-case definition, local validation, continuous monitoring, and structured response to drift or failure. (18, 19) This approach supports both patient safety and sustainable clinical value, while reducing the risk that AI adoption becomes driven by expectations rather than evidence. (5, 6, 12)

Discussion

Artificial intelligence has moved from a largely experimental technology to a set of clinically deployed tools that increasingly influence radiological workflows. The present article intentionally adopts a conservative and practice-oriented perspective: rather than focusing on technological potential alone, it integrates current evidence, implementation frameworks, radiation safety culture, and regulatory developments to assess where AI already contributes meaningful value and where limitations remain. Across the reviewed sources, a clear trend emerges: the field has transitioned from early enthusiasm and disruption narratives to methodological realism and a stronger emphasis on governance, quality assurance, and sustained clinical responsibility. (11)

Clinical value and the role of radiology in modern healthcare

Radiology's contribution to clinical care is best understood as multidimensional. It includes diagnostic accuracy, timely and actionable interpretation, consultation, multidisciplinary integration, patient communication, and stewardship of appropriate imaging. (14, 15, 17, 20, 22) Importantly, radiology's value is not always captured by traditional productivity metrics such as report volume or turnaround time. Instead, its impact is often indirect, distributed across clinical decisions and patient pathways. This makes "value" harder to measure, but not less real.
The value-based healthcare perspective reinforces that radiology cannot be reduced to a commodity service. Radiologists create value when imaging results are integrated into clinical reasoning and translated into management-relevant conclusions. (14, 15, 22) In this context, the radiologist's consultative role becomes central, especially in complex cases where interpretation depends on context and where imaging findings must be weighed against differential diagnoses, risks, and downstream consequences. (17, 20)
Patient-centered value also deserves explicit attention. Surveys and feedback-focused initiatives suggest that patients and referring

clinicians increasingly evaluate radiology not only by technical quality, but by clarity, communication, responsiveness, and trust. (18, 19) This has implications for reporting style, accessibility of results, and radiology's visibility within the healthcare system. (16, 23)

Evidence quality: progress, heterogeneity, and persistent gaps

While AI systems have demonstrated strong performance in specific tasks, the evidence base remains heterogeneous. Many studies are retrospective, use enriched datasets, or evaluate performance under controlled reader-study conditions that do not fully reflect routine clinical complexity. (1–4) Prospective outcome-driven trials remain relatively rare, and external validation across diverse institutions and patient populations is still limited. (2, 3, 11)

A critical insight from human–AI interaction research is that AI assistance does not uniformly improve performance. The effect of AI depends on the task, the reader, the clinical setting, and the error profile of the system. (1) Incorrect AI outputs can negatively influence radiologists, illustrating that AI errors are not neutral but can propagate through cognitive bias and workflow pressure. (1, 11) These findings challenge simplistic narratives of universal benefit and support a cautious approach to deployment, particularly in high-risk pathways.

Methodological frameworks such as DECIDE-AI and guidance on clinical evaluation highlight the need for staged evidence generation, transparency, and context-aware reporting. (4, 5) Health-economic standards such as CHEERS-AI further emphasize that claims of value must include implementation costs, workflow effects, and real-world constraints, rather than relying on speculative efficiency arguments. (6) Taken together, these frameworks reflect a broader shift: AI in radiology must be evaluated as a clinical intervention embedded in complex systems, not as a standalone algorithm.

Radiation protection and AI: complementary safety cultures

The inclusion of radiation protection as a cultural concept (technology, behavior, organization) provides an important parallel to AI governance. Radiation safety has long been recognized as a socio-technical challenge: technology enables dose optimization, but outcomes depend on training, behavior, organizational structures, and continuous monitoring. (24 – 28) This logic applies directly to AI. As with radiation protection, safe AI adoption requires not only technical tools but also professional responsibility, institutional processes, and a learning culture.

This perspective supports the argument that AI governance should be integrated into existing safety and quality infrastructures rather than treated as a separate "digital innovation" track. Radiology departments already have experience managing complex technologies with invisible risks; AI extends this responsibility into the domain of software-driven decision support.

Generative AI: meaningful support, but not autonomy

Generative AI and large language models introduce new opportunities and risks. Their value may lie primarily in administrative and cognitive support, such as report drafting, structured documentation, summarization, and information retrieval. (29, 34, 40) However, these systems are prone to hallucinations, instability across prompts, and outputs that may appear plausible while being incorrect. (9, 41) Therefore, their safe use requires constrained use cases, strict oversight, and careful workflow design.

The emerging consensus across regulatory and professional discussions is that generative AI should be positioned as support rather than replacement. (29, 39) This framing aligns with the clinical reality that radiology depends on contextual reasoning, accountability, and communication—elements that current AI systems cannot reliably replicate.

Regulation, governance, and quality assurance as prerequisites

Regulatory developments are increasingly shaping AI adoption in radiology. In Europe, radiology AI tools are typically treated as high-risk systems, implying stronger requirements for documentation, transparency, human oversight, and life-cycle risk management. (7, 8, 12) These requirements are not merely legal constraints; they define the minimum conditions for responsible clinical use.

A key challenge is that AI performance is not static. Dataset shift, protocol changes, population differences, and software updates can degrade performance over time. (10, 11) This makes quality assurance a continuous obligation rather than a one-time validation step.

Testing processes proposed for clinical environments emphasize local acceptance testing, monitoring, and controlled updating. (10) Without these measures, even well-performing systems may become unreliable in practice.

The discussion of governance also highlights a central ethical and professional principle: radiologists remain accountable for clinical decisions, even when AI is involved. (12) This requires that AI tools are implemented in ways that preserve meaningful human oversight, rather than shifting responsibility without control. In practice, robust governance structures, auditability, and incident management processes are necessary to prevent *"accountability gaps,"* particularly as AI becomes more integrated into multi-step workflows. (7, 10)

Limits of current systems and realistic expectations

The limitations of current AI systems are best understood as limitations in robustness, common-sense reasoning, and clinical generalization rather than limitations in narrow pattern recognition. (11) AI can be strong within defined boundaries but remains vulnerable to atypical cases, confounders, and shifts in clinical reality. Explainability methods may improve transparency, but they do not fully solve the deeper problem of contextual reasoning and safe behavior under uncertainty. (9, 11)

Therefore, a realistic near-term outlook is incremental transformation rather than disruption. AI will likely deliver value where tasks are repetitive, measurable, and well-defined—such as quantification, segmentation, triage support, and structured reporting—while radiologists remain essential for synthesis, contextual interpretation, consultation, and responsibility. (1, 7, 10, 11)

Implications for practice

The practical checklist provided in this article translates these insights into implementable steps. It emphasizes governance, use-case definition, local validation, monitoring, documentation, and health-economic evaluation. (5 – 8, 10, 12) Importantly, such checklists should not be seen as bureaucratic burdens but as safety instruments comparable to established radiology QA practices.

A conservative implementation strategy does not slow innovation unnecessarily; rather, it protects patients and radiologists from preventable failures and supports sustainable adoption. The ultimate goal is not rapid deployment, but clinically meaningful integration with demonstrable benefit.

Conclusion

Artificial intelligence is increasingly becoming a practical component of radiology, but its clinical value depends less on headline performance metrics and more on evidence-based implementation, robust governance, and sustained human oversight. Current AI systems can improve efficiency and support task-specific performance, yet limitations in generalizability, human–AI interaction effects, and real-world robustness remain substantial. Radiology therefore enters a post-hype phase in which responsible adoption requires methodological rigor, continuous quality assurance, and alignment with evolving regulatory frameworks. Rather than replacing radiologists, AI is best understood as a supportive technology that can strengthen radiology's clinical role—provided that accountability, safety culture, and patient-centered value remain the guiding principles.

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Declarations

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Optic Nerve Sheath Meningocele: a case report and review of the literature

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Abstract

Optic nerve sheath meningocele (ONSM) is a rare condition with only a few cases reported in the medical literature. The etiology is unknown. The condition is characterized by an expansion of the cerebrospinal fluid space surrounding the optic nerve, without associated inflammation or the presence of orbital or cerebral neoplasms at the apex of the orbit. The condition is characterized by the absence of specific symptoms, with the most common being blurred vision and retro-orbital pain. We present the case of a young patient who was admitted to the emergency department at an external hospital. A clinical examination revealed painless right exophthalmos. No additional neurological symptoms were observed. A Computed Tomography (CT) scan and Magnetic Resonance Imaging (MRI) revealed an ONSM.

Keywords: Optic nerve; Sheath, Meningocele; CT; MRI

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Introduction

ONSM is a rare condition consisting of dilation of the nerve sheath that creates a cavity filled with cerebrospinal fluid (CSF) around the optic nerve without any underlying pathology (1, 2, 3). In 1918, Bane described primary dilation of the optic nerve sheath and referred to it as an optic nerve dural sheath cyst. Since then, a few cases have been reported (4, 5, 6).

One theory suggests that the difference in osmotic gradient between the cerebral and perioptic subarachnoid spaces leads to fluid accumulation. Another theory suggests that congenital narrowing of the optic or cranio-orbital junction may lead to accumulation in the perioptic subarachnoid space (2).

There are no characteristic symptoms associated with optic nerve sheath meningocele. However, blurred vision and retrobulbar pressure are common symptoms (4). An MRI of the orbits is often used to diagnose the condition, as it easily reveals a dilated optic nerve sheath filled with CSF.

Due to the rarity of ONSM, there is currently no consensus on the optimal therapeutic approach.

Case Report

A 16-year-old patient was admitted to the emergency department of an external hospital with painless right exophthalmos. No history of head trauma or other neurological deficits was detected. A CT head was performed. The images revealed a well-defined hypodense cystic mass located just behind the right eye, with evidence of displacement of the extraocular muscles. There was no evidence of bone expansion or erosion (Fig. 1)

MRI demonstrate the presence of an expansive cystic process, measuring 19 x 23 x 21 mm, with well-defined by a thin capsule, located in intraconal space of the right orbit. It has a close anatomical relationship with the optic nerve, which causes anterior compression, deformity, and displacement of the eyeball. In addition, the MRI showed signal characteristics equivalent to those of cerebrospinal fluid in all sequences. No significant anomalous enhancement was observed in the walls or within the lesion after the paramagnetic contrast (gadolinium) intravenous injection (Fig. 2).

Discussion

ONSM is a rare condition involving dilation of the nerve sheath. This dilation creates a cavity filled with CSF around the optic nerve without any underlying pathology such as inflammation, orbital, or brain neoplasia at the apex of the orbit. (1, 5). Bane was the first to describe optic nerve sheath dilation in 1918, referring to it as an optic nerve dural sheath cyst (4). Garrity et al. described an "optic nerve sheath meningocele" in a historical article on 13 patients. Since then, a few cases have been documented in the literature (1, 3, 4, 6, 8).

One theory suggests that the difference in osmotic gradient between the cerebral and periorbital subarachnoid spaces leads to fluid accumulation. This assertion is further substantiated by Lunari et al., that documented elevated protein levels in the CSF of an optic nerve cyst (7). Another theory suggests that a congenital narrowing of the optic or cranio-orbital junction may lead to CSF

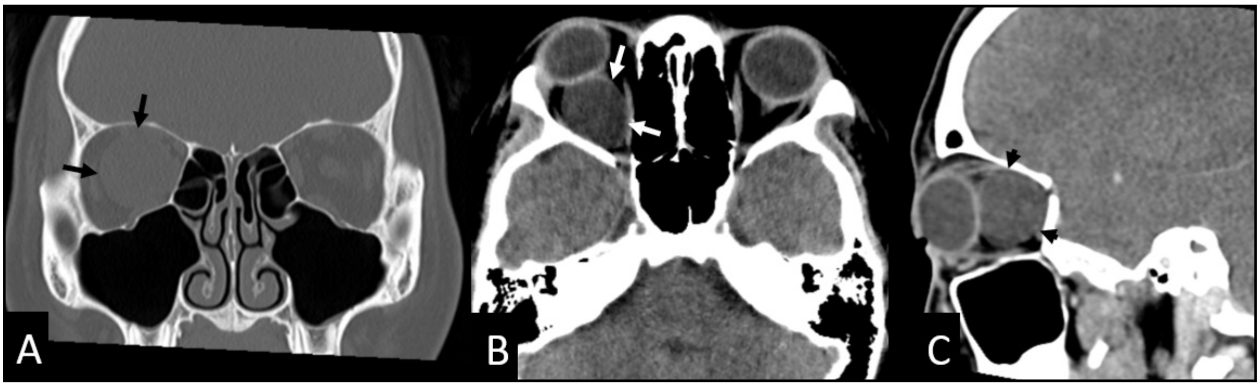

Figure 1: CT: well-defined intraconal cystic mass without bone compromise (black arrows); homogeneous hypodense mass with evidence of extraocular muscle displacement (white arrows), without enhancement after intravenous contrast injection (black arrowheads) A. bone window, B. soft tissues window, C. soft tissues window+contrast.

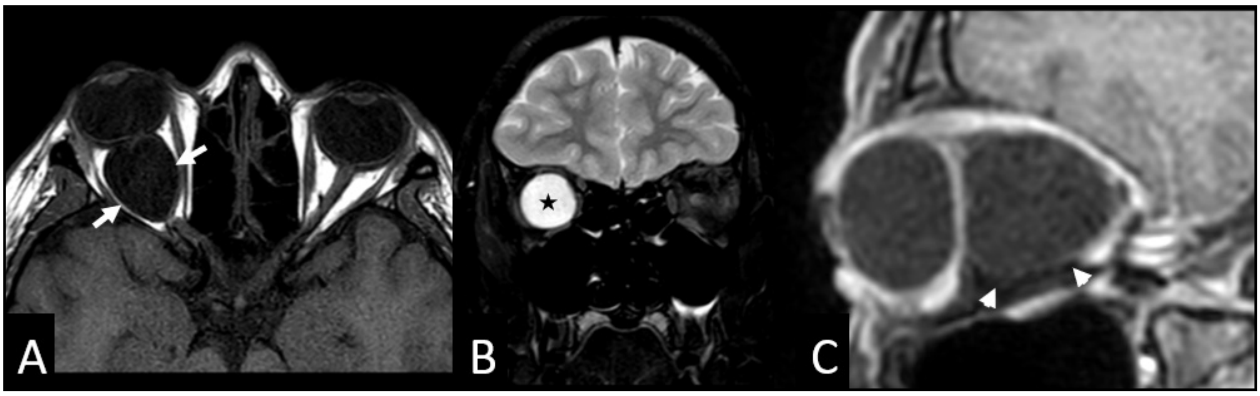

Figure 2: MRI: A) hypointense on T1 WI retroorbital mass with anterior displacement of the globe; B) hyperintense on T2 WI identical signal to cerebrospinal fluid (black star); C) No evidence of enhancement after intravenous contrast injection (white arrowheads)

accumulation in the perioptic subarachnoid space (2, 3).
Enlargement of the optic nerve or optic nerve sheath complex may be indicative of an apical neoplastic mass, such as a meningioma, vascular hamartoma, glioma, neurofibromatosis, von Hippel-Lindau disease, hemangioma, intracranial hypertension or skull-orbital fracture (3, 4, 5).

ONMS does not present with characteristic symptoms. However, blurred vision, headache, retrobulbar pressure, and retroorbital pain are common symptoms (2, 4).
Typically, a MRI scan of the orbits is used to diagnose the condition, as it allows for visualization of a dilated optic nerve sheath filled with CSF (5, 8). Some T2-weighted coronal images show a "bull´s eye" appearance, representing the expanded CSF spaces around the optic nerve (3). The use of fat suppression techniques is an effective method for ruling out the presence of intra-orbital tissue lesions and optic nerve compression (4).
Furthermore, MRI provides a more detailed differential diagnosis of ONSM, including other optic nerve tumor lesions, such as gliomas or meningiomas, especially cystic ones (2, 3, 4, 6).

Due to the rarity of ONSM, there is currently no consensus on the optimal therapeutic approach. Treatment is customized to meet each patient's specific needs (1). In some cases, medical therapy with oral acetazolamide has shown positive results (3). In cases where no improvement has been observed with medical treatment, surgical decompression is the preferred option, especially when vision loss is progressive (1, 5, 6, 7, 8). In situations where progress is minimal or nonexistent, observation may be a valuable approach (2).

Conclusion

ONSM is a rare disorder with no characteristic symptoms, characterized by the collection of cerebrospinal fluid in the subarachnoid space of the intraorbital portion of the optic nerve. The etiology of this condition remains unclear, underscoring the necessity for comprehensive diagnostic imaging. Among the available imaging modalities, MRI is regarded as the preferred study to guide treatment, which can range from conservative therapy to complex surgical repair. Therefore, it is essential to implement individualized treatment protocols to optimize patient outcomes.

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Declarations

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Radiographers' Perceptions of Artificial Intelligence and Theranostics: Implications for Job Security and Professional Adaptation

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Abstract

Background: Artificial Intelligence (AI) and theranostics are transforming radiographic practice by enhancing diagnostic precision and enabling personalized treatment. However, these innovations raise concerns about professional adaptation and job security.

Objectives: To investigate Nigerian radiographers' awareness, perceptions, and adaptability regarding these technologies, with a focus on job security and professional relevance.

Method: A cross-sectional survey of 349 Nigerian radiographers assessed awareness, perceptions, and adaptability regarding AI and theranostics. Data were analyzed using descriptive and inferential statistics (SPSS v25).

Results: Awareness was higher for AI than theranostics: 31.2% were moderately familiar and 28.7% very familiar with AI, whereas 34.4% were not familiar with theranostics. Most respondents (64.5%) had not attended training or seminars. Regarding job security, 41.8% agreed AI and theranostics could reduce the demand for manual radiography skills, and 30.7% agreed automation might cause role displacement. Nevertheless, adaptability was promising: 51.3% expressed interest in further education or certification, and 48.1% viewed adoption as an opportunity for career growth. Key adaptation factors included mentorship (50.7%), financial support (45.6%), and curriculum integration (41.5%).

Conclusion: Nigerian radiographers demonstrate moderate familiarity with AI but limited understanding of theranostics. While job security concerns persist, willingness to upskill is strong. Structured training, mentorship, and curriculum reform are essential to support professional adaptation and safeguard radiographers' relevance in the era of AI and theranostics.

Contribution: This study highlights the need for radiography professional bodies and policymakers to prioritize structured training pathways, financial incentives, and cross-disciplinary collaborations to ensure radiographers remain central to technological transitions.

Keywords: Artificial Intelligence, Theranostics, Radiography, Job Security, Professional Adaptation, Nigeria

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Introduction

Artificial intelligence (AI) and theranostics are rapidly transforming healthcare, particularly within medical imaging and radiographic practice, some of which include workflow optimization, image acquisition, diagnostic interpretation, and treatment planning (1).

Recent advances in deep learning and neural networks have accelerated the integration of AI into clinical imaging, offering greater efficiency, improved accuracy, and enhanced patient safety (2). In parallel, theranostics — an approach that combines diagnostic imaging with targeted therapy — has gained increasing importance in nuclear medicine and precision oncology (3). By enabling clinicians to both detect and treat specific pathologies, theranostics exemplifies the move toward personalized medicine.

Globally, radiographers' perceptions of these innovations have been mixed. While many acknowledge AI's capacity to reduce errors, optimize workflows, and advance radiographic practice, others express concerns about automation leading to job displacement (4, 5). A study in Zimbabwe found that radiographers anticipated reduced roles and altered professional practices with AI adoption (6).
Similarly, Saudi Arabian radiographers largely agreed that AI would play a significant role in imaging, but cited barriers such as cost, lack of expertise, and machine reliability (7). Badera et al. (8) reported generally favorable attitudes toward AI among radiographers and radiologists but highlighted mentorship gaps as a key obstacle to adoption. These findings illustrate the global tension between optimism about technological progress and apprehension about professional security.

Despite these developments, the Nigerian context remains underexplored. Although AI and theranostics are increasingly discussed in international literature, limited research has examined how Nigerian radiographers perceive these technologies or how prepared they are to adapt. Considering Nigeria's evolving healthcare infrastructure, absence of theranostics training in most radiography curricula, and limited access to mentorship and continuing education, this knowledge gap is particularly significant. Without understanding local awareness and readiness, the professional practice in Nigeria risks falling behind in adapting to global technological shifts.
This study therefore investigates Nigerian radiographers' awareness, perceptions, and adaptability regarding AI and theranostics. Specifically, it examines their concerns about job security, willingness to upskill, and the structural and educational supports necessary for effective professional adaptation.

Materials and Methods

This study employed a prospective cross-sectional survey design, conducted between October 2024 and January 2025 across private and federal government hospitals in Nigeria. Ethical clearance was obtained from an institutions review board (NHREC/05/01/2008B-FWA00002458-1RB00002323). The study population consisted of licensed radiographers registered with the Radiographers Registration Board of Nigeria (RRBN). Only practicing radiographers who consented to participate were included, while other healthcare workers, academic radiographers, industrial radiographers, and radiographers unwilling to participate were excluded.

A convenience sampling technique was used and data were collected using a structured, self-administered questionnaire designed in Google Forms. The instrument consisted of three sections: Section I covered demographic characteristics such as age, gender, years of practice, specialty, and geopolitical zone of practice; Section II assessed awareness and understanding of AI and theranostics; while Section III focused on perceptions of job security, willingness to adapt, and factors influencing adaptation.

The questionnaire was pretested on 15 radiographers at a university teaching hospital to assess internal consistency using Cronbach's alpha, and this yielded a coefficient of 0.79, indicating acceptable reliability. Content validity was ensured through expert review by radiography lecturers and clinical practitioners. The questionnaire link was distributed via professional WhatsApp groups, LinkedIn, email lists, and direct contacts of practicing radiographers. Participation was voluntary, and informed consent was obtained prior to completing the survey.
Completed responses were exported from Google Forms into IBM SPSS version 25 for

analysis. Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize demographic and awareness data, while inferential statistics, including cross-tabulations and mean comparisons, were applied to explore perceptions and adaptability patterns. Results were presented in tables for clarity. Anonymity was maintained by ensuring that no personal identifiers were collected, and data were stored securely for academic purposes only.

Results

Demographic Characteristics

Of the 349 radiographers who participated in the study, majority were male (56.7%) and within the 25–34 years age group (46.1%). Most respondents had practiced for fewer than five years (61.6%), reflecting a predominantly early-career workforce. The South-East geopolitical zone contributed the highest proportion of respondents (39.5%), while diagnostic radiography was the most common specialty (79.7%) (Table 1).

Awareness and Understanding of AI and Theranostics

From Table 2, familiarity with AI was generally higher than with theranostics. About 31.2% reported being moderately familiar with AI and 28.7% very familiar, while only 7.4% were not familiar at all. In contrast, awareness of theranostics was low, with 34.4% reporting no familiarity and only 7.7% describing themselves as extremely familiar.

Knowledge sufficiency was also limited, as 42.7% either disagreed or strongly disagreed that their current knowledge of AI and theranostics was adequate to meet future professional demands. Furthermore, 64.5% of respondents had never attended training or seminars on either technology.

Perceptions of Job Security

Concerns about job security were evident. More than two-fifths of respondents (41.8%) agreed that AI and theranostics could reduce the demand for manual radiography skills, while 30.7% agreed that automation might lead to role displacement.
At the same time, 74.5% acknowledged that integration of these technologies would require radiographers to acquire new skills to remain relevant (Table 3).

Willingness to Adapt

Despite concerns, respondents expressed a strong willingness to adapt.
Over half (51.3%) indicated interest in pursuing further education or certifications in AI and theranostics, while 48.1% agreed that adoption of these technologies represented an opportunity for personal growth. Although peer resistance was reported as a possible barrier, most respondents viewed adaptation positively (Table 4).

Factors Influencing Adaptation

In Table 5, more than half (50.7%) agreed that access to structured mentorship programs would facilitate adaptation, and 45.6% emphasized the need for financial support or incentives from employers. A further 41.5% supported the inclusion of AI and theranostics training in undergraduate curricula, while 44.4% highlighted the importance of collaboration with other healthcare professionals.
However, workplace infrastructure was identified as a barrier, as only 40.1% agreed that their facilities had sufficient technological support.

Table 1 - Demographic Characteristics of Respondents (n = 349)

Variable	Frequency (n)	Percentage (%)
Gender		
Male	198	56.7
Female	151	43.3
Age Range (Years)		
Below 25	109	31.2
25 - 34	161	46.1
35 - 44	55	15.8
45 - 54	15	4.3
Above 55	9	2.6
Years of Practice		
Less than 5	215	61.6
5 - 10	83	23.8
11 - 20	40	11.5
Above 20	11	3.2
Geopolitical Zone of Practice		
North Central	37	10.6
North East	30	8.6
North West	27	7.7
South East	138	39.5
South-South	50	14.3
South West	67	19.2
Area of Specialty		
Diagnostic Radiography	278	79.7
Nuclear Medicine	17	4.9
Therapeutic Radiography	54	15.5

Table 2 - Awareness and understanding of AI and Theranostics (n = 349)

Variable	**Not familiar**	**Somewhat familiar**	**Moderately familiar**	**Very familiar**	**Extremely familiar**	**Mean ± SD**
How familiar are you with the concept of Artificial Intelligence (AI) in medical imaging?	26 (7.4)	80 (22.9)	109 (31.2)	100 (28.7)	34 (9.7)	3.10 ± 1.10
How familiar are you with theranostics as a field in radiography?	120 (34.4)	77 (22.1)	84 (24.1)	41 (11.7)	27 (7.7)	2.36 ± 1.27
	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	
My current knowledge of AI and Theranostics is sufficient to meet future demands in radiography	44 (12.6)	105 (30.1)	117 (33.5)	65 (18.6)	18 (5.2)	2.74 ± 1.06
There are sufficient resources available to educate radiographers about AI and Theranostics	49 (14.0)	111 (31.8)	101 (28.9)	66 (18.9)	22 (6.3)	2.72 ± 1.06
	No		**Yes**			
I have attended training or seminars on AI and Theranostics	225 (64.5)		124 (35.5)			
Average mean response - 2.73						

Table 3 - Perception of impact of AI and theranostics on job security (n = 349)

Variable	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
AI and theranostics could reduce the demand for manual radiography skills	20 (5.7)	6 (16.0)	87 (24.9)	146 (41.8)	40 (11.9)
Automation through AI might lead to role displacement for radiographers	30 (8.6)	83 (23.8)	94 (26.9)	107 (30.7)	35 (10.0)
The integration of AI and theranostics will require radiographers to acquire new skills to remain relevant	13 (3.7)	18 (5.2)	58 (16.6)	150 (43.0)	110 (31.5)

Table 4 - Radiographers' willingness to adapt to AI and theranostic technologies (n = 349)

Variable	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean ± SD
I am interested in pursuing further education or certifications in AI and theranostics	7 (2.0)	17 (4.9)	67 (19.2)	179 (51.3)	79 (22.6)	3.38 ± 0.88
I see the adoption of AI and theranostics as an opportunity for personal growth in my career	13 (3.7)	14 (4.0)	61 (17.5)	168 (48.1)	93 (26.6)	3.90 ± 0.96
Resistance from peers could influence my decision to adopt new technologies in radiography	47 (13.5)	82 (23.5)	110 (31.5)	84 (24.1)	26 (7.4)	3.11 ± 1.14
Average mean response - 3.46						

Table 5 - Factors influencing radiographers' adaptation (n = 349)

Variable	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean ± SD
Access to structured mentorship programs would facilitate my adaptation to AI and theranostics	10 (2.9)	15 (4.3)	60 (17.2)	177 (50.7)	87 (24.9)	3.91 ± 0.91
Financial support or incentives from employers is necessary for adopting these technologies	14 (4.0)	21 (6.0)	71 (20.3)	159 (45.6)	84 (24.1)	3.80 ± 1.00
AI and theranostics training should be included in the curriculum of undergraduate radiography programs	8 (2.3)	10 (2.9)	75 (21.5)	145 (41.5)	111 (31.8)	3.98 ± 0.93
Radiographers from specific geopolitical zones may face unique challenges in adapting to AI and theranostics	9 (2.6)	29 (8.3)	94 (26.9)	131 (37.5)	86 (24.6)	3.73 ± 1.00
Technological infrastructure in my current workplace supports the use of AI and theranostics	46 (13.2)	79 (22.6)	84 (24.1)	91 (26.1)	49 (14.0)	3.05 ± 1.26
Collaboration with other healthcare professionals will play a key role in adapting to AI and Theranostics	7 (2.0)	13 (3.7)	80 (22.9)	155 (44.4)	94 (26.9)	3.91 ± 0.91

Discussion

Radiographers in this study demonstrated higher familiarity with artificial intelligence (AI) than with theranostics, a pattern that reflects the relative availability of these technologies in Nigeria. While AI is beginning to attract interest in some private institutions, it has not yet been integrated into routine clinical practice or healthcare policy (9 – 12).
By contrast, theranostics remains entirely theoretical in developing countries, with no established facilities nationwide (13, 14). The limited awareness observed among respondents is therefore an expected outcome rather than a professional deficiency, and it underscores the need for anticipatory training as these technologies evolve globally.

Concerns about job security were evident, with 41.8% of respondents believing that AI and theranostics could reduce the demand for manual radiography and 30.7% fearing outright role displacement.

These anxieties ranged from fears of redundancy—particularly in modalities such as CT, MRI, and mammography—to expectations of shifts in responsibility. Some respondents even extended these fears to conventional radiography, where automation might reduce the importance of patient positioning. Such perceptions echo findings from Saudi Arabia and Zambia (6, 7), where radiographers expressed unease about being sidelined by automation. Similar concerns has earlier been expressed in other climes and related professions (15 – 19). These results points to a possible global tension between technological progress and professional stability.

Despite these concerns, willingness to adapt was strong. Over half of the respondents expressed interest in pursuing further education or certification, and nearly half viewed the adoption of AI and theranostics as an opportunity for personal growth. This optimism is reinforced by the demographic profile of the study population: 61.6% had fewer than five years of professional experience. A predominantly young workforce may be more open to technological change and flexible in adapting to new systems compared to older counterparts, (20) an advantage that Nigeria can leverage in shaping its future radiography workforce. Similar studies in other regions also point to optimism where structured training and institutional support are available (21, 22).

Barriers to adaptation, however, are significant, with mentorship emerging as a key challenge. An instance is younger radiographers perceiving senior colleagues as disengaged from training responsibilities and more preoccupied with personal advancement (23). Financial barriers were also prominent, and this may be because few employers provide sponsorship for training or certifications (24). Infrastructure represents a further limitation: AI-enabled picture archiving and communication systems (PACS) are not widely available, and theranostics facilities are entirely absent (13). These barriers reflect systemic issues rather than shortcomings in professional willingness. Without addressing these gaps, the enthusiasm of younger radiographers may not translate into practical adaptation.

Taken together, the findings position Nigeria at an early but promising stage in the integration of AI and theranostics. AI has already been incorporated into the Core Curriculum Minimum Academic Standards (CCMAS) for radiography, but theranostics has yet to be introduced (25). This curricular reform is timely, but its effectiveness will depend on parallel investments in faculty development, mentorship programs, and infrastructural support. Radiography professional bodies and policymakers should therefore prioritize structured training pathways, financial incentives, and cross-disciplinary collaborations to ensure radiographers remain central to technological transitions.

Conclusion

Nigerian radiographers are cautiously optimistic about the integration of AI and theranostics into clinical practice. While concerns about job displacement persist, the willingness to adapt is encouraging, particularly given the predominantly young workforce. The limited awareness of theranostics reflects its absence from the Nigerian healthcare landscape, highlighting the need for proactive educational reforms. To safeguard professional relevance and enhance patient care, stakeholders must address systemic barriers through curriculum reform, mentorship, financial support, and infrastructural development. With these supports in place, Nigerian radiographers are well-positioned to embrace emerging technologies and lead their integration into clinical practice.

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to restore the dignity of man

Declarations
Consent for publication: The author clarifies that written informed consent was obtained and the anonymity of the patient was ensured. This study submitted to Swiss J. Rad. Nucl. Med. has been conducted in accordance with the Declaration of Helsinki and according to requirements of all applicable local and international standards. All authors contributed to the conception and design of the manuscript, participated in drafting and revising the content critically for important intellectual input, and approved the final version for publication. Each author agrees to be accountable for all aspects of the work, ensuring its accuracy and integrity.
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The authors declare that there were no conflicts of interest within the meaning of the recommendations of the International Committee of Medical Journal Editors when the article was written.

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Visual Journey through Tuberous Sclerosis Complex: Multisystem Imaging Insights

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Abstract

Tuberous sclerosis complex (TSC) is a rare genetic disorder affecting several systems, characterized by hamartomatous lesions in the brain, kidneys, lungs, skin, and bones. Imaging plays a pivotal role in diagnosis and management. We report a case series of four patients exhibiting diverse clinical manifestations who received multimodality imaging from 2022 to 2024. The imaging findings were aligned with clinical and diagnostic criteria established by the 2012 International TSC Consensus guidelines. The cases had distinctive radiological characteristics of TSC, encompassing subependymal nodules, subependymal giant cell astrocytomas (SEGAs), renal angiomyolipomas, pulmonary lymphangioleiomyomatosis (LAM), cutaneous lesions, and skeletal anomalies. Cross-sectional imaging facilitated precise diagnosis and directed therapies, including embolization, for renal pseudoaneurysms. The series highlights the significance of a thorough imaging strategy in recognizing both typical and incidental characteristics of TSC. Prompt identification enables swift diagnosis, focused treatment, and long term surveillance.

Keywords: Tuberous sclerosis complex; Subependymal giant cell astrocytoma (SEGA); Renal angiomyolipoma; Lymphangioleiomyomatosis (LAM); Cardiac rhabdomyoma; Neurocutaneous syndrome.

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Introduction

Tuberous sclerosis complex (TSC), also known as Bourneville disease is a rare autosomal dominant neurocutaneous disorder characterized by the development of benign hamartomatous lesions in multiple organ systems, including the central nervous system (CNS), kidneys, lungs, heart, and skin (1). It results from mutations in either the TSC1 or TSC2 genes, which encode the proteins hamartin and tuberin, respectively—both key regulators of the mammalian target of rapamycin (mTOR) signaling pathway. Dysregulation of this pathway leads to abnormal cell proliferation and differentiation, contributing to the diverse clinical and imaging manifestations of the disease (2).

TSC has an estimated incidence of approximately 1 in 6,000 to 1 in 10,000 live births and affects both sexes equally (3). The disorder exhibits complete penetrance but variable expressivity, resulting in a wide spectrum of clinical severity even among individuals within the same family. The clinical presentation of TSC is highly variable, ranging from neurologic symptoms such as epilepsy and intellectual disability to renal, pulmonary, and cardiac complications. Even the classic clinical Vogt's triad is seen in less than 50% cases only (4). Due to its multisystem involvement and phenotypic variability, imaging plays a central role not only in the initial diagnosis but also in long-term surveillance and management.

This case series aims to highlight the imaging spectrum of TSC through four representative cases, each demonstrating various manifestations across multiple organ systems. By correlating imaging findings with clinical data and current literature, this series underscores the pivotal role of radiology in the diagnosis, follow-up, and multidisciplinary care of patients with TSC.

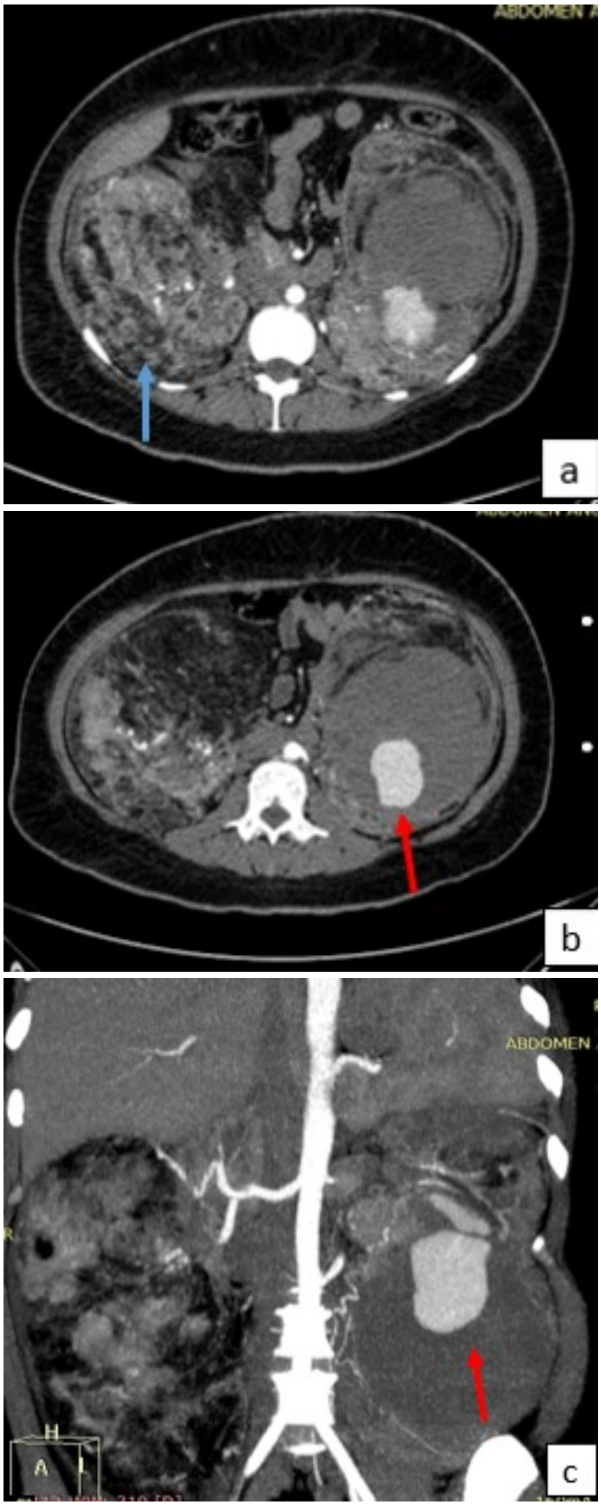
Materials and Methods

This case series includes four patients who underwent multimodality imaging evaluation at our institution between 2022 and 2024. Diagnosis was based on established clinical and/or genetic criteria in accordance with the 2012 International Tuberous Sclerosis Complex Consensus Conference guidelines (Table 1) (5). Written informed consent was obtained from all the patients. As this was a retrospective case series using anonymized data, institutional review board (IRB) approval was waived.

Case Presentations

Case 1

A 29-year-old female arrived at the casualty with left-sided flank pain and haematuria. She was conscious with a feeble pulse, tachycardia (PR 108/min) and hypotension (BP 100/60 mmHg). She had a diffusely tender mass over the left lumbar area. After initial stabilisation, she was referred for a contrast-enhanced computed tomography (CECT) scan of the abdomen, which identified a large lesion originating from the lower pole of the left kidney characterized by an enhancing soft-tissue component, regions of fatty attenuation and anomalously dilated vascular channels (Fig. 1a-b). A rounded contrast-filled out-pouching was observed at the centre of the lesion, corresponding to a large pseudoaneurysm originating from the accessory left renal artery that supplies the lower pole of the mass (Fig. 1c-d). A comparable large lesion featuring multiple small intrarenal aneurysms was also observed in the right kidney. The abdominal findings suggested bilateral renal angiomyolipomas (AMLs). The investigation was expanded to incorporate computed tomography (CT) imaging of the brain which revealed multiple calcified subependymal nodules (SENs) (Fig. 1e). The clinical examination also showed multiple dark papulonodular lesions over her face (Fig. 1f). A diagnosis of TSC was made based on three major features. The patient was then transferred to the Digital Subtraction Angiography (DSA) suite for urgent endovascular management. Selective catheterisation of the left lower pole renal artery showed a large pseudoaneurysm arising from the distal branch which was then subsequently treated with coiling (Fig. 1g-i).



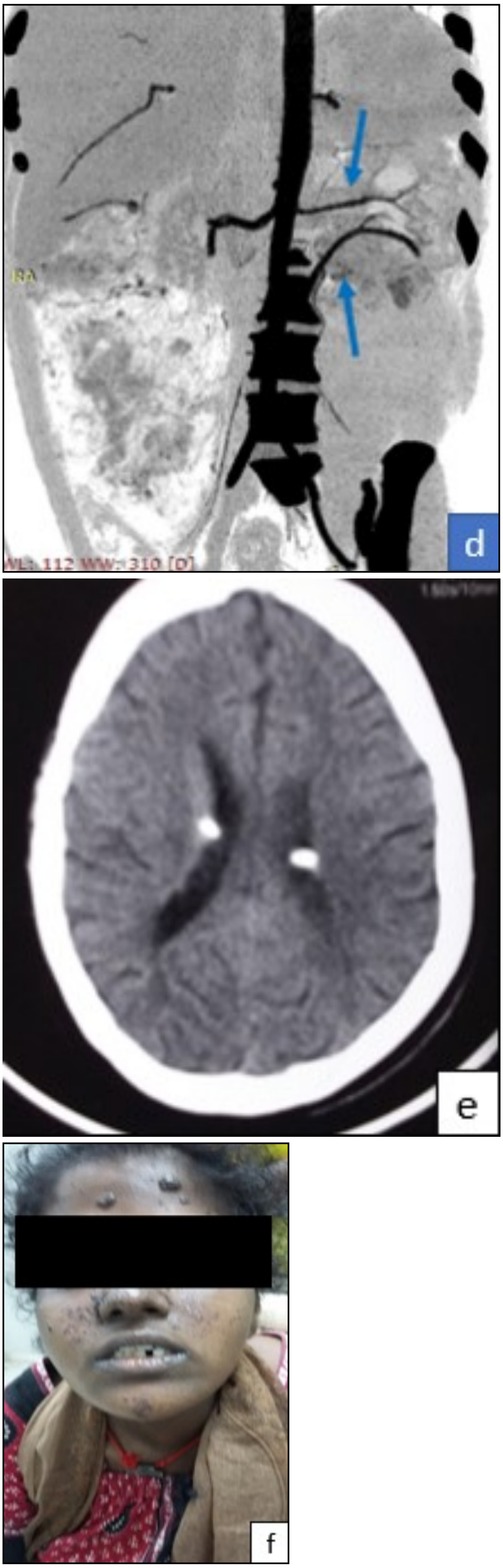


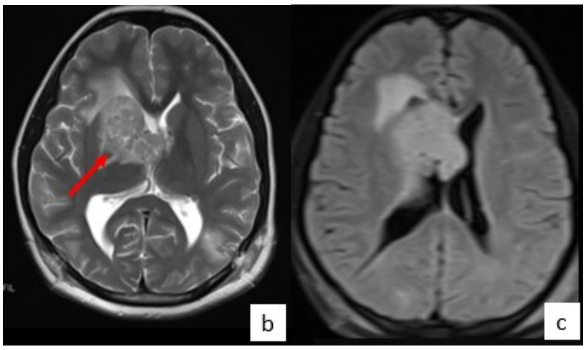
Fig. 1 a) – CECT abdomen showing well marginated heterogenous tumor predominantly fat density of size 23 x 12 x 10 cm arising from the right kidney and extending up to right iliac fossa (blue arrow) **b)** Another similar mass lesion of size 24 x 12 x 11 cm noted arising from the lower pole of left kidney with large pseudoaneurysm within (red arrow). **c, d)** – angiogram MIP images showing normal abdominal aorta and double left renal artery (blue arrows). Upper left renal artery appear normal and lower one at L3 level displaced by mass and pseudoaneurysm arising from the distal branch (red arrow). Right renal artery of normal calibre with multiple small aneurysms seen arising from the intra renal branches **e)** – CT brain image showing multiple calcified subependymal nodules **f)** – Clinical image of face of the patient showing multiple angiofibromas **g)** – DSA image showing large pseudoaneurysm arising from the distal branch of left lower pole renal artery (red arrow), **h)** – after coiling of the feeder vessel, no contrast filling of pseudoaneurysm, **i)** – Multiple intrarenal aneurysms arising from the right renal artery (blue arrow).

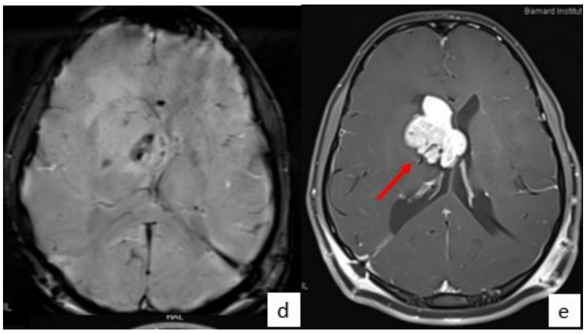
Case 2

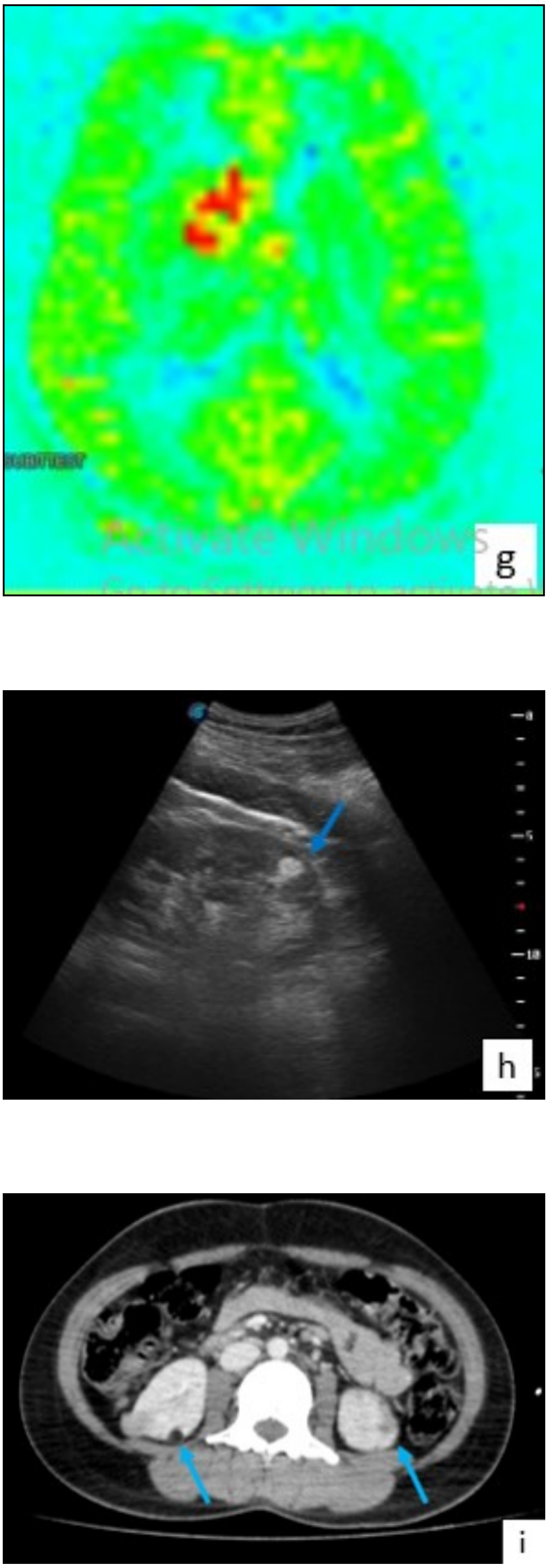
A 19-year-old female presented with new-onset seizures accompanied by persistent vomiting for one week. She also reported a two-month history of progressive headaches. On physical examination, multiple facial angiofibromas were noted (Fig. 2a), raising clinical suspicion for a neurocutaneous syndrome.

Magnetic resonance imaging (MRI) of the brain revealed an ill-defined T2/FLAIR hyperintense lesion arising from the septum pellucidum and extending into the anterior horn of the right lateral ventricle and the foramen of Monro. The lesion demonstrated internal blooming foci on susceptibility-weighted imaging and avid enhancement following contrast administration—imaging features consistent with a subependymal giant cell astrocytoma (SEGA) (Fig. 2b-g).

Given these findings, further systemic evaluation was undertaken. Abdominal ultrasonography and contrast-enhanced CT revealed multiple bilateral renal angiomyolipomas (Fig. 2h-i). Additionally, skeletal window imaging demonstrated several discrete sclerotic bone lesions (bone islands) (Fig. 2j-k). Based on the fulfillment of three major diagnostic criteria, a definitive diagnosis of TSC was established.







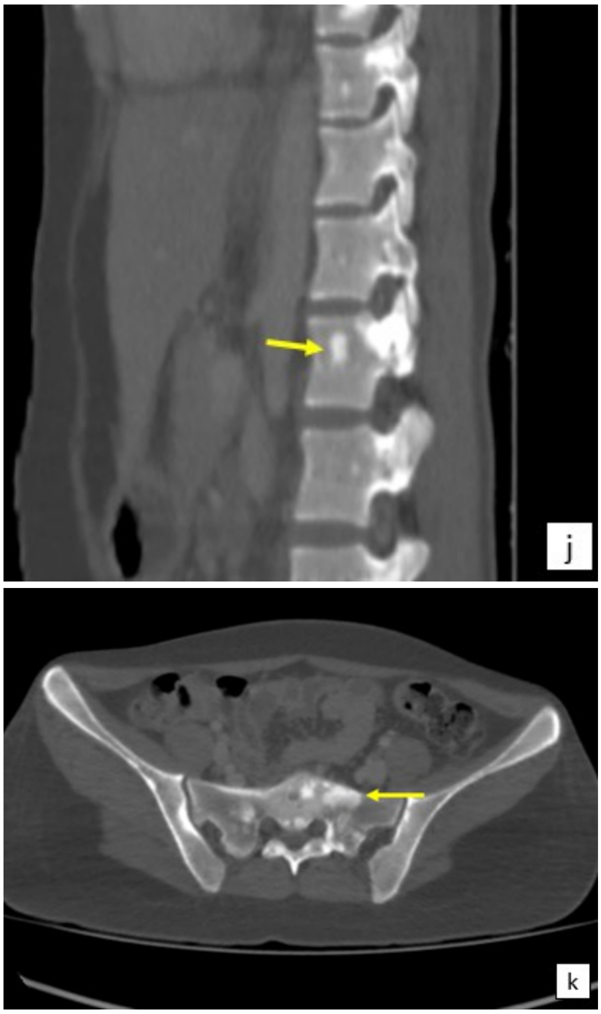
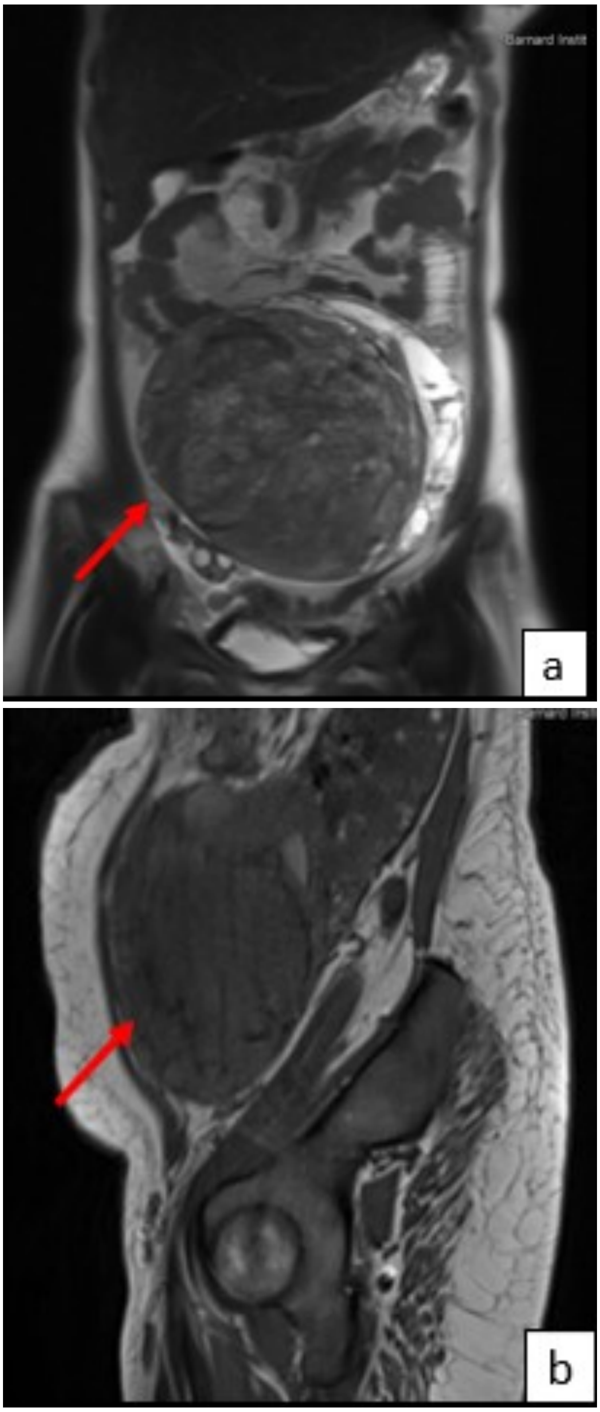
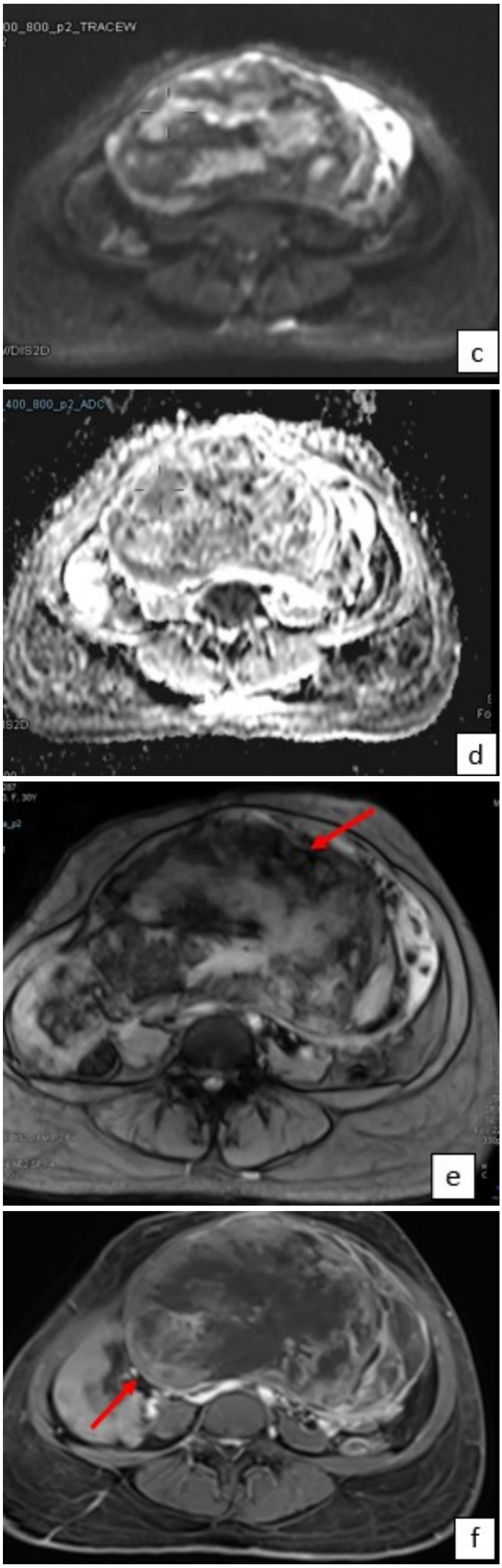


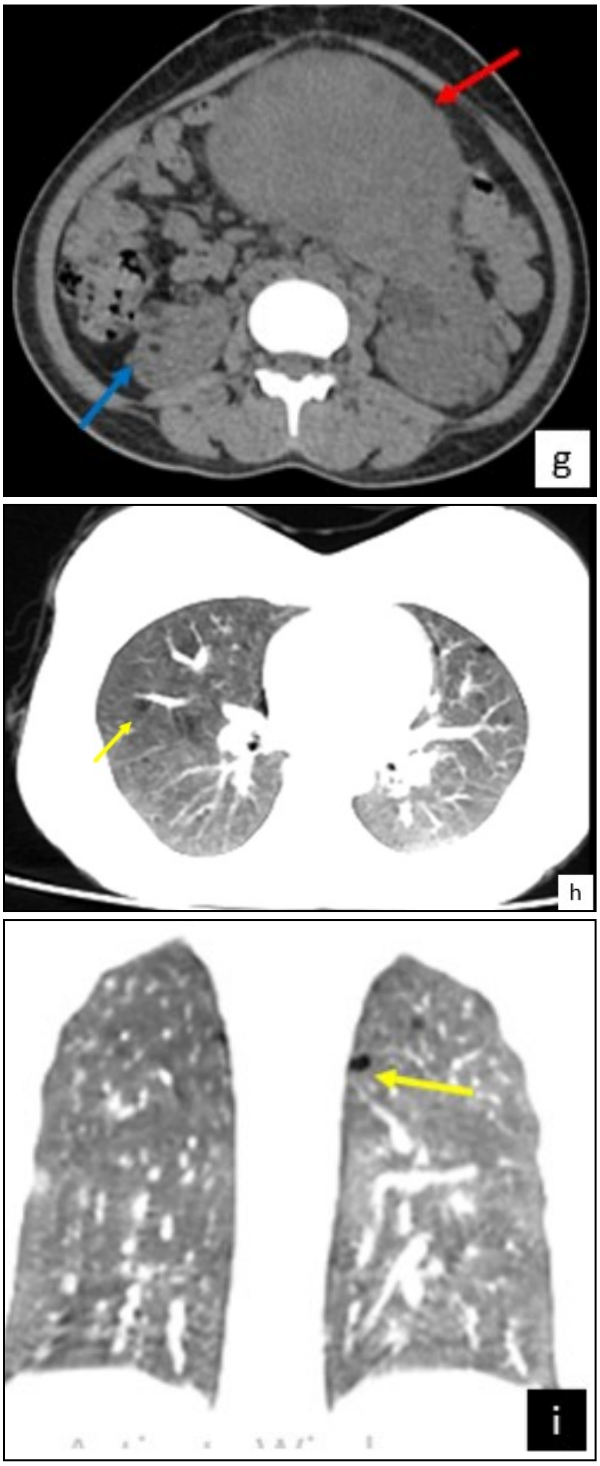
Fig. 2 a) – Clinical image of the patient's face revealing angiofibromas **b, c)** - MRI images showing an ill defined T2/Flair hyperintense lesion (red arrow) measuring 3.1 x 2.8 x 2.5 cm showing internal gradient blooming **d)** with avid contrast enhancement (red arrow) **e,f)** and increased perfusion **g)** noted arising from the septum pellucidum and extending into the right foramen of monro, consistent with SEGA. **h, i)** – USG and CECT of the abdomen showing multiple bilateral small renal angiomyolipomas (blue arrow). **j, k)** – multiple bone islands noted in dorsal vertebra and in pelvis (yellow arrow)

Case 3

A 32-year-old female with a known history of seizure disorder on regular medication presented with abdominal pain for one week. An initial abdominal ultrasound at an outside facility revealed a large heterogeneous mass arising from the left kidney. MRI of the abdomen showed a large T2 heterointense solid-cystic lesion with predominant solid components arising from the lower pole of the left kidney, displacing adjacent bowel loops. Gradient sequences demonstrated multiple blooming foci suggestive of haemorrhage, and the lesion exhibited peripheral diffusion restriction. Post-contrast images revealed peripheral heterogeneous enhancement with central non-enhancing areas (Fig. 3a-f). A similar but smaller lesion was noted in the mid-pole of the right kidney. Screening CT confirmed the presence of fat within both lesions, consistent with renal AMLs (Fig. 3g). A subsequent CT chest demonstrated diffuse ground-glass opacities with scattered thin-walled cysts, suggestive of pulmonary lymphangioleiomyomatosis (LAM) (Fig. 3h-i) and a CT brain revealed multiple calcified SENs (Fig. 3j). Based on these findings, a diagnosis of tuberous sclerosis complex was established.







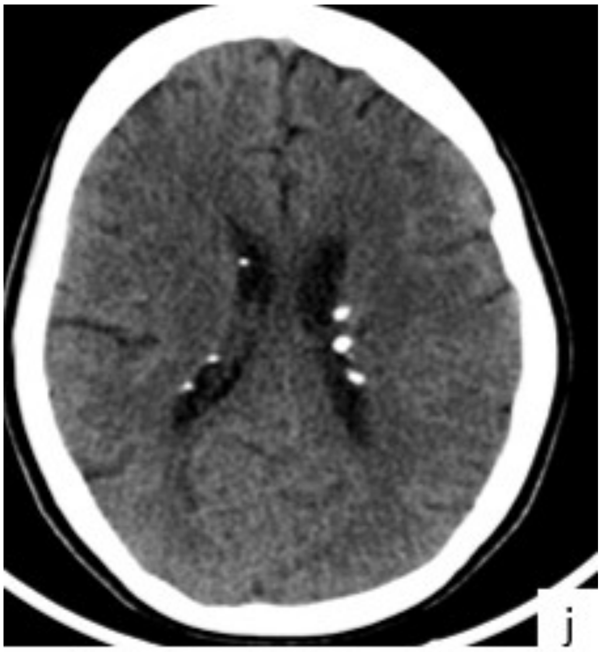


Fig. 3 a, b) – MRI images showing large T2 heterointense solid lesion measuring 12 x 17 x 21 cm arising from left kidney showing (red arrow) **c, d)** - DWI images showing peripheral diffusion restriction (red arrow) and **e)** – Gradient image showing few internal gradient blooming (red arrow) **f)** - with peripheral contrast enhancement and central non enhancing areas (red arrow) **g)** – CT image showing large lesion with internal fat densities in left kidney (red arrow) and a smaller lesion (blue arrow) in right kidney, **h, i)** – CT lung showing diffuse ground glass opacities with few scattered thin walled cysts in upper lobes (yellow arrow), **j)** – CT brain showing multiple calcified subependymal nodules

Case 4

An 18-year-old male presented to the dermatology clinic with multiple facial lesions of cosmetic concern. Dermatological evaluation revealed numerous bilaterally symmetrical facial angiofibromas (Fig. 4a) distributed across the cheeks, nasolabial folds, and chin. Additional findings included multiple hypo-pigmented macules—commonly referred to as “ash leaf” spots—over the lower back and upper limbs (Fig. 4b-c).

Given the constellation of cutaneous features suggestive of a phakomatosis, neuroimaging and abdominal imaging were pursued. MRI of the brain demonstrated a cortical tuber in right parietal region and multiple enhancing subependymal nodules along the walls of the lateral ventricles, appearing heterointense on T2-weighted sequences, with a few showing susceptibility on gradient imaging. Notably, a dominant lesion greater than 1 cm in diameter, located adjacent to the foramen of Monro, was identified and interpreted as a SEGA (Fig. 4d-g).

Abdominal CT revealed multiple bilateral renal AMLs, along with incidental sclerotic bone lesions in the dorsolumbar vertebrae (Fig. 4h-i). With the presence of five major diagnostic criteria—including dermatological, neurological, and renal findings—the diagnosis of TSC was unequivocally established.

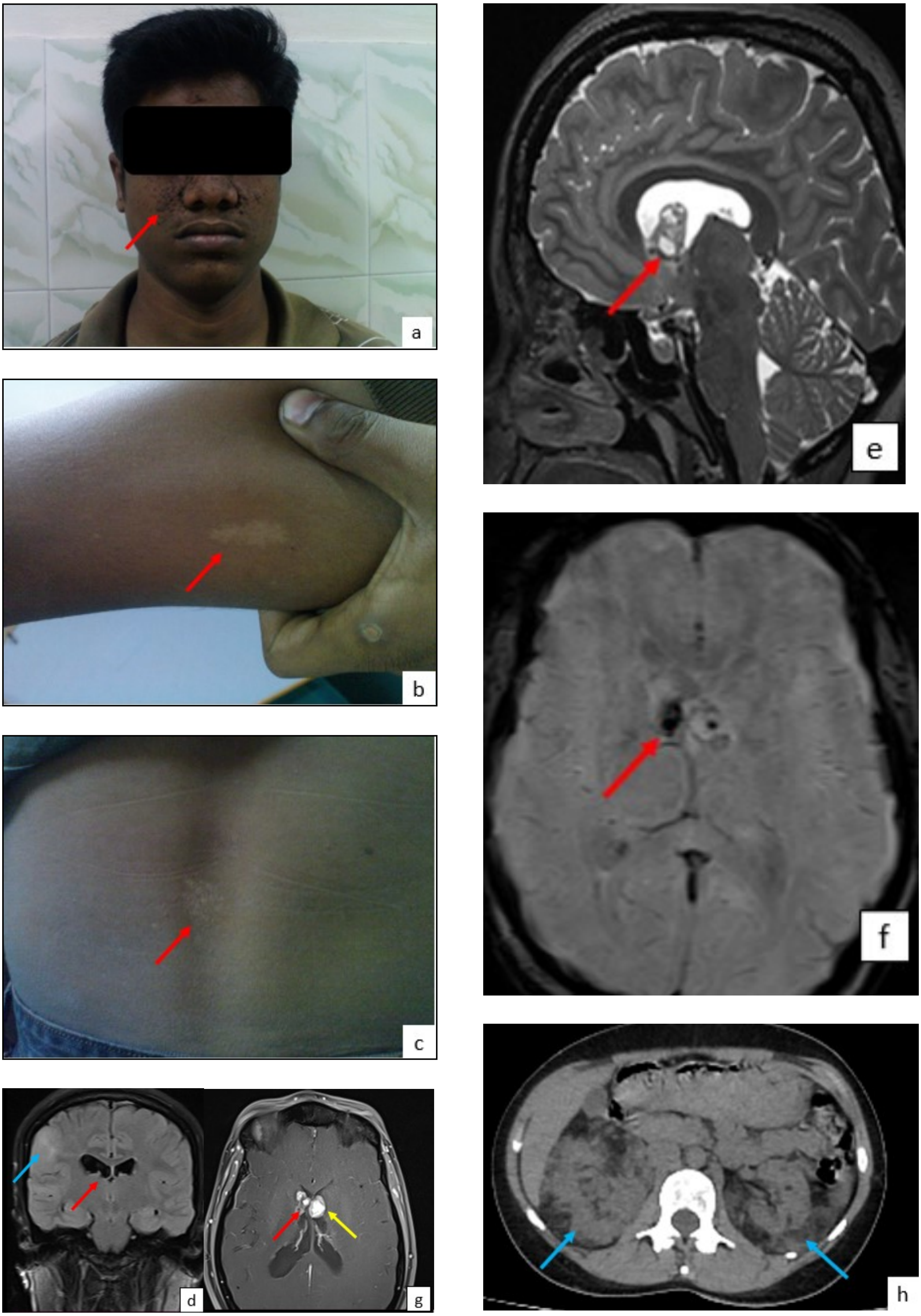

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Fig. 4 a) – Clinical image of the patient showing multiple facial angiofibromas (red arrow) **b, c)** – Hypomelanotic macules noted in lower back and upper arms (red arrow) and **d)** – MRI Flair image showing cortical tubers in right parietal region (blue arrow) and subependymal nodules (red arrow) **e)** – T2 heterointense subependymal nodules noted with **f)** – few showing gradient blooming indicating calcification (red arrow) **g)** – Few subependymal nodules showing contrast enhancement (red arrow) and a large lesion consistent with SEGA (yellow arrow) noted, **h)** – CT abdomen showing bilateral renal AMLs (blue arrows), **i)** – CT bone window showing bone islands (green arrow).

Discussion

TSC is an uncommon genetic disorder characterized by diverse manifestations and a tendency for hamartomatous growth in many organs (6).

Depending on the organ of involvement, the patient presents with a wide range of clinical symptoms. Consequently, the 2012 International TSC Consensus Conference established revised diagnostic criteria, differentiating between major and minor features. A definitive diagnosis necessitates the presence of two major features or one major feature in conjunction with two minor features (7). Significantly, most of the major features can be discerned by imaging, underscoring the radiologist's essential and prominent function in the diagnosis process.

Cutaneous lesions frequently act as the initial indicator in the diagnosis of TSC, particularly in paediatric and teenage population. Hypomelanotic macules (90%), face angiofibromas (75%), shagreen patches (30%), and ungual fibromas are established dermatological manifestations (8). In Case 4, the occurrence of many angiofibromas and hypo-pigmented macules triggered imaging referrals and subsequent verification of systemic involvement. These lesions facilitate diagnosis, enable genetic counseling, and initiate screening for at-risk relatives.

Neurological involvement occurs in more than 90% of patients and represents the earliest clinical manifestation, especially in the form of seizures (9). The classic triad observed on imaging includes cortical tubers, SENs, and SEGA. Cortical tubers and/or subependymal nodules represent the predominant CNS manifestations, exhibiting a prevalence of 95-100% (10). Approximately 40% of cases also exhibit white matter lesions like radial migration lines (RML) (11).

Cortical tubers are hyperintense lesions on T2/FLAIR imaging within the cerebral cortex, which act as epileptogenic foci. SEGAs commonly develop adjacent to the foramen of Monro and can lead to obstructive hydrocephalus (12). In our series, two patients exhibited SEGAs, each exceeding 1 cm in size and displaying avid enhancement, aligning with established diagnostic criteria. SEN typically manifests on the ependymal surface of the lateral ventricles and exhibits a propensity for calcification over time. The possibility of SENs developing into SEGAs, especially in adolescence and early adulthood, highlights the significance of serial CNS imaging.

Renal symptoms are the second most prevalent findings in TSC. Approximately 20% of people with renal AML are identified with TSC, whereas 80% of individuals with TSC present with renal AMLs (13). AMLs are frequently large, bilateral, and multiple in the context of TSC. Cases 1 and 3 revealed substantial bilateral AMLs, accompanied by indications of hemorrhagic consequences and intratumoral aneurysms. AMLs exceeding 4 cm or exhibiting intratumoral aneurysms more than 5 mm are deemed at elevated risk for bleeding and may qualify for

Table 1. - Major and minor features for TSC diagnosis according to the revised clinical diagnostic criteria in the second "International Tuberous Sclerosis Complex Consensus Conference" held in Washington, DC, in 2012. TSC-1, tuberous sclerosis complex-1, TSC-2, tuberous sclerosis complex-2.

Major features	Minor features	Diagnosis
1. Hypomelanotic macules (3 or more and each ≥5 mm in diameter.)	1. Confetti skin lesions	Diagnosis of definitive TSC requires one of the following:
2. Angiofibromas (3 or more) or fibrous cephalic plaque	2. Dental enamel pits (More than 3)	1. Identification of either a TSC1 or TSC2 pathogenic mutation in DNA from normal tissue
3. Ungual fibromas (2 or more)	3. Intraoral fibromas (2 or more)	2. Two major features
4. Shagreen patch	4. Retinal achromic patch	3. One major + at least two minor features.
5. Multiple retinal hamartomas	5. Multiple renal cysts	
6. Cortical dysplasias include tubers and radial migration lines of cerebral white matter.	6. Nonrenal hamartomas.	
7. subependymal nodules (SENs)		
8. Subependymal giant cell astrocytoma (SEGA)		
9. Cardiac rhabdomyoma		
10. Lymphangioleiomyomatosis (LAM)		
11. Angiomyolipomas (AML) (2 or more)		

embolization or mTOR treatment (14). TSC-associated AML typically manifest at a younger age and exhibit more rapid progression than sporadic variants. Other infrequent renal symptoms encompass bilateral multiple renal cysts, present in approximately 18-53% of cases, and clear cell renal cell carcinoma (RCC), observed in about 2-3% of instances (15).

Pulmonary involvement, predominantly manifesting as lymphangioleiomyomatosis (LAM), is an acknowledged characteristic of TSC, affecting approximately 26 to 39% of women with the condition (16). LAM is distinguished by diffuse, thin-walled cysts shown on high-resolution CT, frequently associated with ground-glass opacities or chylous effusions.

Case 3 has characteristic symptoms of LAM, stressing the necessity for chest imaging in asymptomatic adult female patients with TSC, due to the likelihood for spontaneous pneumothorax. LAM may sometimes manifest sporadically, necessitating additional major features for a conclusive diagnosis of TSC. Additional uncommon thoracic conditions encompass multifocal micronodular pneumocyte hyperplasia (MMPH) and clear cell sugar tumor (CCST) of the lung (13).

The principal cardiac manifestation of TSC is cardiac rhabdomyomas, which are the most often identified lesions in utero or in newborns. It manifests in approximately 70% of children, with the majority regressing during childhood. They are typically asymptomatic but can induce deadly arrhythmias, necessitating resection (17).

Skeletal involvement, although frequently incidental, includes sclerotic bone lesions, especially inside the axial skeleton (18).
Although asymptomatic, their existence, as observed in Cases 2 & 4, reinforces the diagnosis and may function as minor or ancillary criteria when the clinical presentation is ambiguous. Additional abdominal manifestations include hepatic angiomyolipomas, splenic hamartomas, and colorectal polyps in a minor percentage of TSC individuals (18).

The management of TSC is multidisciplinary and increasingly influenced by imaging techniques. The introduction of mTOR inhibitors, such as Everolimus, has transformed the treatment of TSC-associated SEGAs and AMLs (19). Serial imaging is essential for evaluating progression, guiding treatment response, and monitoring complications, thereby requiring precise baseline imaging and subsequent measurements. In summary, imaging serves as cornerstone in the assessment and management of TSC.

Conclusion

This case series emphasizes the diverse radiological manifestations of TSC, highlighting the necessity of a thorough, cross-sectional imaging strategy—especially in individuals exhibiting apparently isolated symptoms. Prompt recognition of distinctive lesions, such as SEGAs, renal angiomyolipomas, and pulmonary cysts, not only enhances rapid diagnosis but also directs clinical judgements for surgical or medical interventions. Radiologists must be attentive to subtle diagnostic imaging clues, since these may be crucial in identifying a potentially overlooked multisystem disorder.

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Declarations

Consent for publication: The author clarifies that written informed consent was obtained and the anonymity of the patient was ensured. This study submitted to Swiss J. Rad. Nucl. Med. has been conducted in accordance with the Declaration of Helsinki and according to requirements of all applicable local and international standards. All authors contributed to the conception and design of the manuscript, participated in drafting and revising the content critically for important intellectual input, and approved the final version for publication. Each author agrees to be accountable for all aspects of the work, ensuring its accuracy and integrity.
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Conflict of interest:

The authors declare that there were no conflicts of interest within the meaning of the recommendations of the International Committee of Medical Journal Editors when the article was written.

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Is Bigger Always Bad ? Evaluating Effect of Sedation on MRI-Based Optic Nerve Sheath Diameter Measurements in Children

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Abstract

Objectives

To assess the impact of sedation on optic nerve sheath diameter (ONSD) as measured by MRI in pediatric patients. ONSD is a widely accepted non-invasive marker for estimating raised intracranial pressure (ICP), but potential effects of sedation on its accuracy remain under-studied in children.

Materials and Methods

A retrospective observational study was conducted on brain MRI scans from pediatric patients aged 0–18 years. Patients were divided into two groups: those who received sedation and those who underwent MRI without sedation. Bilateral ONSD was measured at a standardized point 3 mm posterior to the globe on axial T2-weighted images. Inter-observer agreement was analyzed, and group comparisons used non-parametric statistical methods.

Results

Out of 78 pediatric patients, 38 received mild sedation and 40 were imaged without sedation. The mean ONSD in the non-sedated group was 4.8 ± 0.3 mm compared to 5.7 ± 0.4 mm in the non-sedated group ($p = 0.02$). This difference was statistically significant ($t (68.5) = -11.2$, $p <$ <0.01, Cohen's $d = 2.53$). Age-stratified data affirmed a normal increase in ONSD across early childhood with stabilization during adolescence.

Conclusion

Sedation significantly influences ONSD measurements on MRI in pediatric patients. These findings highlight the need for careful consideration of sedation status when using ONSD as a surrogate for ICP. Age-related trends further highlight the importance of using adjusted reference values.

Keywords: Intracranial pressure; MRI; sedation; optic nerve sheath; children;

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Introduction

Assessing intracranial pressure (ICP) accurately is critical in pediatric neurology, yet direct invasive monitoring techniques can pose significant risks and are often impractical in children. As a result, the optic nerve sheath diameter (ONSD) has gained attention as a non-invasive proxy for estimating ICP, particularly through imaging techniques like MRI and ultrasound (1 – 3). While ultrasound offers rapid bedside evaluation, its operator-dependent nature can introduce variability. MRI, on the other hand, provides a high-resolution and reproducible alternative for ONSD measurement (4). However, performing MRI scans in children frequently necessitates sedation to reduce motion arti-

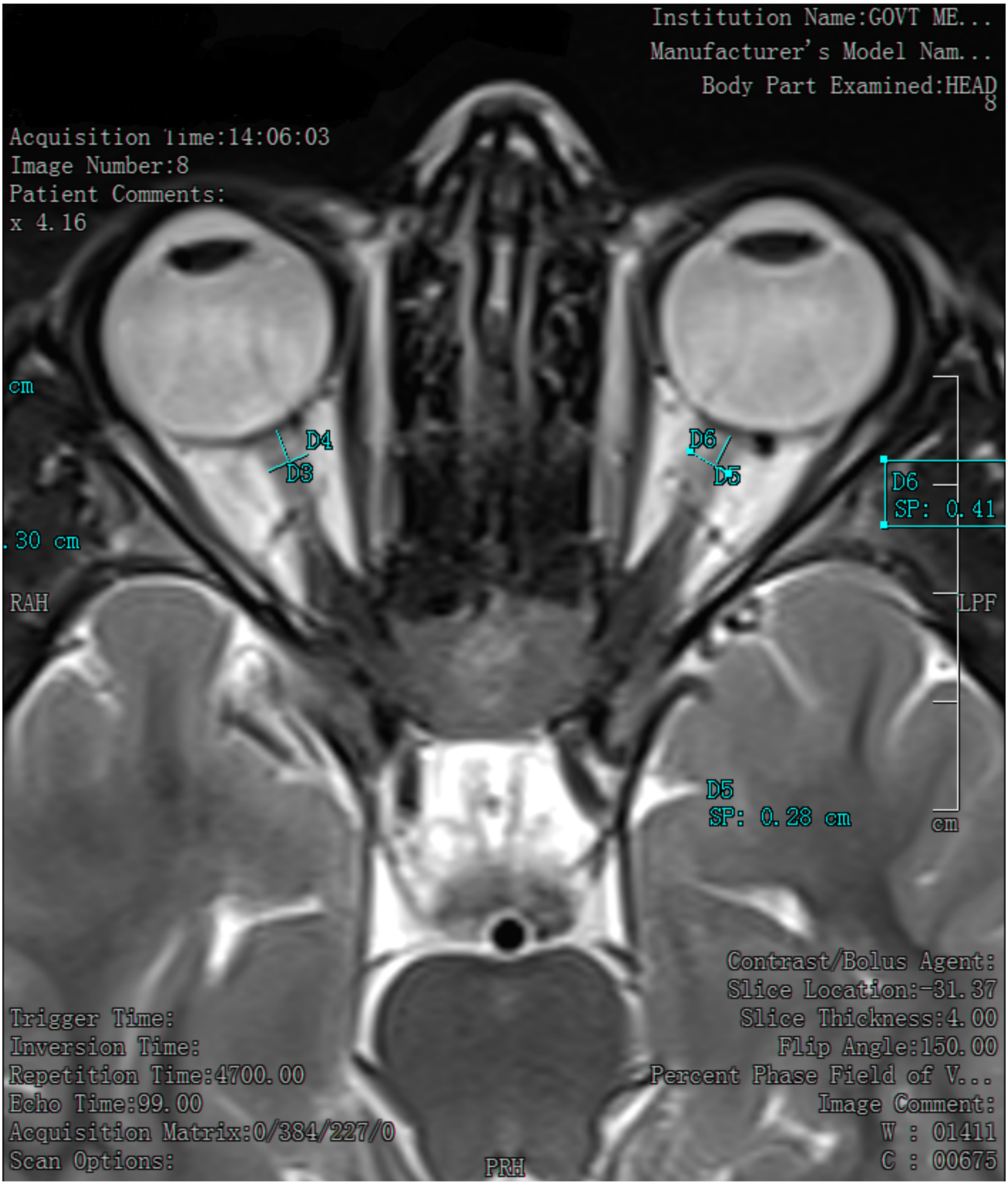

Fig 1 : ONSD 3mm behind the papilla in a non sedated patient.

facts. Sedative agents may potentially alter cerebral compliance, CO_2 levels, or cerebrospinal fluid dynamics—factors that could, in turn, influence imaging-based ONSD measurements. Although prior research has examined the effects of general anesthesia on ONSD, there is limited data on how commonly used sedatives impact these measurements (5, 6). This study investigates whether sedation alters MRI-based ONSD readings in pediatric patients.

Materials and Methods

Study Population

We conducted a retrospective review of brain MRI scans performed at Government Medical College, Srinagar, India, between January 2024 and January 2025. Pediatric patients aged 0–18 years were included. Exclusion criteria included prior neurosurgical procedures, orbital pathology, poor image quality, or undocumented sedation status.

Grouping

Patients were categorized into two groups:

- *Sedated Group (n = 38):* Received Triclofos (oral), Ketamine (IV), or Midazolam (IV).

- *Non-Sedated Group (n = 40):* Underwent MRI without sedation.

Imaging Protocol and Analysis

MRI was performed using a 3.0T scanner. All patients underwent standard clinical MRI sequences, including T1-weighted, T2-FLAIR, T2-weighted, heme-sensitive (T2* GRE or SWI), and diffusion-weighted imaging. The orbital protocol included 2–3 mm thick axial and coronal slices, post-contrast T1, and T2 sequences with and without fat saturation. Sub-millimeter heavily T2-weighted volumetric images of the orbits were also acquired. ONSD was measured transversely at 3 mm behind the globe on slices demonstrating maximum sheath width (7, 8) (Fig 1 & 2).

Statistical Analysis

Continuous variables were tested for normality (Shapiro–Wilk). Normally distributed data are presented as mean ± SD and compared using the independent-samples t-test. Categorical data were compared using the Chi-square test (or Fisher's exact when needed). Effect sizes were reported as Cohen's d for group differences and Spearman's ρ for correlations. Inter-observer agreement was assessed with ICC (>0.8 = excellent). A p-value < 0.05 was considered statistically significant.

Results

Demographics

A total of 78 pediatric patients were included (mean age 7.9 years; 40 males, 38 females). Age did not differ significantly between groups (sedated: 7.7 ± 3.6 years vs. non-sedated: 8.0 ± 3.9 years, t (76) = -0.81, p = 0.42). Sex distribution also showed no significant difference (χ^2 = 0.26, p = 0.61).

ONSD Findings

Non-Sedated Group:

- Mean ONSD = 4.8 ± 0.3 mm

Sedated Group:

- Mean ONSD = 5.7± 0.4 mm (t(68.5) = -11.2 ,p <<0.01 ,Cohen's d = 2.53)

A positive correlation between age and ONSD was observed (p < 0.01), consistent with developmental trends. Inter-observer ICC for ONSD measurement was 0.93 (95% CI: 0.87–0.97), indicating excellent agreement.

Discussion

Our analysis reveals a statistically significant increase in MRI-based ONSD measurements among sedated children. The difference of nearly 1 mm between groups corresponds to a very large effect size (Cohen's d = 2.5), suggesting that sedation introduces clinically meaningful bias in estimating intracranial pressure. This suggests that sedation, even with non-anesthetic agents such as ketamine or midazolam, may impact ONSD values and potentially lead to overestimation of ICP. The optic nerve sheath is a direct extension of the intracranial subarachnoid space, which allows transmission of intracranial pressure changes into the orbit. Thus, artificially elevated ONSD in sedated patients may reflect transient physiological changes rather than true ICP elevations.

Our results align with prior literature confirming the positive correlation between ICP and ONSD (9 – 12). We also reaffirm the known developmental increase in ONSD with age (13), underscoring the importance of age-adjusted interpretation. Clinically, these findings emphasize the need for caution when evaluating ONSD in sedated pediatric patients. Agent-specific correction factors may improve diagnostic accuracy. Future research, ideally with simultaneous invasive ICP measurements, is warranted to establish a more definitive relationship between sedation, ONSD, and true intracranial dynamics.

Clinical Implications

- Risk of Overestimation: Sedation-related ONSD expansion may mimic elevated ICP.

- Need for Adjustments: Agent-specific effects should be accounted for when interpreting ONSD.

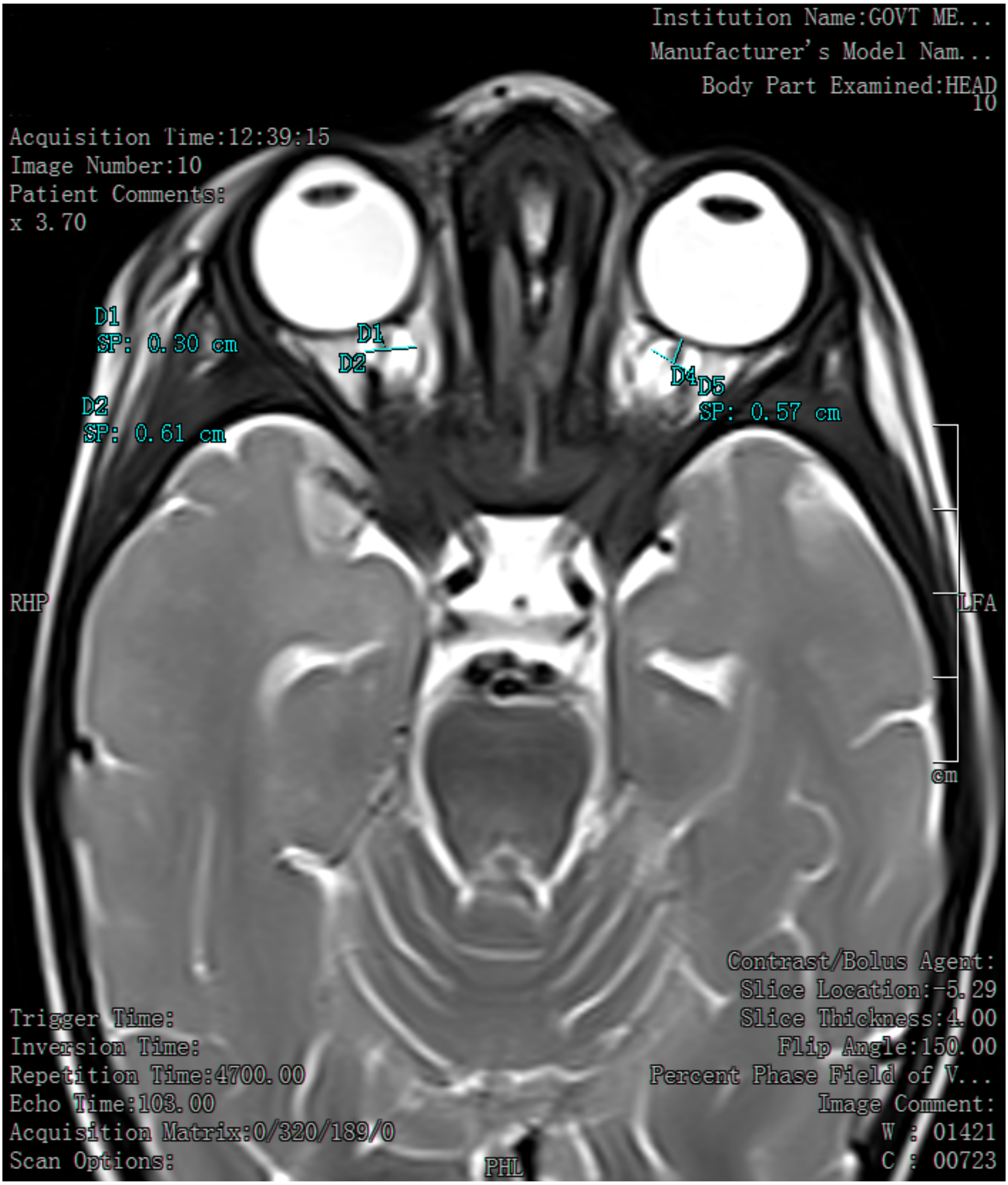

Fig 2 : ONSD 3mm behind the papilla in a sedated patient.

- Future Research: Prospective studies with invasive ICP monitoring are needed to validate these findings.

Limitations

This study is limited by its retrospective design, absence of invasive ICP measurements, and variability in sedation documentation. These factors may introduce bias and reduce the generalizability of findings.

Conclusion

Sedation markedly increases MRI-based ONSD measurements in pediatric patients, with a very large effect size. This expansion likely reflects transient physiological changes rather than true ICP elevation. Careful interpretation of ONSD values is essential when evaluating sedated children. Further studies are needed to refine imaging protocols and develop correction strategies for improved diagnostic precision.

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Declarations

Consent for publication: The author clarifies that written informed consent was obtained and the anonymity of the patient was ensured. This study submitted to Swiss J. Rad. Nucl. Med. has been conducted in accordance with the Declaration of Helsinki and according to requirements of all applicable local and international standards. All authors contributed to the conception and design of the manuscript, participated in drafting and revising the content critically for important intellectual input, and approved the final version for publication. Each author agrees to be accountable for all aspects of the work, ensuring its accuracy and integrity.
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Decision-Making Impact of [^{18}F]FDG PET/CT in the Management of a Bone Metastasis from Thyroid Carcinoma: Complete Biochemical Remission after Local Treatment

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Abstract

Introduction: Bone metastases represent the second most common site of distant spread in differentiated thyroid cancer and are associated with a significantly poorer prognosis than lymph node or pulmonary metastases. In this context, poorly differentiated thyroid carcinomas generally show heterogeneous uptake on iodine-131 scintigraphy and on [^{18}F]FDG PET/CT. The optimal therapeutic strategy for oligometastatic disease remains poorly defined, lying between systemic treatments (iodine-131 therapy) and localized approaches such as surgery or stereotactic radiotherapy.

Clinical Case: We report the case of a 54-year-old woman followed for papillary thyroid carcinoma. Post-therapeutic scintigraphy performed after administration of 100 mCi of radioactive iodine revealed a bone uptake focus in the mid-third of the left femur, suggestive of metastasis. The post-radioiodine therapy assessment showed a marked increase in serum thyroglobulin levels, reaching 1960 ng/mL. [^{18}F]FDG PET/CT demonstrated a single, intensely hypermetabolic bone lesion extending from the mid- to the distal third of the left femoral diaphysis. Postoperative evolution was remarkable, with a spectacular drop in thyroglobulin levels following complete surgical excision performed with curative intent.

Conclusion: [^{18}F]FDG PET/CT is an essential tool in the diagnostic and therapeutic evaluation of poorly differentiated follicular-origin thyroid carcinomas. Its contribution is pivotal in guiding clinical decision-making. Moreover, surgical management of isolated bone metastases can offer a genuine opportunity for durable disease control.

Keywords: Bone Neoplasms, Positron-Emission Tomography and Computed Tomography, Thyroglobulin, Thyroid Neoplasms

*Corresponding author: Batani - received: 12.12.2025 - peer reviewed, accepted and published: 31.01.2026

Introduction

Thyroid cancer is the most common malignant endocrine tumor worldwide. Histologically, differentiated thyroid carcinoma of follicular origin (DTC), which develops from the epithelial cells of the thyroid gland, is the most frequent subtype (1). In the 5th edition of the World Health Organization (WHO) classification of thyroid tumors, these neoplasms are categorized according to their pathological features, molecular profile, and biological behavior (2). Follicular carcinomas, papillary carcinomas, and clear cell ovarian carcinomas are traditionally grouped under well-differentiated thyroid carcinomas and are distinguished from other, less differentiated types. In this same edition, a new category of non-anaplastic high-grade follicular-derived carcinomas was introduced. It includes poorly differentiated thyroid carcinoma and high-grade differentiated thyroid carcinomas, characterized by tumor necrosis and/or increased mitotic activity, with an intermediate prognosis between well-differentiated and undifferentiated carcinomas (2).

Distant metastases are a rare but unfavorable prognostic event in DTC, with a prevalence of approximately 5% (3). Bone metastases represent the second most common site of distant spread in differentiated thyroid cancer (4) and are associated with a significantly poorer prognosis than lymph node or pulmonary metastases (5).

Iodine-131 scintigraphy ($[^{131}I]I$ WBS) plays an essential role in the management of patients with DTC. It is used for postoperative assessment of residual thyroid tissue, detection of distant metastases, determination of eligibility for radioactive iodine therapy, and evaluation of treatment response (6). During the dedifferentiation process, thyroid cancer cells progressively lose their ability to uptake iodine and to organize functionally, which significantly limits the use of this radioisotope—not only for diagnosis but also for therapy—thus complicating patient management (7).

The introduction of positron emission tomography combined with computed tomography (PET/CT) has profoundly transformed the management of cancer patients. Among the various radiotracers, fluorodeoxyglucose ($[^{18}F]FDG$) is the most widely used, and its clinical value has been confirmed by numerous studies, particularly in patients with follicular-derived thyroid carcinoma, including poorly differentiated and undifferentiated subtypes (8, 9). Well-differentiated follicular-origin thyroid carcinomas, without high-grade features, typically show strong uptake of radioactive iodine and low uptake of $[^{18}F]FDG$. Conversely, dedifferentiated thyroid carcinomas are characterized by intense $[^{18}F]FDG$ uptake and lack of radioactive iodine uptake. Poorly differentiated thyroid carcinomas may exhibit heterogeneous uptake of both radiotracers (7).

The optimal therapeutic strategy for oligometastatic disease lies between systemic treatments (radioiodine therapy) and localized approaches (surgery or stereotactic radiotherapy). We report the case of a poorly differentiated thyroid carcinoma that presented a remarkable biochemical response after local treatment of an isolated femoral metastasis.

Clinical Observation

This is a 54-year-old female patient followed for papillary thyroid carcinoma diagnosed fourteen years earlier. The initial treatment consisted of a left lobectomy–isthmectomy performed for diagnostic and therapeutic purposes, which concluded with a diagnosis of papillary microcarcinoma. Postoperative evolution under suppressive therapy was favorable, with no evidence of local or metastatic recurrence for several years.

During follow-up, biological tests revealed an elevation in thyroglobulin levels. At the same time, cervical ultrasound showed nodular changes classified as EU-TIRADS IV in the right thyroid lobe, with features suggestive of a suspicious contralateral thyroid carcinoma. The patient subsequently underwent a complementary right lobectomy–isthmectomy, resulting in a total thyroidectomy. Histopathological examination of the right surgical specimen revealed a 1.3-cm papillary thyroid carcinoma of the follicular variant, associated with a 4-mm papillary microcarcinoma, with no vascular emboli, no capsular invasion, nor lymph node involvement.

Given the histological subtype, the multifocal nature of the tumor, and the intermediate risk of recurrence, adjuvant radioactive iodine (^{131}I) therapy was indicated in accordance with international recommendations. The patient thus received a course of radioiodine therapy under TSH stimulation. Post-therapeutic scintigraphy showed residual thyroid uptake associated with a focus of osseous uptake in the mid-shaft of the left femur, consistent with a metastatic lesion (Figure 1). The post-therapy assessment revealed a marked elevation of serum thyroglobulin, reaching 1960 ng/mL, with suppressed TSH and absence of anti-thyroglobulin antibodies. In this context, an $[^{18}F]FDG$ PET/CT was performed in accordance with the American Thyroid Association (ATA) recommendations. The examination demonstrated a single, intensely hypermetabolic osseous lesion extending from the mid-shaft to the distal third of the left femoral diaphysis (Figure 2). The lesion was intramedullary, associated with medullary expansion and cortical thinning, without overt bone lysis or pathological fracture. No additional pathological uptake was identified (Figure 2).

The isolated bone lesion prompted presentation of the case at a multidisciplinary orthopedic oncology and nuclear medicine tumor board. Given the solitary and accessible nature of the lesion, a complete curative-intent surgical excision was recommended. The procedure was performed without complication and allowed an en bloc resection of the femoral lesion while preserving bone stability.

Histopathological analysis of the surgical specimen confirmed the metastatic nature of the tumor, corresponding to a poorly differentiated thyroid carcinoma derived from a papillary carcinoma.

Postoperative evolution was marked by a dramatic drop in serum thyroglobulin from 1960 ng/mL to 2.2 ng/mL, indicating a complete biochemical response. No evidence of local or metastatic recurrence was observed on the six-month follow-up imaging.

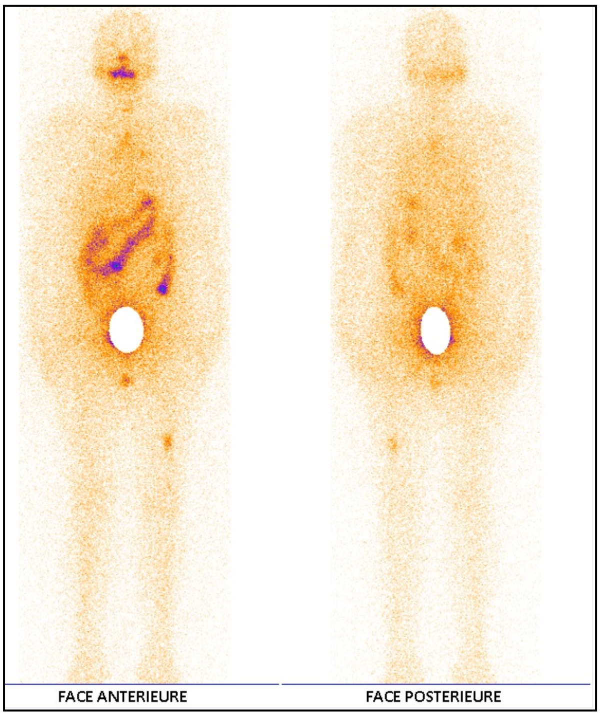

Figure 1: *Whole-body scan on day 4 post-radioiodine therapy.*

Discussion

Differentiated follicular thyroid carcinoma (DTC) is one of the most curable cancers (10). DFTCs are characterized by a slowly progressive evolution and show a 10-year survival rate of 90% (4). However, the occurrence of distant metastases reduces this rate to 40% (11). Age, sex, and the involvement of multiple organs are independent factors associated with mortality in patients with DTC.

Patients with DTC and bone metastases have a poor prognosis, with 10-year survival rates ranging from 0 to 34% (12). Bone metastases from DTC are resistant to radioactive iodine therapy (10, 13), the reference treatment for metastases particularly in vital organs—arising from differentiated thyroid cancer (DTC).

Surgical resection is generally recommended for isolated, solitary, and accessible metastases (14), and it is associated with a significant improvement in survival (15). However, in patients with multifocal disease, the role of surgical resection is less clearly defined. Local treatment of bone metastases is recognized as a significant factor in improving survival rates (16). Similarly, guidelines specify that complete resection of isolated bone metastases may prolong overall survival. In the patient presented in this case, surgical excision led to an almost complete decrease in thyroglobulin levels, reflecting an excellent therapeutic response.

This marked decrease represents a major biological indicator of treatment effectiveness, suggesting a significant reduction in residual tumor tissue and confirming the relevance of the surgical strategy adopted.

Conclusion

[^{18}F]FDG PET/CT is a valuable tool in the diagnosis and treatment of differentiated follicular thyroid carcinoma. Its impact on clinical management is tangible. Surgical management of isolated bone metastases, although rare, can offer curative potential or durable disease control. This case illustrates in an exemplary manner the relevance of [^{18}F]FDG PET/CT in the management of poorly differentiated thyroid carcinomas refractory to radioactive iodine.

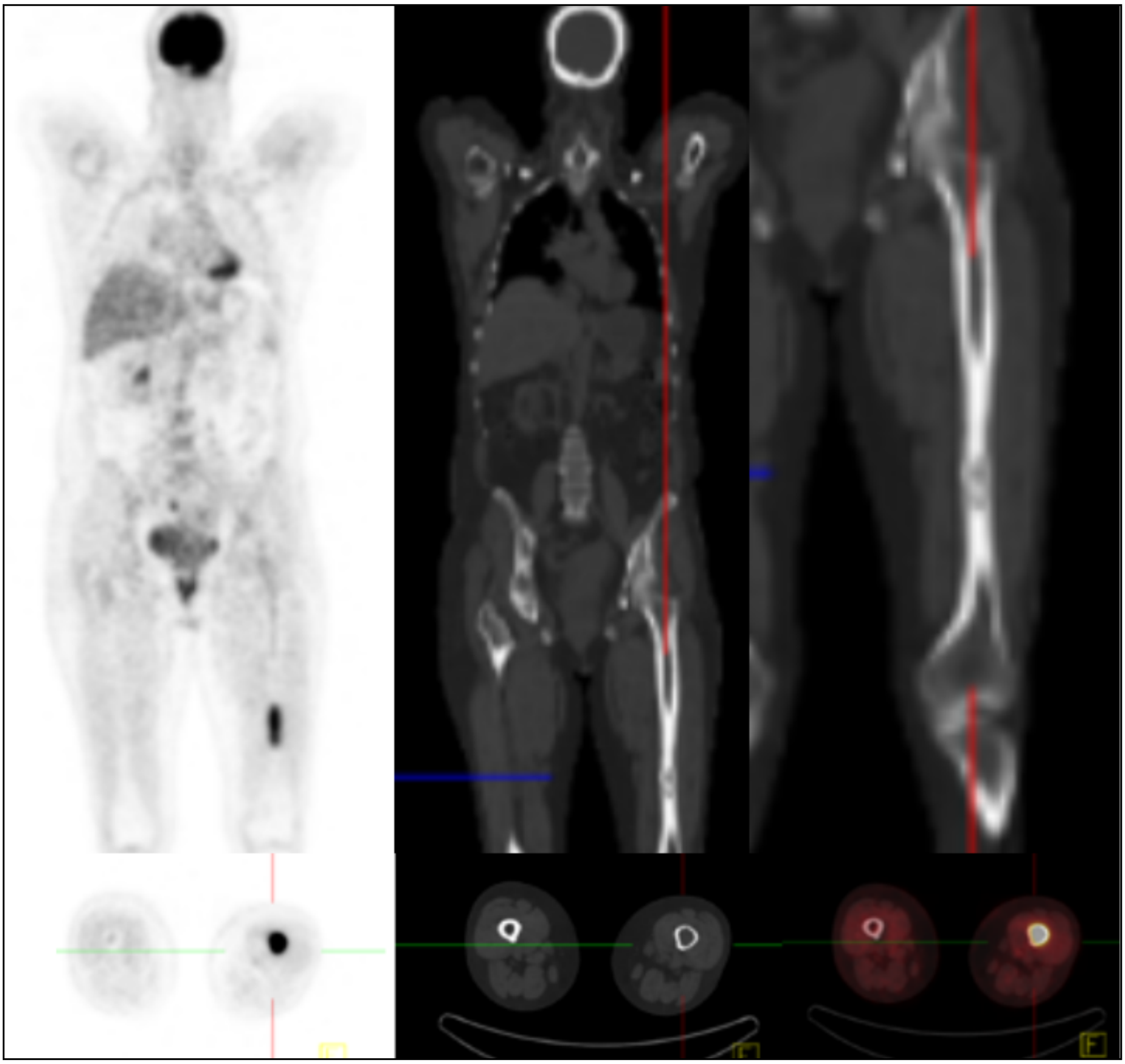

***Figure 2:** PET/CT image showing a hypermetabolic lesion in the mid-third of the left femoral diaphysis*

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1. Halima Batani: Conceptualization, investigation, data curation, writing – original draft.
2. Hafsa Bensimimou: Methodology, supervision, writing – review & editing.
3. Abdel Amide Gbadamassi: Formal analysis, visualization.
4. Zakaria Ouassafrar: Formal analysis, visualization.
5. Amal Guensi: Supervision, project administration, validation

Declarations

Consent for publication: The author clarifies that written informed consent was obtained and the anonymity of the patient was ensured. This study submitted to Swiss J. Rad. Nucl. Med. has been conducted in accordance with the Declaration of Helsinki and according to requirements of all applicable local and international standards. All authors contributed to the conception and design of the manuscript, participated in drafting and revising the content critically for important intellectual input, and approved the final version for publication. Each author agrees to be accountable for all aspects of the work, ensuring its accuracy and integrity.

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Impact of Diabetes and Diabetic Kidney Disease on Bone Mineral Density at the Lumbar Spine and Femoral Neck

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Abstract

Background:
Type 2 diabetes mellitus (T2DM) and diabetic kidney disease are associated with metabolic disturbances that negatively affect bone health, increasing the risk of reduced bone mineral density (BMD), osteopenia, and osteoporosis. This study aimed to determine and compare the prevalence of osteopenia and osteoporosis among patients with T2DM with and without chronic kidney disease (CKD) and healthy non-diabetic controls.

Materials and Methods:
A total of 210 participants were enrolled and categorized into three groups: patients with T2DM and CKD, patients with T2DM without CKD, and healthy controls. BMD was measured at the lumbar spine and femoral neck using dual-energy X-ray absorptiometry (DEXA). Bone status was classified according to World Health Organization criteria: normal (T-score ≥ –1), osteopenia (T-score between –1 and –2.5), and osteoporosis (T-score < –2.5).

Results:
The prevalence of osteopenia and osteoporosis was significantly higher among diabetic patients compared to controls, with the highest rates observed in patients with diabetic kidney disease. Vertebral osteoporosis and osteopenia were present in 54% and 38% of patients with diabetic kidney disease, respectively. In patients with T2DM without CKD, osteoporosis and osteopenia were observed in 24% and 52% of cases, respectively. At the right femoral neck, osteoporosis prevalence was 24% in patients with diabetic kidney disease, 8% in patients with T2DM without CKD, and 4% in controls. Corresponding osteopenia rates were 38%, 42%, and 20%, respectively.

Conclusion:
Patients with T2DM, particularly those with concomitant CKD, exhibit a substantially higher prevalence of osteopenia and osteoporosis compared to non-diabetic individuals. These findings emphasize the need for routine bone health assessment and early osteoporosis screening in diabetic patients to reduce fracture risk and improve clinical outcomes.

Keywords: Osteoporosis, Diabetes, Chronic kidney disease, Osteopenia, Bone mineral density, DEXA.

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Introduction

Diabetes mellitus represents a major and escalating public health burden in India, with prevalence rates rising at an alarming pace. It is projected that the number of individuals affected by diabetes will increase from 40.6 million in 2006 to approximately 79.4 million by 2030 (1). This upward trend is likely to accelerate further as life expectancy increases and mortality from communicable diseases declines. Individuals with type 2 diabetes mellitus (T2DM) are predisposed to a broad spectrum of microvascular and macrovascular complications, the incidence and severity of which are largely determined by disease duration and the degree of glycemic control (2, 3, 4).

Beyond the well-recognized complications such as ischemic heart disease, cerebrovascular events, and diabetic nephropathy, mounting evidence indicates that individuals with T2DM are at a substantially increased risk of fractures compared to their non-diabetic counterparts. This elevated fracture risk has traditionally been attributed to diabetes-related complications, including hypoglycemia induced by antidiabetic therapy, impaired muscle strength, visual impairment secondary to diabetic retinopathy, peripheral arterial disease, and diabetic neuropathy, all of which contribute to imbalance and an increased propensity for falls. However, recent studies have demonstrated that diabetes exerts direct effects on bone metabolism at the molecular level, resulting in altered bone remodeling dynamics, increased bone resorption, and compromised bone quality (5, 6, 7).

Current evidence suggests a strong association between diabetes and reduced bone mineral density (BMD), manifesting as osteopenia and osteoporosis. This risk is further amplified in individuals with long-standing diabetes and those who develop chronic kidney disease (CKD), owing to disturbances in mineral metabolism, secondary hyperparathyroidism, and vitamin D deficiency (8, 9, 10). Despite the growing recognition of skeletal fragility in diabetes, data on the prevalence of osteopenia and osteoporosis among Indian patients with T2DM—particularly those with concomitant CKD—remain limited.
In view of these considerations, the present study was undertaken to estimate and compare the prevalence of osteopenia and osteoporosis in patients with T2DM with and without CKD and to contrast these findings with those observed in non-diabetic healthy controls.

Materials and Methods

Study Design and Setting

This hospital-based cross-sectional study was conducted between 2022 and 2023 through a collaborative effort between the Departments of Radiodiagnosis and Imaging and Medicine/Endocrinology at a tertiary care teaching hospital in the Kashmir Valley, India. Participants were recruited from the outpatient services of the Departments of Medicine and Endocrinology.

Participants

Eligible participants were adults aged ≥18 years attending the outpatient department who were approached consecutively and provided with detailed information regarding the study objectives and procedures. Written informed consent was obtained from all participants prior to enrollment. Patients diagnosed with T2DM, with or without diabetic kidney disease, were included. Healthy controls were selected from attendants of patients admitted for elective surgical procedures and were screened to ensure the absence of diabetes or other systemic illnesses affecting bone metabolism.

Case Definitions

Participants were categorized into three groups of 70 individuals each: T2DM with CKD, T2DM without CKD, and non-diabetic controls.
The control group was age- and sex-matched and recruited from the same hospital setting to provide representative reference BMD values.

T2DM was defined by one or more of the following criteria: fasting plasma glucose ≥126 mg/dL, postprandial plasma glucose ≥200 mg/dL, glycated hemoglobin (HbA1c) ≥6.5%, or a prior diagnosis of diabetes with ongoing antidiabetic therapy.
Diabetic kidney disease was defined as urinary albumin excretion >15 µg, 24-hour urinary albuminuria >300 mg/day, or serum creatinine >120 µmol/L in a patient with diabetes.

Study Procedures

Following informed consent, all participants underwent a comprehensive baseline clinical evaluation and laboratory assessment. Sociodemographic and clinical data—including medical and surgical history, smoking and alcohol consumption, medication use, physical activity levels, and other factors influencing bone metabolism—were collected using a standardized questionnaire.

Laboratory investigations included fasting and postprandial plasma glucose, HbA1c, renal function tests, 24-hour urinary protein estimation, serum 25-hydroxyvitamin D, calcium, phosphorus, albumin, alkaline phosphatase, and thyroid-stimulating hormone levels. Bone mineral density of the lumbar spine and right femoral neck was assessed using dual-energy X-ray absorptiometry (DEXA).

Variables and Definitions

Bone mineral density was classified according to World Health Organization criteria: normal BMD (T-score ≥ −1), osteopenia (T-score between −1 and −2.5), and osteoporosis (T-score < −2.5). Body mass index (BMI) was calculated using standard formulas.

Sample Size

Sample size estimation was based on previous studies reporting the prevalence of osteoporosis in patients with T2DM. Assuming a power of 80% and a two-sided alpha of 0.05, a minimum sample size of 70 participants per group was calculated to detect statistically significant differences in BMD between patients with T2DM with and without CKD.

Statistical Analysis

Categorical variables were expressed as frequencies and percentages. The distribution of continuous variables was assessed using histograms, probability plots, and the Kolmogorov–Smirnov and Shapiro–Wilk tests. Normally distributed variables were summarized as mean ± standard deviation, while non-normally distributed variables were expressed as median with interquartile range. Comparisons between categorical variables were performed using Pearson's χ^2 test or Fisher's exact test, as appropriate. The Mann–Whitney U test was used for comparisons between two groups, and the Kruskal–Wallis test was applied for comparisons involving more than two groups. Statistical analyses were performed using Stata version 15.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee. Written informed consent was obtained from all participants. Individuals younger than 18 years and those with cognitive impairment affecting decision-making capacity were excluded.

Results

Demographic and Clinical Characteristics

A total of 210 participants were included: 70 patients with T2DM and CKD (Group 1), 70 patients with T2DM without CKD (Group 2), and 70 healthy controls (Group 3). The three groups were comparable with respect to age and sex distribution. The mean age was 60.16 ± 10.32 years in Group 1, 58.26 ± 9.93 years in Group 2, and 59.60 ± 4.92 years in Group 3. Male participants constituted 62.86%, 62.86%, and 60% of Groups 1, 2, and 3, respectively. Body mass index did not differ significantly among the groups.

Serum electrolytes, calcium, phosphorus, and albumin levels were comparable across groups. However, fasting and postprandial glucose levels and HbA1c values were significantly higher in Group 1 compared to Group 2, with both groups exhibiting higher values than controls. Serum urea and creatinine levels were significantly elevated in patients with diabetic kidney disease.

Bone Mineral Density

Mean vertebral T-scores were −2.49 ± 0.88, −1.69 ± 1.25, and −0.75 ± 1.02 for Groups 1, 2, and 3, respectively, with corresponding Z-scores of −1.62 ± 1.02, −0.76 ± 0.95, and −0.62 ± 1.22. These differences were statistically significant.

At the right femoral neck, mean T-scores were −1.29 ± 1.06, −0.84 ± 1.13, and −0.40 ± 0.90 for Groups 1, 2, and 3, respectively, with corresponding Z-scores of −0.42 ± 1.24, −0.25 ± 1.03, and −0.26 ± 1.12. The differences in T-scores were statistically significant.

Discussion

Diabetes mellitus and osteoporosis are prevalent chronic disorders that substantially impair quality of life, particularly among older adults (11). Diabetes and diabetic kidney disease induce complex metabolic and hormonal alterations that adversely affect bone

Table 1: Comparison of demographic and clinical parameters in the three groups

	T2DM and CKD (Group 1)	T2DM without CKD (Group 2)	Healthy controls (Group 3)	p-value
Age, mean ±SD	60.16 ± 10.32	58.26 ± 9.93	59.60 ± 4.92	0.081
Gender, males n (%)	44 (62.86%)	44 (62.86%)	42(60%)	0.087
BMI	25.96 ± 4.52	25.71 ± 4.51	23.44 ±4.44	0.23
Blood sugar (F) mg/dl	195.66 ± 55.82	147.32 ± 39.30	90.99 ± 4.76	**< 0.001**
Blood sugar (PP) mg/dl	245.64 ± 139.49	220.17 ± 57.08	124.6 ± 25.4	**< 0.001**
HbAlc %	10.31 ± 1.61	8.59 ± 2.07	5.45 ± 0.02	**< 0.001**
Serum urea mg /dl	74 ± 23.72	40.77 ± 23.03	38.64 ± 0.46	**< 0.001**
Serum creatinine mg /dl	2.3 ± 1.17	0.94 ± 0.14	0.72 ± 0.16	**< 0.001**
Serum sodium mmol/L	140.68 ± 3.11	137.72 ± 3.8	142.4 ± 5.2	0.084
Serum potassium mmol /L	4.19 ± 0.61	3.82 ± 0.25	3.96 ± 0.32	0.226
Serum calcium mg /dl	8.81 ± 0.82	9.26 ± 0.46	9.53 ± 0.62	0.569
Serum phosphorus mg /dl	4.3 ± 1.25	3.78 ± 0.79	4.34 ± 0.56	0.421
Serum albumin g/dl	3.49 ± 0.41	3.78 ± 0.41	3.96 ± 0.34	0.078
ALP U/L	174.74 ± 69.82	118.56 ±40.37	126 ± 24.56	**< 0.001**

Table 2: T and Z-scores of Bone mineral density at Vertebra and right neck of femur (R-NOF)

	T-Score Vertebra	Z-Score Vertebra	T- Score R-NOF	Z-Score R NOF
Diabetic Kidney disease	-2.49 ± 0.88	-1.62 ± 1.02	-1.29 ± 1.06	-0.42 ± 1.24
Uncomplicated DM	-1.69 ± 1.25	-0.76 ± 0.95	-0.84 ± 1.13	-0.25 ± 1.03
Controls	-0.75 ±1.02	-0.62 ±1.22	-0.40 ± 0.90	-0.26 ± 1.12
p-value	**<0.001**	**<0.001**	**0.002**	0.72

T and Z scores compared between the three groups.

turnover, leading to reduced bone mineral density and increased skeletal fragility (12, 13). When combined with an elevated risk of falls due to neuropathy and visual impairment, these changes significantly increase fracture risk in diabetic individuals (14, 15).

The present study demonstrated a markedly higher prevalence of osteopenia and osteoporosis among patients with T2DM, particularly those with concomitant CKD, compared to non-diabetic controls. Vertebral osteoporosis and osteopenia were observed in 54% and 38% of patients with diabetic kidney disease, respectively, whereas patients with T2DM without CKD exhibited lower prevalence rates. The control group showed substantially lower rates of both conditions. These findings are consistent with prior studies that have reported an increased burden of osteoporosis in patients with diabetes, especially in the presence of CKD (16, 17, 18, 19, 20).

At the femoral neck, osteoporosis prevalence was highest among patients with diabetic kidney disease, followed by those with uncomplicated diabetes and controls. This is clinically significant, as femoral neck fractures are associated with considerable morbidity, loss of independence, and increased mortality. Our findings corroborate previous reports demonstrating reduced femoral neck BMD in patients with diabetic kidney disease (21, 22, 23, 24, 25). Collectively, these results underscore the need for early identification and proactive management of bone disease in patients with diabetes. Routine screening for osteoporosis in patients with long-standing diabetes, particularly those with CKD, may facilitate timely intervention, reduce fracture risk, and improve long-term functional outcomes.

Conclusion

This study demonstrates a significantly higher prevalence of osteopenia and osteoporosis among patients with T2DM, with the greatest burden observed in those with concomitant CKD. Both vertebral and femoral neck bone mineral density were significantly lower in diabetic patients compared to non-diabetic controls. These findings high-light the importance of routine osteoporosis screening and early bone health assessment in diabetic patients, particularly those with diabetic kidney disease, to mitigate fracture risk and prevent associated functional impairment.

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Declarations

Consent for publication: The author clarifies that written informed consent was obtained and the anonymity of the patient was ensured. This study submitted to Swiss J. Rad. Nucl. Med. has been conducted in accordance with the Declaration of Helsinki and according to requirements of all applicable local and international standards. All authors contributed to the conception and design of the manuscript, participated in drafting and revising the content critically for important intellectual input, and approved the final version for publication. Each author agrees to be accountable for all aspects of the work, ensuring its accuracy and integrity.

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Multivessel Transcatheter Arterial Embolization to Treat Hip Osteoarthritis: A Pilot Case Series

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Abstract

Chronic hip pain due to osteoarthritis (OA) is a prevalent source of disability in older adults. While total hip arthroplasty (THA) remains the standard treatment for end-stage disease, many patients are not surgical candidates due to comorbidities or personal preferences. Transcatheter Arterial Embolization (TAE) of the hip has emerged as a minimally invasive treatment for OA-related pain, but further evidence is warranted to establish its role in treatment pathways.

This prospective, single-center pilot case series was conducted under IRB approval and reviewed the feasibility of multivessel hip TAE for pain treatment. Four patients with OA-related chronic hip pain underwent hip TAE which targeted the medial and lateral circumflex arteries, and obturator arteries. Technical success was reached in all cases, defined as a resolution in synovial blush on post-embolization angiography. Pain outcomes were measured at baseline, 1, 3, and 6 months post-procedure using the Visual Analog Scale (VAS). All four patients achieved ≥50% reduction in VAS from baseline (average 9.75 baseline --> 1.75 at the end of the study period). No ischemic complications were observed.

Study results demonstrate multivessel hip TAE may be viable as an effective minimally invasive treatment for patients with OA-related hip pain, with meaningful and sustained pain reduction and no adverse complications occurring. Larger and sham-controlled studies are necessary to further generalize these findings and establish hip TAE.

Keywords: Osteoarthritis, hip, pain, embolization.

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Introduction

Chronic hip pain from osteoarthritis (OA) is a prevalent source of disability and joint pain, particularly among older adults (1 - 3). The lifetime risk of symptomatic hip OA in individuals living to the age of 85 is estimated to be over 25% (2). OA is a complex and multifactorial disease, characterized by pathological changes in cartilage, bone, and surrounding structures of the joint. Recent literature suggests that OA may be influenced by increased vascularity of the synovium (3 - 5). This results in joint pain, mobility impairment, and reduced quality of life (1, 4, 6).

Conservative treatments are typically used to alleviate pain and improve function. Many patients experience temporary benefit from measures such as oral analgesics, non-steroidal anti-inflammatory drugs (NSAIDs), physical therapy, and/or intra-articular steroid injections (7, 8). For end-stage OA, total hip arthroplasty (THA) remains the definitive option. However, arthroplasty is not always feasible for patients due to advanced age, comorbidities, or personal preference (8, 9).

Table 1: Summary of patient demographics and outcomes.

	Age	Sex	BMI	Diagnosis	Initial VAS	1 mo. VAS	3 mo. VAS	6 mo. VAS
Case 1	79	Female	25.5	Left Hip OA	10	1	0	0
Case 2	85	Female	27.3	Left Hip OA	10	2	5	5
Case 3	83	Female	23.2	Left Hip OA	9	5	2	2
Case 4	76	Male	22.4	Right Hip OA	10	0	0	0

As a result, there is a need for adjunctive, minimally invasive alternatives that can reduce pain and maintain mobility (10 - 12).

Transcatheter arterial embolization (TAE) has shown promise in managing OA-related pain in the knee and shoulder (8, 10, 11, 13). The procedure involves selective cannulation and embolization of abnormal synovial hypervascularity to reduce inflammation (8, 10). By targeting synovial neoangiogenesis, hip TAE disrupts the inflammatory cascade and provides pain relief and functional improvement (13, 14). Although TAE has shown efficacy in various joints, there is limited research on application of this technique within the hip (14). Early studies have evaluated short-term outcomes of hip TAE among patients with moderate to severe OA of the hip, but long-term evaluation is necessary (12, 15).

Given this relatively unexplored avenue, this pilot case series assesses the feasibility of multivessel TAE for OA-related hip pain. We present four patients with advanced hip OA and multiple comorbidities who underwent the procedure for pain relief.

Methods

This single-center prospective case series was conducted under full IRB approval. All four patients had chronic and persistent hip pain secondary to osteoarthritis, which was refractory to conservative treatments. Following clinical and imaging evaluation, the procedures were performed by an experienced interventional cardiologist with certification from the American Board of Endovascular Medicine. The procedure was performed using a multivessel approach, defined as the embolization of two or more arterial contributors to the hip joint (notably the medial and lateral circumflex femoral and obturator arteries). These vessels were selectively cannulated and embolized using Primaxin, a suspension of imipenem-cilastatin, and 50 - 100 µm or 100 - 300 µm Embospheres, to achieve complete cessation of pathological blush. Technical success was defined as the resolution of abnormal synovial hypervascularity or blush displayed in the post-embolization angiography.

Pain outcomes were assessed using the Visual Analog Scale (VAS), a validated 0–10 measure of pain intensity, where 0 indicates no pain and 10 represents the worst pain imaginable (17). The objective was to evaluate the clinical success of hip TAE for OA-related pain. Clinical success was defined as a ≥50% reduction in VAS score from baseline, measured during follow-up evaluations at 1, 3, and 6 months.

Case 1

A 79-year-old female with frailty, type II diabetes mellitus, OA, and chronic venous insufficiency presented with progressive bilateral hip osteoarthritis-related pain, worse on the left. Her symptoms were associated with severe limitations in activities of daily living (ADLs), with pain reaching a 10/10 VAS score. The patient had previously tried multiple conservative therapies, including oral analgesics, physical therapy, and intra-articular steroid injections, all of which failed to provide lasting relief. Due to her comorbidities and frailty, she was not a candidate for total hip arthroplasty and elected to undergo TAE for her left hip pain.
Ultrasound-guided retrograde access of the right (contralateral) common femoral artery was obtained. A 5F Prelude sheath (Merit Medical) was placed and exchanged for a 5F 45 cm Roadster sheath, which was advanced into the left (ipsilateral) common femoral artery through an up-and-over approach. An abdominal aortogram was performed using a 4F 65 cm Berenstein catheter (Merit Medical) to delineate pelvic inflow prior to selective catheterization of the left-sided hip-supplying vessels. Using a Fielder XT-R wire and 1.4F

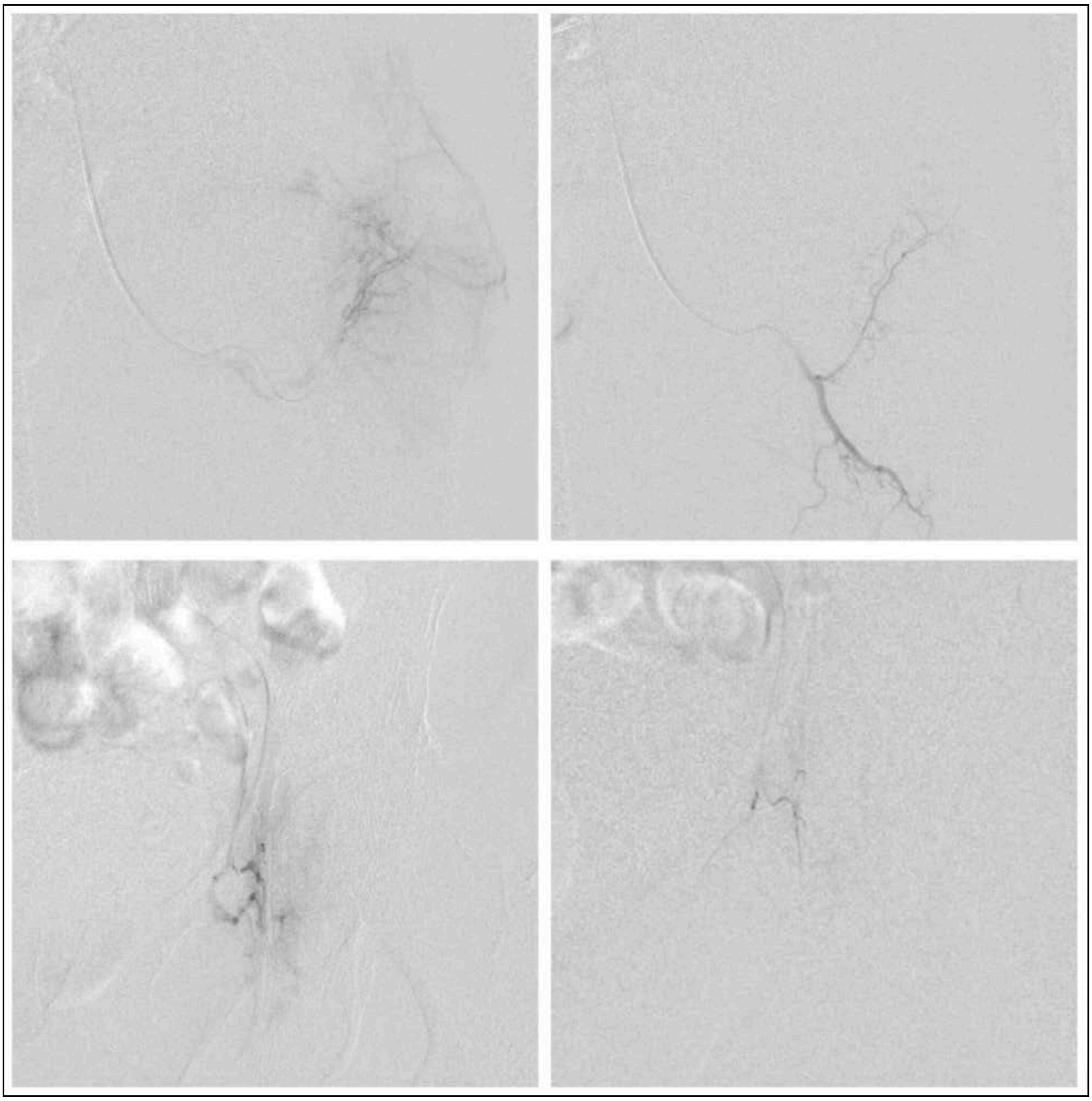

Figure 1: Pre (left) and post (right) angiographic imaging for left medial circumflex artery (top) and obturator artery (bottom).

135 cm Caravel microcatheter (Asahi Intecc Medical), target arteries were selectively cannulated and injected with 50 mcg nitroglycerin, saline flush, and contrast dye to demonstrate angiographic blush. After confirming angiographic blush visualized in Figure 1, embolization of the left medial circumflex femoral artery was performed with 0.5 mL of Primaxin, the left lateral circumflex femoral artery with 0.2 mL of 100–300 µm Embospheres, and the left obturator artery with 0.2 mL of Primaxin. Post-embolization angiography confirmed a reduction of abnormal blush with preserved femoropopliteal flow. Hemostasis was achieved using a 5F Celt closure device (Vasorum) at the access site.

At 1-month post-embolization, the patient reported marked improvement, with her VAS pain score decreasing from 10/10 to 1/10. By this time, she was able to resume routine activities such as standing, cooking, and shopping with minimal limitations. At 3 months, she reported complete resolution of left hip and compensatory back pain (VAS 0/10), an effect that sustained at her 6-month follow-up. In this case, hip TAE provided effective pain relief with meaningful improvement in daily function.

Case 2

An 85-year-old female with hypertension, atrial fibrillation, and OA presented with progressive osteoarthritis-related left hip pain. Her discomfort limited ADLs, and she rated her pain 10/10 VAS score. Multiple intra-articular steroid injections to the left hip and knee provided only temporary relief. Given the persistence of pain, functional decline, and lack of further surgical options, she elected to undergo left-hip transcatheter arterial embolization (TAE) as a minimally invasive treatment.

Ultrasound-guided retrograde access of the right (contralateral) common femoral artery was obtained, and a 5F Prelude sheath (Merit Medical) was placed. Following placement, the 5F Prelude sheath (Merit Medical) was exchanged for a 5F 45 cm Roadster sheath, which was advanced into the left (ipsilateral) common femoral artery through an up-and-over approach. An abdominal aortogram was performed using a 4F 65 cm Berenstein catheter, which delineated pelvic inflow before selective catheterization of the left-sided hip vessels. Using a Fielder XT-R wire and 1.4F 135 cm Caravel microcatheter (Asahi Intecc Medical), the left lateral circumflex femoral artery was selectively cannulated. Intra-arterial nitroglycerin (50 mcg) was given before angiography to minimize vasospasm. Embolization was performed with 1.0 mL of Primaxin, resulting in reduction of angiographic blush while preserving femoropopliteal flow, visualized in Figure 2. The medial circumflex femoral artery was not able to be cannulated due to diffuse calcific disease and thus not treated, and the obturator artery showed no significant blush. Hemostasis was achieved using a 5F Celt closure device (Vasorum).

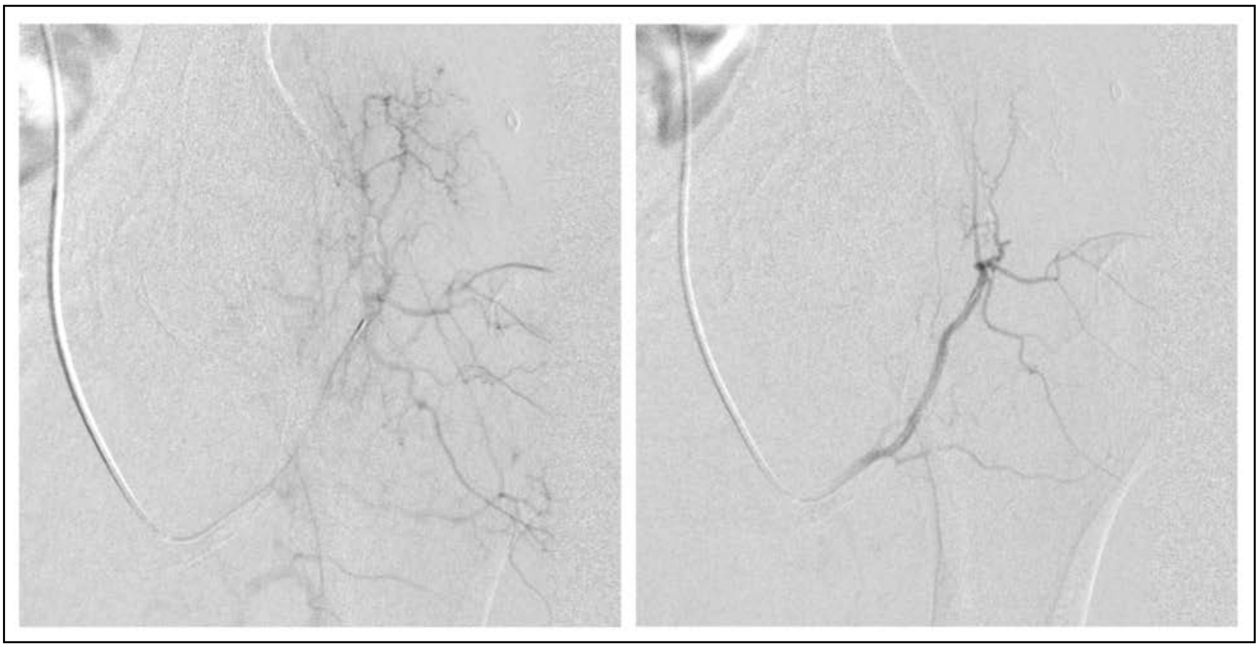

Figure 2: Pre (left) and post (right) angiographic imaging for left lateral circumflex artery.

At baseline, the patient reported severe left hip pain rated 10/10 on the VAS, which significantly limited her activities of daily living. At 1 month, her pain improved to VAS 2/10, with increased mobility and reduced discomfort. At 3 months, she continued to note improvement (VAS 5/10) but described ongoing bilateral lower-extremity tenderness and swelling, consistent with previously documented chronic venous insufficiency. At 6 months, her hip pain remained improved relative to baseline (VAS 5/10) and she reported a sense of tightness, particularly when sitting. No ischemic or procedural complications were observed. Overall, hip TAE resulted in meaningful pain reduction and functional improvement over the 6-month follow-up period in a patient with multiple comorbidities.

Case 3

An 83-year-old female with a history of type II diabetes mellitus, hypertension, and OA, presented with progressive left hip pain. The patient described a gradual onset of symptoms over several years without antecedent trauma or recent falls. Diagnostic imaging demonstrated osteoarthritis of the left hip. Conservative measures, including physical therapy, steroid injections, and prescription analgesics, provided only minimal pain relief. At baseline, she required a cane for ambulation assistance and rated her pain 9/10 on the VAS. Given the severity of her disease, limited response to conservative therapies, and hesitancy to pursue arthroplasty, she elected to proceed with left hip TAE for her pain.

Ultrasound-guided retrograde access of the right (contralateral) common femoral artery was obtained, and a 5F 10 cm Terumo Pinnacle sheath was placed. This was subsequently exchanged for a 5F 45 cm Roadster sheath, which was advanced into the left (ipsilateral) common femoral artery through an up-and-over approach. Selective angiography of the left profunda femoris and lateral circumflex femoral arteries demonstrated significant blush, visualized in Figure 3. An abdominal aortogram was performed using 4F 65 cm Berenstein catheter (Merit Medical).
A 1.4F 135cm Asahi Caravel microcatheter and Fielder XT-R wire were used for selective catheterization of the target vessels. Intra-arterial nitroglycerin (50 mcg) was administered prior to angiography to minimize vasospasm. Embolization was performed with 0.2 mL of 100–300 µm Embosphere particles under fluoroscopic guidance, resulting in resolution of the blush while preserving femoropopliteal flow. The medial circumflex and obturator arteries were selectively cannulated but showed no significant blush. Hemostasis was achieved using a 5F Celt closure device (Vasorum) at the access site.

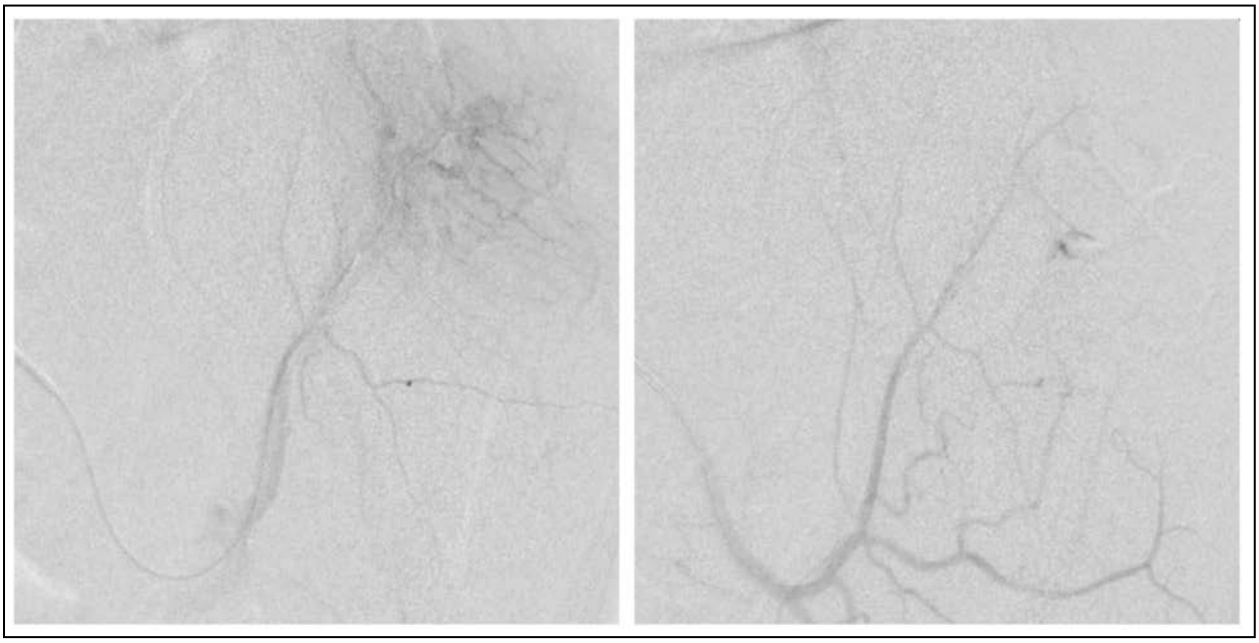

Figure 3: Pre (left) and post (right) angiographic imaging for left lateral circumflex artery.

At baseline, the patient reported severe left hip pain rated 9/10 on the VAS with substantial restriction in mobility and daily activities.

At 1-month post-embolization, she reported significant improvement in pain and function, noting marked improvement in hip pain and no longer requires routine cane use to ambulate in her home, after relying on it for 4–5 months before the procedure.

At 3 months post-embolization, the patient continued to report significant improvement in her left hip symptoms compared to baseline, rating her pain level a 2/10 on the VAS. At 6-month post-embolization, she continued to report durable pain relief, with pain rated 2/10 on the VAS. In this case, left hip TAE provided substantial and sustained pain reduction with improved mobility and functional recovery in a patient with severe osteoarthritis and limited surgical options.

Case 4

A 76-year-old male with a history of carotid artery stenosis, coronary artery disease, and hyperlipidemia presented with progressively worsening right hip pain secondary to radiographically confirmed moderate OA. He described that his pain and stiffness limited his ability to walk long distances, climb stairs, and play golf. Conservative therapies, including physical therapy, intra-articular steroid injections, and oral analgesics, failed to resolve his hip pain, which was rated 10/10 on the VAS. Due to the persistence of his symptoms and hesitancy to pursue arthroplasty, he opted for right hip TAE for his pain.

Under ultrasound guidance, contralateral common femoral artery retrograde access was obtained, and a 5F sheath (Merit Medical) was placed. This was subsequently exchanged for a 5F 45 cm Roadster sheath, which was advanced into the right (ipsilateral) common femoral artery through an up-and-over approach. Intra-arterial nitroglycerin (50 mcg) was administered to minimize vasospasm. After an abdominal aortogram was performed using a 4F Berenstein catheter (Merit Medical), selective angiography of

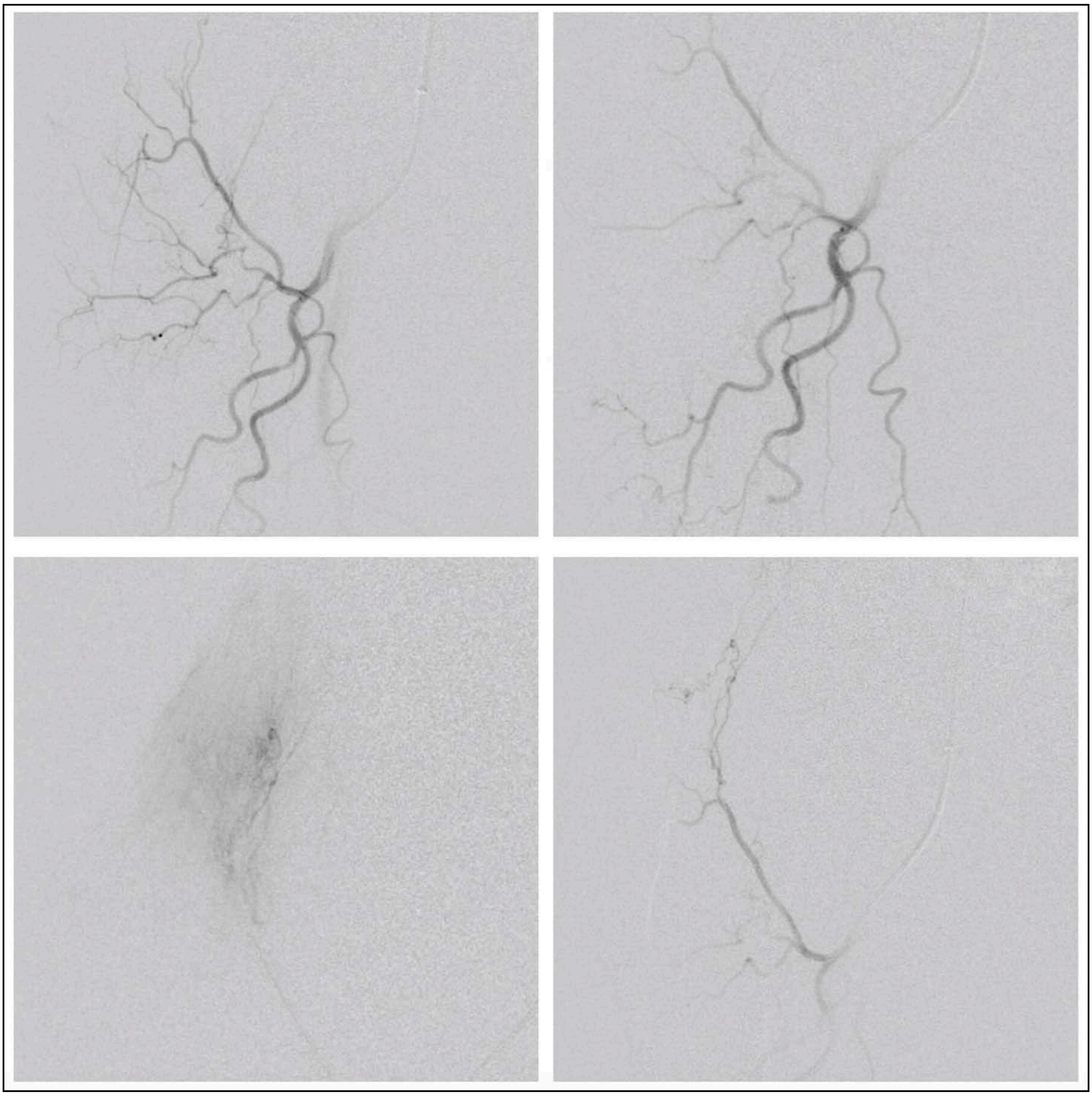

Figure 4: Pre (left) and post (right) angiographic imaging for left medial circumflex artery (top) and obturator artery (bottom).

the right profunda femoris as well as lateral and medial circumflex femoral arteries demonstrated significant angiographic blush, as shown in Figure 4. Selective catheterization of the target hip vessels followed through usage of a 1.4F Asahi Caravel microcatheter and Fielder XT-R wire. Under fluoroscopic guidance, embolization was performed on the ascending and transverse branches of the right lateral circumflex with 1 mL of Primaxin and 0.5 ml of 50-100 μm Embosphere embolization particles injected into the ascending and 1 mL of Primaxin injected into the transverse branches respectively. The right medial circumflex femoral artery was treated with 0.3 mL Primaxin. Moreover, the obturator artery was selectively cannulated but showed no significant blush. Following the procedure, fluoroscopic guidance confirmed significant improvement of blush with preservation of femoropopliteal flow. Hemostasis was achieved using a 5F Celt closure device (Vasorum) at the access site.

At 1-, 3-, and 6-month follow-up, the patient reported complete resolution of right hip pain (VAS 0/10) with full return to normal mobility and daily activities. In this case, right hip TAE provided substantial and durable pain relief with restoration of functional ability in a patient with moderate osteoarthritis and limited surgical options.

Discussion

In this case series, hip TAE provided meaningful and sustained pain reduction in patients with end-stage OA where THA was not appropriate. Once conservative treatments fail, effective alternatives remain sparse for resolving pain in this patient population. However, all four patients achieved clinical success, defined as a greater than 50% reduction in VAS scores at six months post-procedure. Although standardized functional scales were not employed, all patients reported improved mobility and independence in ADLs and decreased reliance on pain medications.

This pilot series builds on the foundational TAE studies of Okuno et al. (10, 11) and expands upon the findings of Correa et al. for hip TAE (12, 13). Our multivessel approach, targeting the synovial hypervascularity or blush surrounding the hip joint, supports the feasibility of hip TAE as a minimally invasive treatment for OA-related hip pain.

Procedural technique was crucial to ensure both safety and efficacy. Subselective catheterization of the medial and lateral circumflex femoral and obturator arteries was performed under angiographic guidance, with intra-arterial nitroglycerin administered to minimize vasospasm. Selective cannulation and embolization followed. Embolization was carried out using a combination of transient Primaxin (imipenem-cilastatin) and non-resorbable 50-100 μm or 100–300 μm Embosphere (Merit Medical) particles until pathological blush resolved. This technique avoided ischemic complications and preserved femoropopliteal flow. No major adverse events, including soft tissue necrosis, osteonecrosis, or access-site injury, were observed. Mild lower extremity edema was noted in the patients (Case 1 and 2) with preexisting venous insufficiency and remained stable with conservative management. The use of temporary embolic agents such as Primaxin mitigated this risk, allowing for transient vascular occlusion (17). Non-target embolization did not occur, underscoring the safety of the procedure when performed with careful fluoroscopic guidance and judicious embolic delivery.

Although these results are encouraging, several limitations must be acknowledged. The small sample size, lack of randomized design, and follow-up period limited to six months restrict the generalizability of these findings. Pain assessment relied on patient-reported VAS scores, which, while validated, are subjective and may not fully reflect clinical outcomes (18). Future studies with larger cohorts, sham-controlled designs, objective activity measures, and longer follow-up will be necessary to confirm TAE's long-term efficacy and safety.

Conclusion

This case series demonstrates that transcatheter arterial embolization of the hip offers significant and durable pain relief for patients with end-stage osteoarthritis refractory to treatment. All patients achieved clinical success (≥50% reduction from baseline VAS score) and demonstrated improved mobility without any procedural complications. Findings imply that hip TAE may be utilized as a safe and effective minimally invasive alternative for patients where conservative measures have failed to resolve their OA-related pain. Further prospective investigations are necessary to confirm these outcomes and generalize findings.

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Declarations

Consent for publication: The author clarifies that written informed consent was obtained and the anonymity of the patient was ensured. This study submitted to Swiss J. Rad. Nucl. Med. has been conducted in accordance with the Declaration of Helsinki and according to requirements of all applicable local and international standards. All authors contributed to the conception and design of the manuscript, participated in drafting and revising the content critically for important intellectual input, and approved the final version for publication. Each author agrees to be accountable for all aspects of the work, ensuring its accuracy and integrity.

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The authors declare that there were no conflicts of interest within the meaning of the recommendations of the International Committee of Medical Journal Editors when the article was written.

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