Artificial intelligence software in biomedical imaging: a pharmaceutical perspective on radiology and contrast-enhanced ultrasound applications

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Received on March 7, 2025; accepted on April 24, 2025.

Clin Exp Rheumatol 2025; 43: 822-828.

Key words: diagnosis, artificial intelligence, contrast media, radiology, ultrasonography

Competing interests: the authors are all employees of Bracco Imaging SpA.

ABSTRACT

Artificial intelligence (AI) is rapidly transforming radiology, with over 200 CE-marked products in the EU and more than 750 AI-based devices authorised by the FDA in the US, mainly used for x-ray, CT, MRI, and ultrasound imaging. Despite regulatory challenges, the adoption of AI in radiology is growing, driven by venture capital funding and anticipated cost and efficiency benefits. Clinical and economic barriers, inconsistent performance, integration challenges, and lack of reimbursement are currently hindering the widespread adoption of AI. However, the role of AI in the future of medical imaging is generally expected to be significant. Contrast agents are crucial in imaging for improving sensitivity and specificity, widely used in angiography, cardiology, and oncology. AI can optimise the use of these agents, reducing dosages and improving image quality. Moreover, AI's synergy with contrast agents in enhancing image clarity and supporting diagnostic accuracy holds significant potential for advancing clinical practices. In summary, the integration of AI with contrast media in radiology offers promising improvements in image quality, diagnostic accuracy, and operational efficiency, although clinical and regulatory hurdles must be addressed for broader application.

Introduction

Artificial intelligence (AI) products are entering radiology departments with already over 200 CE-marked commercial products available for use in the European Union (EU) (1, 2). The *'AI/ML-Enabled Medical Device List'*, published by the Food and Drug Administration (FDA) (3) currently lists 1016 devices based on AI and Machine Learning (ML) authorised for marketing in the United States, of which 777 (76.5%) are for radiology. The 'radiology' category includes applications for x-ray, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound imaging (US). Of note, only the 5% of the applications of the FDA list include in the title the word 'ultrasound' highlighting that Ultrasound applications are far less than those for the major modalities. Medical applications of AI are classified as either software as a medical device (SaMD) or software in a medical device (SiMD). The key difference is that SaMD can function as a standalone device, while SiMD enhances the functionality, performance, or control of a medical device (*e.g.* an imaging scanner). Consistently with these definitions, AI applications for radiology are subjected to the relevant authorities depending on the geography: the Medical Device Regulation (MDR) in EU, the FDA regulation in the United States and the regulation of the National Medical Product Administration (NMPA) in China. However, the regulatory burden it is not a limiting factor for the spurt on new products based on AI in radiology. About 33 new companies per year obtained software approval from the FDA and the number of new authorised applications grew of about 40% per year within 2019 and 2023. Digital Health's venture capital funding has also increased from $2.1 billion in 2013 to $15.3 billion in 2022 and it is projected to be $36 billion by 2025 (4). Based on these numbers, a huge penetration of AI in the clinical practice would be expected but the adoption of AI is still facing some attrition due to both clinical and economic factors. Recent research reported varying opinions about the use of AI in ra-

diology. From the positive side, the expected benefits of AI in terms of cost containment and overall added value are pushing in favour of its implementation in the radiology departments but, on the other hand, the sometimes still inconsistent performance, unstructured integration processes, and consequent lack of thrust from medical doctors is slowing down its adoption (5). Another reason hampering the adoption of AI for radiology is the current lack of reimbursement for AI applications, which discourages providers from investing in these technologies despite their potential benefits (6). Briefly, AI for radiology still requires some consolidation, structured processes, clear evidence of clinical and economic benefits, to generate adequate trust to promote its widespread adoption.

Despite these drawbacks, the general opinion about the future of AI in radiology is very positive. This optimism is driven by the success of AI in other fields and the increasing number of cases where AI outperforms radiologists in specific clinical tasks (7). These cases, supported by strong clinical evidence, are gaining even the attention of medical societies and expert panels, who see AI as a means to improve and transform current clinical practice (8).

Contrast agents are exogenous substances injected into the patient's body before or during imaging procedures to enhance tissue contrast and characterisation. This enhancement significantly improves the overall sensitivity and specificity of the imaging procedure, thereby aiding in more accurate diagnosis and effective therapy. Additionally, the use of contrast agents can reduce examination time causing a positive impact on efficiency. Contrast agents for all the major diagnostic imaging modalities are currently marketed: iodinated agents for x-ray and CT, mainly gadolinium agents for MRI and microbubbles for US. Contrast agents are utilised in a wide range of applications, with angiography, cardiology and oncology imaging being the most prominent. For an extensive review on contrast agents, see Iyad *et al*. and Lusic *et al*. (10, 11).

Given the widespread use of contrast agents in clinical practice, particularly in radiology but also in ultrasound, it is reasonable to explore the interaction between AI and contrast agents, the impact on usage, and whether there are synergistic effects. Understanding these aspects is particularly relevant for a company operating in the contrast agent sector, both to identify opportunities for improving the performance of its products and to highlight potential risks in terms of safety and business.

An analysis of AI products currently available on the market and the scientific literature in the field reveals that AI applications in radiology, particularly those involving contrast agents, can be classified into three categories:

1. Image Enhancers: applications that modify image appearance by adjusting contrast or generating contrast in initially non-contrast images.
2. Acquisition Support: applications that assist during image acquisition by guiding the operator through the process and potentially altering the final procedure.
3. Interpretation Support: applications that operate on images generated with contrast agents, aiding in diagnosis or disease characterisation, and positively impacting clinical performance (*e.g*. improved sensitivity, reduced reporting time).

This work discusses these three cases, with particular attention to their relevance for contrast agents and their clinical applications.

Image enhancers

MRI and CT are two of the most widely used imaging techniques in clinical practice. MRI uses strong magnetic fields and radio waves to produce detailed images of soft tissues, offering high contrast resolution without ionising radiation. CT, on the other hand, employs x-rays and advanced computational techniques to generate cross-sectional images, providing rapid views of both soft and hard tissues. Both modalities often rely on contrast agents to enhance image clarity, significantly improving the visualisation and detectability of lesions, which is essential for accurate diagnosis and treatment planning.

In this context, the emergence of artificial intelligence (AI) in radiological imaging has opened up new possibilities for optimising and eventually improving CT and MRI contrast enhanced procedure in terms of quality and/or sustainability through advanced contrast techniques. These methods leverage machine learning algorithms, such as convolutional neural networks (CNNs) and generative adversarial networks (GANs), to generate synthetic post-contrast images using three distinct approaches. Among these, dose reduction was the first to be explored, aiming to generate post-contrast images from low-dose contrast scans and significantly reduce the amount of contrast agent required (12, 13). Building on this initial research, two additional approaches have been developed: virtual contrast, which claims to generate enhanced images from non-contrast scans (14) and consequently to be able to eliminate the need for contrast agent administration, and dose amplification, which enhances the contrast of standard-dose post-contrast images to improve diagnostic accuracy while maintaining current standards of care (15, 16). This transformative capability has broad implications for clinical practice, reducing or even eliminating the required dose of contrast agents and amplifying contrast to elevate diagnostic precision without altering established imaging protocols.

In MRI, gadolinium-based contrast agents (GBCAs) are commonly used to enhance tissue visualisation, aiding in the diagnosis and monitoring of various conditions, including tumours and neuroinflammatory diseases (17). AI-based reduced-dose contrast imaging, which synthesises enhanced images from low-dose contrast scans, has demonstrated high structural similarity, a measure of semantic similarity between two images, to traditional post-contrast images. For example, studies using U-net architectures have achieved structural similarity indices exceeding 0.9 (maximum value is 1) when generating full-dose contrast MRI images from as little as 10% of the standard gadolinium dose (12, 18). These findings identify AI as a promising approach to maintain diagnostic accuracy while significantly reducing the dose of contrast agents but a full clinical validation is still needed.

For instance, Haase *et al*. demonstrated that using a non-contrast and a low-dose T1w sequence after administering 10% of the standard dose resulted in only 55% of cases where synthesised images were fully or mostly interchangeable with the full-dose sequence without changing the clinical conclusion. More recently, no difference in sensitivity for brain metastases with a maximum diameter larger than 5 mm was found by Pinetz *et al*. The same work reports that including lesions smaller than 5 mm one of the two readers found significantly more metastases in the original than in artificial images (19).

Moreover, the exploration of lowering the contrast agent dose could in principle reach zero with the virtual contrast approach. As previously mentioned, this technique claims to generate post-contrast images from non-contrast scans, potentially eliminating the need for contrast agents while still providing the enhanced diagnostic quality typically associated with contrast-enhanced imaging. Despite its promising potential, virtual contrast imaging also presents limitations and potential risks. These models rely heavily on the quality and diversity of training datasets, which may not comprehensively represent all clinical scenarios, leading to potential biases or reduced performance in less common conditions (20). Additionally, synthesised images can exhibit artifacts or deviate from true contrast-enhanced images in terms of lesion morphology, conspicuity, and fine structural details, as noted in clinical validation studies (21). Such discrepancies can occasionally result in false positives or false negatives, particularly for smaller or less conspicuous lesions. Furthermore, virtual contrast methods cannot reliably replicate dynamic contrast uptake patterns, which are crucial for certain pathologies, such as vascular malformations or perfusion studies. This limitation further underscores the need for caution and rigorous evaluation before widespread clinical implementation (22).

Another promising approach involves amplifying the contrast effect while maintaining the administered dose unchanged. By leveraging deep learning models, enhanced contrast-to-noise ratios and lesion conspicuity can be achieved, effectively mimicking the effect of higher doses without additional agent administration This latter application can be employed to 'artificially' enhance the standard of care contrast, improving diagnostic sensitivity by amplifying contrast in post-contrast imaging. This approach may be particularly valuable for detecting small lesions, indeed, as recently shown by Haase *et al*., images with artificially increased contrast can improve the detectability of brain metastases and could therefore represent a potentially valuable addition to regular single-dose brain imaging (23).

In CT imaging, the application of AI has similarly shown promising results. Within the CT domain, virtual contrast imaging is aimed at synthesising contrast-enhanced images from non-contrast scans using deep learning models like GANs. As an example of works published in the literature, Chandrashekar *et al*. (2023) reported that cycle-GANs could generate contrast CT angiograms with good fidelity (24), achieving Dice similarity coefficients of 92% for vascular and thrombus segmentation. While this highlights potential for reducing risks associated with iodine-based agents, in analogy with the MRI domain also here virtual contrast remains in the experimental phase and requires further validation to address limitations such as artifacts and deviations from true contrast-enhanced images. These challenges, especially in less common pathologies or subtle lesions, underscore the need for further investigation and caution before clinical adoption.

Dose reduction strategies are being explored to minimise the use of contrast agents while maintaining diagnostic quality. AI-based techniques, including GANs, have shown promising preliminary results in this domain. For example, Haubold *et al*. (25) demonstrated that conditional GANs (cGANs) could reduce the contrast agent dose by 50% while maintaining high image quality and diagnostic consistency, as evidenced by structural similarity indices (SSIM) above 99% and pathological consistency scores of 100%. Similarly, Shin *et al*. (26) applied an AI-based contrast-boosting model to paediatric abdominal CT, achieving a 31% reduction in iodine usage while maintaining diagnostic accuracy and lesion conspicuity, and Kang *et al*. obtained improved CNR and hepatic vessel conspicuity without significantly impairing per-lesion sensitivity for HCCs with low radiation dose and low contrast (30% reduction) compared to standard acquisition, in participants at high risk for HCC (27). Despite these promising outcomes, challenges remain. Reducing the contrast agent dose may result in diminished diagnostic consistency, emphasising the importance of balancing dose reduction with clinical reliability. Furthermore, these techniques rely heavily on high-quality, diverse training datasets to ensure robust performance across varied clinical scenarios, which can be a significant limitation. Ongoing research continues to support the viability of AI in optimising contrast agent usage in CT imaging.

Moreover, novel CT technologies like dual-energy CT (DECT) and photon-counting CT introduce significant opportunities for improving material differentiation. DECT can reconstruct images at low keV levels, amplifying iodine attenuation and enhancing contrast visibility. When combined with AI algorithms, DECT imaging can be further optimised by reducing noise and mitigating artifacts, improving image quality even with lower contrast doses. Photon-counting CT, with its ability to detect individual photons, obtain monoenergetic images and provide high spatial resolution, enables advanced material decomposition and precise contrast differentiation. These features, when integrated with AI-driven approaches, could further refine contrast imaging protocols, paving the way for tailored, patient-specific imaging strategies.

In conclusion, artificial intelligence (AI) may play a transformative role in the future of contrast media research for both MRI and CT imaging. AI-based techniques, such as virtual contrast, dose reduction, and contrast amplification, offer significant potential benefits. However, despite these advancements, the adoption of AI in clinical practice still

has limitations. The performance of AI models heavily relies on the availability and quality of diverse training datasets, which may not always represent the full spectrum of clinical conditions. This can lead to biases, reduced accuracy in rare pathologies, and occasional image artifacts. Furthermore, AI-generated images may not fully replicate the dynamic and temporal aspects of contrast uptake, such as in perfusion studies or vascular malformations, limiting the applicability of virtual contrast to certain clinical scenarios. As AI technologies advance, ongoing clinical validation, robust testing, and consideration of these limitations will be essential for their successful and safe integration into routine clinical workflows.

Acquisition support

Contrast-enhanced ultrasound (CEUS) is a dynamic imaging technique that utilises ultrasound contrast agents (UCAs) to enhance the visualisation of blood flow and tissue vascularity in real-time. The technique involves the administration of microbubble-based UCAs, which are safe and well-tolerated, with minimal side effects. CEUS provides detailed information on the vascular architecture and perfusion of tissues, making it an essential tool in oncology for characterising and assessing response to therapies of tumours, in gastroenterology for evaluating inflammatory bowel diseases, in echocardiography, in interventional procedures such as biopsies and ablations and other fields. Its ability to provide high-resolution images without the need for ionising radiation makes CEUS a preferred choice in various clinical settings. Overall, CEUS enhances diagnostic confidence and patient management by offering precise and non-invasive imaging capabilities (28, 29). In summary, CEUS has a lower cost and it is safer with respect to other modalities and it has the potential to contribute to giving access to medical imaging to the huge part of the world's population that currently does not have access to it (30).

Ultrasound is highly demanding in terms of the expertise, training, and education required to perform the acquisition procedure adequately and to interpret the images correctly. Many AI applications developed in the field of echography differs from the mainstream AI solutions for MR and CT because they are designed to support physicians during the acquisition process rather than during interpretation, with the ultimate goal of reducing training requirements and controlling intra-operator variability.

CEUS is at least as complex as ultrasound. It is well known and recognised, in fact, that the quality of execution and interpretation of CEUS examinations are highly correlated to the experience of the physician (31, 32). The significance of education is undeniable; however, it can be hypothesised that artificial intelligence (AI) may positively reduce the entry barrier for contrast-enhanced ultrasound (CEUS) by simplifying the learning process, particularly for young or inexperienced physicians. Currently, the potential synergistic effect of AI in enhancing the adoption of CEUS remains speculative since, as yet, there are no marketed AI applications for CEUS.

One of the fields in which the use of AI in ultrasound has been particularly developed is echocardiography. In echocardiography AI embedded in intelligent scanners have been developed to assist novice sonographers in capturing technically correct images. These tools are particularly beneficial for non-experts. The software, directly installed on the scanner, employs an algorithm to provide real-time positional directions, guiding users to capture diagnostic images. Utilising deep learning, the software identifies incorrect or off-axis views and offers guidance on probe movement to obtain accurate images. Once the software deems the images diagnostic, they are automatically acquired (33). The current drop in cost, size, availability and safety could make ultrasound scanners replacing stethoscope in the future but the high demand in terms of training and experience is hampering its adoption. The interest from both the industry and the clinical side in solving this problem has contributed to the development of AI applications in this field, leading to several scientific and commercial successes to make this modality usable also by non-experts (34) and possibly promoting point-of-care solutions usable by nurses (35). As reported above, the benefits of CEUS in echocardiography are recognised especially when used in substitution of other modalities that may be associated with additional risks, time delays, and costs. Nevertheless, the use of ultrasound contrast agents in echocardiography adds another layer of complexity on top of an already demanding imaging procedure with potential negative impact on adoption. The use of AI embedded in the imaging devices may mitigate this problem, for example supporting physicians in selecting the right acquisition parameters besides probe placement, potentially promoting the use of CEUS with benefits both in terms of patient management and costs. It is important to note that none of the AI solutions for echocardiography currently available were developed for CEUS. To utilise the potential of AI in this area, dedicated applications should be developed, or existing applications should be adapted for this purpose. Several applications of AI assistance during scanning have been studied and developed beyond echocardiography (36), suggesting that, similarly to the echocardiography case, the adoption of CEUS may benefit of these advancements in other indications for which it is approved.

Beyond ultrasound, the role of AI in assisting during acquisition has been proposed for other modalities, including MRI. Specifically, it has been suggested that AI could aid brain MRI acquisition by automating protocol configuration, and dynamically customising imaging, based on initial MR scans which do not require the use of contrast agents (37). In this vision, AI could determine the necessity of contrast agent injection for each patient. These systems propose an alternative approach to the use of contrast agents, which requires comprehensive understanding from regulatory, safety, and efficacy perspectives before it can be effectively implemented. Nonetheless, this approach can significantly improve current practices, potentially fostering a more targeted application of contrast agents and a better risk/benefit ratio of examinations.

Another work evaluates the impact of an AI-based automated cardiac MRI (CMR) planning software on procedure errors and scan times compared to manual planning (38). Note that CMR is an imaging procedure based on the use of GBCAs. The study involved 82 patients undergoing non-stress CMR, randomised into manual or automated scan execution groups. The results showed that the automated group had significantly fewer procedure errors compared to the manual group. This software was particularly beneficial in reducing errors for low- and mid-level experienced radiologists. This automation paves the road for an easier adoption of CMR with reduced cognitive load on technologists, improved data homogeneity with reduced scan times and errors. In this scenario, the AI system is not responsible of taking decisions upon the administration of contrast for which the system includes safety controls by design: " . . . safety interruptions (checks for full contrast administration before proceeding) require human validation". The administration of contrast agents remains consistent with standard practice, indicating that the adoption of this solution has a neutral impact on the safety and efficacy of contrast agent use. In summary, AI support during acquisitions can facilitate the execution of diagnostic exams, enhance repeatability, and reduce technicians' workload, thereby promoting adoption. Technicians, sonographers, and physicians can utilise these solutions in procedures involving contrast, provided that a suitable solution exists in the market and is approved for that procedure. Safety and efficacy concerns may arise when AI makes decisions regarding the administration of contrast, particularly if it leads to off-label use. These concerns can be mitigated by incorporating safety measures designed to require human validation.

Interpretation support

In addition to the applications mentioned previously, AI has traditionally been used in radiology for image interpretation and supporting clinicians in various clinical tasks. AI devices can prioritise cases, detect lesions, aid in diagnosis, and even autonomously interpret images without clinician input. Computer systems used for image interpretation in radiology are historically referred to as variations of "CAD", a word that stems from Computer Aided Detection. There are now several types of CAD that differ according to how the device is intended to be used by clinicians (39). Computer-aided triage (CADt) devices are designed to flag suspicious cases for prioritised review by clinicians. For example, an AI device might flag head CT scans with potential intracranial haemorrhage (ICH) for urgent review by a radiologist (40). Computer-aided detection (CADe) devices help detect the location of lesions by overlaying markings on images. An example of this are AI devices that mark suspicious regions on mammograms to help detect potential breast cancer lesions. In a recent study, AI-supported mammography screening resulted in a similar cancer detection rate compared with standard double reading, with a substantial reduction in screen-reading workload, demonstrating the potential economic advantage that the use of AI in mammography screening could generate (41). Computer-aided diagnosis (CADx) devices aid in diagnosis by providing a score or category for the entire case or specific lesions. They do not explicitly mark the locations of lesions but offer diagnostic insights. For instance, recently the risk score computed by an AI device used in mammography has been shown to predict high risk breasts 4 to 6 years before the actual detection of cancer in the screening programme (42). Computer-aided detection and diagnosis (CADe/x) devices combine detection and diagnosis functionalities. They mark lesions and provide additional diagnostic information, such as scores or categories. A recent example of this has been demonstrated in the field of contrast-enhanced mammography (CEM), which is a special type of mammography that makes use of contrast agents to enhance the capability of mammography in the case of dense breasts and soft lesions (43). In this example, a fully automated pipeline system based on AI was developed to perform the segmentation and classification of breast lesions based on the Breast Imaging Reporting and Data System standard (BI-RADS) (44).

From these examples, one can discern the potential impact that AI could have on clinical practice, including diagnostic procedures utilising contrast agents. Firstly, it is important to note that the primary benefit of using contrast agents is the enhancement of sensitivity within a fixed reporting time. This implies that contrast agents typically improve the ratio of sensitivity to time. We now observe several instances where AI can further enhance sensitivity without affecting the reporting time (7). Consequently, the overall performance of a radiologist using AI in a procedure involving contrast agents is better than the performance of a radiologist not using AI. This synergistic effect is being recognised not only by individuals and institutions but also by medical associations (8). When contrast agents are involved in the procedures, the interaction with AI should be carefully evaluated to maximise the benefits of the combination while also mitigating potential clinical risks arising from an AI not being designed with the specific characteristics of the agents in mind. For example, the detection performance of an AI system can be negatively affected by an improper injection timing (*e.g.* detection of aneurysm or liver lesions). Bad injection timing is normally detected by radiologists at reporting time and managed accordingly to the clinical practice. When AI acts before the human overview, bad injection timing could be overlooked causing a deterioration of AI performance. Image quality issues, including those related to contrast agents, should be detected by a dedicated module before images are submitted to the CAD system and managed/notified accordingly by the software.

A second influence AI might have on the use of contrast agents is competition. As previously mentioned, contrast agents improve sensitivity within a given reporting time, making it impractical for radiologists to report without them due to time constraints. However, current developments indicate that AI can perform reporting tasks, such as disease detection and characterisation, independently on radiologists. This advance-

ment could introduce scenarios where the use of AI competes with the use of contrast agents (45), with the promise of offering substantial equivalence in terms of diagnostic performance in the long term.

Overall, while AI holds tremendous potential to revolutionise diagnostic imaging and the use of contrast agents, careful implementation focused on patient safety and methodological accuracy is crucial. Failure to incorporate considerations specific to contrast agents in AI development might lead to adverse effects, such as incorrect dosages or improper administration techniques. Hence, collaboration among AI developers, radiologists, and pharmacologists is essential to develop guidelines and standards that mitigate these risks. However, the integration of AI into these processes demands rigorous validation through clinical trials and ongoing monitoring to ensure safety and efficacy.

In summary, AI is beginning to perform clinical tasks more and more reliably and it is becoming a significant factor to enhance diagnostic performance in medical imaging. From the perspective of contrast agents, there are clear opportunities to enhance the value of contrast-based procedures, improving the risk-to-benefit ratio for the patient. However, there are also risks of missing opportunities and potentially creating real dangers if AI development does not consider the specific features of contrast agents and best practices related to their use.

Conclusions

AI-based techniques to improve image quality, such as virtual contrast, dose reduction, and contrast amplification, offer promising advancements in diagnostic imaging in CT and MRI. Virtual contrast imaging claim to be able to eliminate the need for contrast agents but for the moment it is far from a full clinical validation. Indeed, virtual contrast is based on the premise that the relevant information about contrast agent behaviour is inherently present, at least in some form, within the combination of available non-contrast sequences and can be extracted using a deep learning approach. However, it remains uncertain to what extent this premise holds true, as AI-generated images may not fully replicate the dynamic and temporal aspects of contrast uptake, thereby limiting their ability to entirely replace the administration of contrast agents in clinical practice. Differently from virtual contrast, dose reduction and amplification strategies seek to optimise contrast usage rather than eliminating it, either minimising contrast usage without compromising image quality or by enhancing contrast effects, targeting an improvement in the risk to benefit ration of contrast-enhanced procedures.

In the realm of ultrasound imaging, CEUS benefits from AI applications designed to support physicians during the acquisition process. These AI tools can reduce training requirements, control intra-operator variability, and potentially simplify the learning process for young or inexperienced physicians. The role of AI in assisting acquisition processes extends beyond ultrasound to other modalities, including MRI. Automated planning software for imaging procedures can reduce errors, scan times, and workload also in MRI, promoting easier adoption of advanced imaging techniques. However, the integration of AI into procedures including contrast agent administration requires comprehensive understanding and validation to ensure safety and efficacy especially when decisions about administration are taken by the AI system autonomously.

Finally, by supporting images interpretation, AI devices can prioritise cases, detect lesions, aid in diagnosis, thus ultimately enhancing the sensitivity, specificity and efficiency of diagnostic procedures involving contrast agents, offering a synergistic effect that benefits radiologists and recognised by medical associations. In some cases, AI is already competing with the use of contrast agents when diagnostic performance of AI on non-contrast images is coming close to that of radiologists using contrast enhanced images.

AI has significant potential to improve diagnostic imaging and optimise the use of contrast agents. Nonetheless, the integration of AI with contrast agents must prioritise patient safety and methodological precision. It is imperative to conduct rigorous validation through clinical trials and maintain continuous monitoring to ensure the safe and effective adoption of AI in routine clinical practices. To mitigate risks associated with ignoring contrast-related factors, collaboration among AI developers, radiologists, and pharmacologists is vital for establishing guidelines and methods that guarantee safety and efficacy.

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