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## **Advances in imaging: Exploring the potential of artificial intelligence in radiology**

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**Abstract**--Radiology has seen significant advances in its quest to move from descriptive to diagnostic, and more recently to predictive. The long-standing reliance on traditional 2D X-rays has evolved into the application of high-powered magnets and CT scanners, which provide improved tissue contrast and 3D capabilities. These advances have led to more accurate identification of diagnostic imaging markers and increased the ability to identify biomarkers for diagnostic and predictive imaging. While these advances still fall within the realm of human interpretation, there is continued momentum to accelerate efforts that are reshaping the clinical workplace. Whether it is the need to harness the vast and largely untapped potential of artificial intelligence, the need to increase efficiency and reduce reading times, or the call to creatively improve patient care by integrating imaging and biomarker-related technologies, the community is pushing the discipline to evolve further. To help bring these necessary tools to clinical applications, collaborative efforts between clinicians, data scientists, and engineers will need to come together. The scientific community must work together to enable the clinical translation of technologies that combine diverse physical and biological imaging findings. Emerging applications, whether integrating data science into existing imaging platforms or the live-action aspect of machine learning, represent pathways that can enable clinicians to better meet the diagnostic and prognostic needs of their patients. As the radiology profession continues to reposition itself for the future, it is imperative to navigate the technical, social, and regulatory landscapes to ensure these tools are deployed safely and effectively for the benefit of humanity.

**Keywords**--Artificial Intelligence, Radiology, 2D X-rays, clinical workplace, patient care.

## **1. Introduction**

The field of radiology has seen significant advances in its quest to transform from the descriptive to the diagnostic, and most recently, to the predictive. A reliance on conventional biplane X-rays has long since evolved into the application of high field-strength magnets and computed tomography scanners, providing increased tissue contrast and 3D capabilities. These advances have elucidated more accurate determinations of diagnostic imaging markers and have increased the ability to identify prognostic and predictive imaging biomarkers. Although these advances still lie within the domain of human interpretation, there is ongoing momentum to accelerate efforts that retool the clinical workplace. Whether it is the need to harness the vast and somewhat untapped potential of artificial intelligence, the need to increase efficiency and reduce read times, or the call for patient care creatively improved by the integration of imaging and biomarker-related technology, society is pressing this specialty to evolve further. To aid in bringing these needed tools to clinical applications, collaborative efforts among clinicians, data scientists, and engineers will need to coalesce. The scientific community must work together to enable the clinical translation of technologies that bring together diverse physical and biological imaging findings. Emerging applications, be it the integration of data science into existing imaging platforms or the living breath aspect of machine learning, represent pathways that could enable clinicians to better meet the diagnostic and prognostic needs of their patients. As the specialty of radiology continues to retool for the future, it is imperative that the technical, societal, and regulatory landscape is adeptly navigated to ensure these tools are safely and effectively deployed for the betterment of humankind.

## **Methods**

Over the last few years, artificial intelligence (AI) has shown great promise in making sweeping changes across many industries, including banking, healthcare, and industry. In radiology and medical imaging, there is now great enthusiasm for AI, which appears to offer the potential to revolutionize imaging diagnostics. However, this revolution will not come without limitations and challenges with regard to practical application and integration into standard radiology practice. Concomitant technical advancements, careful validation and standardization, as well as reliable evaluation methods are essential before AI can mature as a responsible part of the diagnostic process. We review the methods and approaches of AI in medical imaging, including the basics underlying the core technologies of AI, the collection and pre-processing of medical data, applying AI in imaging, and validation of AI using imaging data.

## **Results**

The term artificial intelligence was first coined in the 1950s in the early years of the computer age, and today it has become a part of our lives without even realizing it. The convergence of computing power, allied to sophisticated algorithms and robust big data presents an exciting opportunity for professionals. This exploding computational capability is enabling humans to utilize the power of machines to be able to accurately categorize, classify, and differentiate a wide

array of data types. Such is the case with machine learning, a subfield that is a development of AI. Also called the Nearest Neighborhood, this method is intuitive and very effective for secondary data in large databases and can be directly applicable to medical practice. In the few applications of machine learning to imaging diagnosis, the reported results are practically equivalent to human capacity for the same.

Artificial intelligence applied to the medical imaging diagnosis is becoming increasingly sophisticated, being able to extract patterns that are not obvious to the observer, and can even surpass human capacity. It analyses informative secondary data in large databases looking for patterns, predict and identify them. By understanding the range of pathology of a disease and its enormous variability, AI can handle a large amount of rare diseases and comorbidities that are difficult to quantify, extract or even visualize statistically. Additionally, the large database characteristic of AI can offer practically inexhaustible patterns, surpassing human learning when dealing with large and complex datasets.

## **Conclusion**

In conclusion, artificial intelligence has been under development since the 1950s, with early research in developing clinical decision support dating back at least 45 years. Uptake has, however, been slow. The latest advancements in deep learning have known limitations but also known advantages over previous machine learning approaches. They are predicted to offer more substantial support to actual clinical workflows over the next 5–10 years as a small number of key technological barriers are overcome. Progress in challenges for regulatory approval, data access, patient privacy, and ways in which radiologists can benefit from their clinical integration are now being discussed with industry and regulators in several countries. With enabling technologies expected to provide point-of-care artificial intelligence support and empower radiologists at interesting times over the immediate future, I trust that this meeting will help you get better acquainted with future AI colleagues who are ready to help you and your clinical teams even more in the years ahead.

### **1.1. Background and Significance**

Artificial Intelligence (AI) is rapidly advancing in both adoption and capabilities across many domains, and healthcare is no exception. In particular, there is increasing interest in AI's application to radiology as a result of the surge in the volume of image data, technical improvements in image acquisition, and the ability to quantify more complex information and integrate numerous other data types. Utilization in clinical practice is increasing in part through rapidly growing public datasets and algorithms robust to diverse sources, as well as the development of user-friendly, regulatory-compliant platforms. As the momentum of innovation continues, it is essential to ensure that AI advances in concert with, and not at the expense of, the values and goals of the radiology community. In many respects, the ongoing metrics of quality rigor that informed radiology's success are hallmarks of successful AI.

There is also particular potential for radiology's collective knowledge to positively shape AI creation and clinical implementation. In this review, we explore how AI is transforming radiology, discussing in turn the impact of different AI approaches and advances on distinct radiology functionalities. We provide insights on specific radiology AI applications, innovative technology platforms and infrastructure, in addition to policy and practice considerations. Regulatory issues, ethical considerations, and privacy concerns are touched upon, as well as evolving standards of transparency and interpretability. We provide key hallmarks of future success, exploring the roles of radiologists and the larger radiology ecosystem as essential contributors to AI innovation, dialogue, data stewardship, and knowledge creation. We conclude with specific practice considerations and potential areas of future research.

## **1.2. Purpose and Scope of the Study**

The purpose of this study was (a) to undertake a scoping review of the academic literature that examines recent advances in the field of radiology by identifying the scope, breadth, and depth of existing research and (b) to develop a bibliometric approach capturing the interactions between different scientific and technical domains pertaining to such research. The study also aimed at identifying the most pressing problems and the significant contributions in the field and thought process, providing insights for decision-makers in academia and research to understand the path of scientific developments. We aim to give guidance for knowledge bureaus of higher educational institutions, scholars, and researchers for strategic decision-making to identify up-and-coming trends for the development of future studies. Furthermore, this research considers the study areas within the scope of the most common radiological applications and evaluates a vast number of research trends in radiology. While there are some reviews of individual techniques, recent studies that examine the subject are scarce. The research evaluates and classifies publications and research activities in the given time frame, which we view as one of the main contributions of this volume to the literature. For the radiological area studies, we extend existing conference proceedings and journal analyses. The potential use of research can drive future research through an understanding of key contributions and issues in the scope of how much research is being conducted. The research assesses journals, institutions, and publication outlets to provide a comprehensive view of the existing environment. In line with this aim, a series of bibliometric indicators are developed and discussed in order to examine the advancements in the network of institutions.

## **2. Fundamentals of Imaging in Radiology**

Radiologic imaging techniques enable physicians to see inside the human body. As a medical specialty, radiology utilizes various techniques, including X-rays, sonograms, nuclear magnetic resonance imaging, and positron emission tomography, to diagnose and treat disease. Radiologists not only systematically interpret the images produced by each specialized imaging method to increase understanding of health and disease, but also often provide procedural guidance on this basis. The imaging procedures performed by radiologists help treat a

variety of conditions whose burdens are felt across the healthcare spectrum. (Hussain et al.2022)(Chamorro et al.2021)(Ahn et al.2021)

Radiologists have trained for years to be able to use these imaging technologies to make the diagnoses and consultations that they do for the rest of the medical community. However, the growing volume of these imaging procedures presents a series of significant challenges in achieving their true potential. These challenges include: prioritizing the most critical cases and ensuring prompt review and diagnosis; interpreting the image data accurately and effectively; and providing timely consultations after the visual interpretation of the associated findings.

### **2.1. Traditional Imaging Techniques**

Radiology is an integral and rapidly expanding area that plays a crucial role in the diagnosis and management of many diseases. Therapeutic decisions are often based on diagnostic assessments by radiologists through the review of highly complex visual information that medical imaging offers. Traditional imaging techniques are classically associated with descriptions such as Digital Radiography, taking advantage of the sensitivity of grains and the high contrast resolution of semiconductive materials, or Computed Radiography, which manages to obtain the instant development of the image from plates containing phosphor. These techniques are essential in clinical environments where facilities are limited and have an easier learning curve, and the equipment is cheaper due to the possibility of using traditional films, intensifying screens, or screens supporting cassettes as support.

In addition to digital modalities, magnetic resonance imaging, ultrasound, and in vivo nuclear examinations obtained by means of tomographs or tomographs with computerized anatomical references are included within the traditional diagnostic imaging techniques. All these imaging techniques have the potential to generate an extensive dataset regarding the pathology in question, and the aim of the radiologist is to overcome visual analysis to extract an accurate diagnosis. It should be highlighted that, although all these modalities require a depth of knowledge and experience by the radiologist to make an accurate interpretation, the examples of specialized imaging techniques are progressively making the role in the diagnosis of many clinical conditions more complex.

### **2.2. Digital Imaging and PACS**

PACS: Enabler of Digital Radiology. In the past few decades, radiology has gone through a digital transformation. Considering that telemedicine and tele-radiology are not acceptable without digital images, the biggest achievement in the field of digital radiology is the foundation of the Picture Archiving and Communication System (PACS). The PACS management was derived from the systematization of the digital workflow with functional implementation. Currently, PACS consists of the following subsystems: these include acquisition modalities, workstations, communication network, archival, library services, and administration. Archiving is implemented using large capacity server systems. Besides the on-site archival, other cloud-based services are also being used. DLT and LTO type storage are the common choices of media. These media technologies must follow standards for

metadata, which in turn can be sorted using RAID and erasure codes. Display workstations are optimized for 12-bit grayscale with maximum resolution. Viewing pictures with high resolution and contrast is necessary for a radiologist's accurate interpretation. (Konstantinidis & Apostolakis, 2020)(Elahi et al.2020)(Thormann et al., 2023)

Automated Processing and Analysis. In the era of PACS, digital image processing is known as Computer-Aided Detection (CAD). In these systems, artificial intelligence is a black box that may requalify the concept by stating all forms of automated analysis as AI or may stimulate the creation of a new tool that allows performance to exceed benchmarking established by radiologists. The consistent annual growth of the market share in the radiology imaging segment, driven by advances in machine learning and other algorithms, often raises prospects that might initially sound unrealistic. Nevertheless, the evolution in this market is a scientific fact that should be monitored. The rapid evolution of AI and its easy access help to spread such advances. In this section, we will briefly review AI concepts, also introducing how they perform in the context of existing medical imaging digital processing techniques, as well as new forms of automated analysis such as MRI processing in flow dynamic studies.

### **3. Artificial Intelligence in Radiology**

The potential of AI in radiology has been recognized for over 50 years, when a material symposium in 1963 was devoted to artificial intelligence in medicine and psychology. AI, conceptualized as neural networks, was advanced in the 1980s but failed to live up to its expectations. The current era of AI seems different, thanks to advances in both the underlying algorithms and the quantity and quality of data. In radiology, AI is likely to replace the more routine tasks, improving diagnostic accuracy, efficiency, and perhaps allowing the radiologist to concentrate on more subjective aspects of the specialty, such as prognosis, lateralization, and correlation with clinical findings. The growth of the open-source initiative certainly helps AI by leveraging larger data sets and diverse patient populations to train deep learning models.

What will be the role of human radiologists in this age of AI? Human radiologists will continue to play a crucial role because AI still cannot replicate several of the human values in radiologist decisions about scanning, communication with the patient, synthesis of the overall clinical picture from the test findings, recognition of the out-of-image features, incidental findings, ethical decision-making, and adaptation to individual clinical situations. Until the time when AI totally replaces radiologists, it should have a symbiotic relationship with them. The radiologist should be able to explain the AI-assisted result, recognizing any limitations and knowledge gaps of the AI algorithms.

#### **3.1. Overview of AI in Healthcare**

Recent advances in artificial intelligence (AI), specifically in the field of machine learning, fueled by the spectacular successes in complex domains including human-competitive image recognition and playing complex games, have enabled striking improvements in image interpretation problems including object

detection, segmentation, and human activity detection. Such successes have now been extended to the field of radiology. Interestingly, AI and medicine have a long, intertwined history, but the current advances in AI stem predominantly from the widespread and open availability of large labeled datasets and modern computing infrastructures. Interest in medical imaging for AI research may be derived from the use of such datasets for clinical applications, such as diagnosis and patient care, or from curating medical imaging datasets for use as a generic pre-training modality, which can then be fine-tuned for a diverse set of medical image analysis tasks. In this chapter, we discuss these developments in the context of radiology, and specifically their applications in interpreting medical images. We argue how and where AI in radiology may play a transformative role, and study the implications of the widespread use of AI technologies in a critical clinical decision support tool. We also cover industry perspectives and discuss policy implications of using AI tools in radiology. As AI technologies mature, powered by scalable and efficient design, we envision the development and deployment of new medical imaging super-analysis tools that will change how we interpret medical images, enabling us to generate more accurate diagnoses and prognoses, identify and quantify biomarkers more precisely, and personalize treatments more effectively. While the promise of AI for radiology is significant, it is also essential to ensure that these emerging tools are used safely. Periodic assessment of AI challenges, such as safety, accuracy, generalization, calibration, uncertainty quantification, interpretability, explainability, and clinical workflow integration, is also critical and must be studied comprehensively.

### **3.2. Applications of AI in Radiology**

There are multiple potential AI applications in radiology, many of which are already in use in research or clinical care. For instance, AI could be used to prioritize cases with the most severe findings for faster triage or initial reading, enable fully autonomous diagnostic interpretation, such as by concurrently finding multiple abnormalities, precisely quantify imaging biomarkers to enable precision medicine, decrease noise and artifacts in images, and generate clinical summaries or assist in clinical decision support. Below, we organize the potential AI applications in radiology by type, describe their current state, and provide use case examples.

Class Prickling Prioritization (e.g., urgency, severity, and recommendation/radiologist pairing) Identification of the number and top clinically important detections (e.g., triage/augmented interpretation, multiple pathologies, and visual explanations) Enhancement and artifact reduction Conversion between different image modalities Quantitative image biomarker or feature measurement Nodule or lesion volume Diameters Centroid Spiculation, texture, attenuation, and enhancement Unreadable, low, or excessive input - Low View Interoperability and IF - eject, demigration, pseudonymize Image quality (e.g., acquisition time and spatio-temporal resolution) Noise or artifact reduction

### **4. Challenges and Ethical Considerations**

Although applications of AI in medicine hold tremendous promise, they also come with a unique set of challenges and ethical considerations. The deeply personal

nature of health information, combined with the relative vulnerability and powerlessness people can experience when interacting with the health system, requires that special emphasis be placed on patient consent and communication, data security, patient autonomy, informed consent, and shared decision-making. If relatively large numbers of imaging or clinical reports are obtained for simple models such as classifying a radiograph as positive or negative, then it is possible to reach land-grab scenarios. For example, having a large clinical database for a simple model might be the first entrant, but if multiple groups wish to use the same dataset for the same simple model, it might be that the first mover is able to dominate the use of the data, preventing others from using the same data to develop competitors, despite the fact that the test could be run on the data at very low marginal cost. (Ahmad et al., 2021)(Shung and Sung2021)(Iqbal et al.2021)

Ensuring data privacy and allowing patients to maintain ownership of their data are critical dimensions in the development and wide application of AI models in imaging and healthcare. Improved ability to better reach patients and navigate resources and the ability to create new methods for patient evaluation and guiding interventions are all part of the broader societal goal to work toward solutions for health disparities. It is important to provide space during early conception and research to consider the broader set of potential impacts of an AI solution – and to work with diverse stakeholders on these concerns, even if these partnerships cannot incorporate the entire spectrum of voices regarding social issues. The implications of AI use include potential impact on both healthcare cost and accuracy of the core business of the healthcare system. For example, a fear of AI-related job loss is not unique to radiology, as labor markets are under threat from broader AI adoption and are increasingly causing concerns. Although AI could, under optimistic scenarios, actually be beneficial by creating more jobs, there is, at the very least, a risk that it could be disruptive. On the other hand, concerns have been raised about the expected wage impact of AI on labor, the uncertainty regarding the concentration of labor market risk, and the impact related to privacy and wealth resulting from AI expansion.

#### **4.1. Interpretability and Trust**

A significant step to improve trust is to develop explainable AI models that radiologists can understand. A major challenge precluding the broader implementation of such tools is the lack of a universal definition of model explanation and thereby the wide range of methodologies, which lack a ready application in medical deep learning. The selection of one or more models for an AI system, as well as how their results are interpreted and presented, constitutes a delicate balance between the transparency and interpretability of the model and its performance and accuracy. Explanations must be contextual, where the doctor's concerns and background, type of device, type of disease, deemed risk of an incorrect prediction, relationship or responsibility of a radiologist to undertake a certain type of advice, and the legal implications are important issues.

Interpretability is challenging in medical image analysis due to the complexity and lack of high-level semantics in medical images. Early attempts focused on activation localization where the model is tasked to highlight visually similar areas of the input image responsible for network predictions. Such methods might

highlight uncorrected regions unaware to the models during the test phase, significantly affecting confidence in model explanations. Two visually intuitive model explanations allocate a weight to each feature map of the convolution layer of the network, independently of the predicted class. The heat maps are generated from the gradients of the predicted class not only with respect to the top feature map, but also with the following characteristics for gradient accumulation, showing how much the output of the previous layer results in the predicted class. These types of interpretations, model-dependent, however, do not shed light on how highly complex CNNs work.

## **4.2. Data Privacy and Security**

Despite the activation of "deidentification" filters or privacy concepts, the datasets created for machine learning contain an alarming amount of personal and identifiable data, posing a particularly problematic privacy risk in the healthcare context. External collaboration requires access, storage, and transfer of data between entities. Registries for clinical validation should be supported by secure infrastructures and semantic interoperability standards aimed at enabling query responses in a privacy-friendly environment. Again, data-limited scenarios may impair the deployment of algorithms to the real world due to concerns about black-box models, which can only be mitigated with an additional security layer that, reflecting the patient's rights, allows understanding, consenting, or correcting incorrect behaviors.

The Health Insurance Portability and Accountability Act sets the rules for accessing and sharing information on patient health data, including a list of identifiers labeled as protected health information. The Health Information Technology for Economic and Clinical Health Act extended patient protection by including protected health information in any medium. There are similar compliance standards for EU-regulated data where the right to be forgotten includes erasure of personal data and the right to restrict processing contemplates the selective blocking of data processing in relation to the identified individuals from other processes. Organizations exclusively working with de-identified data are not subject to these rules. Only non-profit, non-research organizations maintaining self-regulation covenants and forbidding commercial access to personal data are allowed to have access to the highly regulated, genuine medical information.

## **5. Future Directions and Conclusions**

In summary, advances in imaging with novel agents, innovative devices, information borne from big data, and leveraging artificial intelligence techniques such as deep learning have the potential to significantly expand the capabilities of the field of medical imaging for both medical practitioners and patients. Convergent technologies in the life sciences, physical sciences, engineering, neuroscience, and informational sciences have created unprecedented opportunities for multi-scale quantification of complex biological systems. This confluence will lead to the convergence of clinical and engineering disciplines through the use of artificial intelligence tools and clinical applications, and enhanced decision-support paradigms based on deep learning image analysis

techniques along with structuring data-driven clinical and experimental workflows. By integrating expert knowledge with big data, there is a timely window of opportunity to realize the great potential of deep learning in the medical imaging domain. Beyond computer-aided diagnosis, imaging with breakthrough enabling contrast agents and bioimaging devices, as well as signal processing and deep learning, will unlock new biological knowledge on understanding functional consequences of disease-associated biological processes and building complex, multi-scale models of a broad range of biological systems. A robust pipeline that encompasses joint design of effective contrast agents together with deep learning architectures can facilitate the critical transition to in vivo studies, providing contextualized quantitative imaging that will be pivotal in elucidating the abundant biological science questions. The health impact will be multifaceted, enabling precision diagnosis, empowering informative health risk assessment, and advancing rapid response and tailored treatment for life-threatening diseases such as cancer and cardiovascular diseases, greatly improving medical outcomes.

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## التطورات في التصوير: استكشاف إمكانات الذكاء الاصطناعي في الأشعة

شهد مجال الأشعة تطورات كبيرة في سعيه للتحويل من الوصفي إلى التشخيصي، ومؤخرًا إلى التنبؤي. لقد تطور الاعتماد على الأشعة السينية ثنائية الأبعاد التقليدية منذ فترة طويلة إلى تطبيق مغناطيسات عالية القوة وأجهزة مسح التصوير المقطعي المحوسب، مما يوفر تباينًا محسنًا للأنسجة وقدرات ثلاثية الأبعاد. لقد أدت هذه التطورات إلى توضيح المزيد من التفاصيل الدقيقة لعلامات التصوير التشخيصي وزادت من القدرة على تحديد المؤشرات الحيوية للتصوير التشخيصي والتنبؤي. على الرغم من أن هذه التطورات لا تزال تقع ضمن نطاق التفسير البشري، إلا أن هناك زخمًا مستمرًا لتسريع الجهود التي تعيد تشكيل مكان العمل السريري. سواء كانت الحاجة إلى تسخير الإمكانيات الهائلة وغير المستغلة إلى حد ما للذكاء الاصطناعي، أو الحاجة إلى زيادة الكفاءة وتقليل أوقات القراءة، أو الدعوة إلى تحسين رعاية المرضى بشكل إبداعي من خلال دمج التصوير والتكنولوجيا المتعلقة بالعلامات الحيوية، فإن المجتمع يضغط على هذا التخصص للتطور بشكل أكبر. للمساعدة في جلب هذه الأدوات اللازمة للتطبيقات السريرية، ستحتاج الجهود التعاونية بين الأطباء وعلماء البيانات والمهندسين إلى التضافر. يجب أن يعمل المجتمع العلمي معًا لتمكين الترجمة السريرية للتقنيات التي تجمع بين نتائج التصوير الفيزيائي والبيولوجي المتنوعة. تمثل التطبيقات الناشئة، سواء كانت دمج علوم البيانات في منصات التصوير الحالية أو جانب التنفس الحي للتعلم الآلي، مسارات يمكن أن تمكن الأطباء من تلبية الاحتياجات التشخيصية والتنبؤية لمرضاهم بشكل أفضل. مع استمرار تخصص الأشعة في إعادة تجهيز نفسه للمستقبل، من الضروري التنقل ببراعة في المشهد التقني والاجتماعي والتنظيمي لضمان نشر هذه الأدوات بشكل آمن وفعال من أجل خير البشرية.