Review

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Improving diagnosis: advances in radiology

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Abstract: Diagnostic radiologists are uniquely positioned to make a difference in the reduction of diagnostic errors in medicine, which was identified as a national priority in a special report of the National Academies of Medicine in 2015. Interest in diagnostic error reduction within the specialty of diagnostic radiology has been accelerated in recent years by the adoption of rapidly evolving technological and process-based solutions for previously identified vulnerabilities (i.e., potential failure modes) in the radiology workflow that are known to increase the risk of errors. Here we describe a range of such potential failure modes contributing to diagnostic error in the practice of diagnostic radiology and summarize evolving efforts to mitigate them. These include fostering the adoption of peer learning and other feedback and education programs, a range of measures under development for ongoing performance evaluation of radiologists and their work-processes, and the deployment of new technologies, most notably artificial intelligence tools, to augment human performance and thereby improve diagnostic accuracy in Radiology.

Keywords: diagnostic radiology; diagnosis error; improvements; framework

Introduction

Diagnostic radiologists are uniquely positioned to influence the reduction of diagnostic errors in medicine; a critical issue identified as a national priority in a 2015 special report by the National Academies of Medicine [1]. In this article we rely on the definition of diagnostic error as set forth in the NAM report, which is "*the failure to (a) establish an accurate and timely explanation of the patient's health problem(s) or (b) communicate that explanation to the patient*" [1].

Here, we summarize the progress that has been made since 2015, the current state, and future directions towards reducing diagnosis error in radiology. We explore key failure modes in radiology, examine evolving strategies to mitigate errors, and discuss the role of systems and process improvements as well as technological solutions for enhancing diagnostic accuracy, highlighting the role of artificial intelligence (AI) in augmenting radiologist performance.

1 What progress has been made since 2015?

In the past decade increasing awareness of diagnostic errors and the rapid advancement of technological solutions in radiology have driven significant progress in identifying and addressing diagnosis errors.

Major advances in diagnostic radiology that contribute to decreasing errors in diagnosis include: establishing follow-up tracking systems for actionable findings, facilitating the adoption of peer learning programs, improved documentation of closed-loop result communications, further adoption of structured reporting, creation of features and tools that help patients understand their results, continued advocacy for clinical decision support (CDS), raising awareness of human-factors engineering, paving the way for AI integration into radiology workflows, advancing quality improvement capacity in radiology, growing the availability of American College of Radiology (ACR) Appropriateness Criteria®, Practice Parameters, and Reporting and Data Systems (RADS). Additional details on each item, along with current state summaries and sample citations/links are provided in Table 1.

2 What problems remain?

To date, like other medical specialties, diagnostic radiology strives for improvement while dealing with bottlenecks in accessing IT support, uncertainties in the ongoing integration of AI, continued inability to make time for in-person

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Table 1: Major advances since 2015.

Advance	Details	Current state	Sample citations & links
Follow-up tracking systems	Track and close loops on incidental/actionable findings to make sure every patient completes recommended follow-up as appropriate	Several practices have adopted this, others are struggling with IT implementation and funding for FTE positions; there is some disagreement on whether radiology practices are larger systems should be accountable for setting up follow-up tracking systems	[2–4]
Peer learning programs	Non-punitive review of discrepancies to drive learning, reflection, and improved performance by radiologists	Growing adoption rates, accepted my accreditation and certifying organizations, accepted for ongoing provider performance evaluation (OPPE) compliance	[5–7]
Closed-loop results communication	Ensures that timely communication of critical & non-routine results is documented	Substantial decrease of undocumented critical result communications; expanded understanding of results that can benefit from verbal result communication. Documentation of critical result was at 19 % in 1990, 72 % in 2010, and >90 % in 2017	[8–11]
Structured reporting	Improves clarity, completeness, and reproducibility	Most radiologists have adopted structured reporting	[12–14]
Patient-centered result reporting	Improves patient understanding of radiology results	Applications evolved from multi-media enhanced reports to AI translations	[15–17]
Clinical decision support, CDS	Evidence-based decision systems to enhance imaging stewardship	Only partially adopted; clinicians resent forced decisions and find work-arounds; evidence behind certain CDS is debatable	[18–20]
Human-factors engineering	Awareness of human factors' contribution to diagnosis error	Awareness is rising, but errors remain compounded by external factors, such as increasing volumes, continued staffing crisis, and IT resource bottlenecks	[21, 22]
AI integration	AI applications can screen for critical findings (e.g., intracranial blood, spine fracture), facilitate quantitative imaging analysis (e.g., tumor volume over time), aid with creating a report and report QA (e.g., right/left errors)	Radiologists are increasingly becoming familiar with AI applications and start integrating them into their workflow	[23–27]
Quality improvement capacity	Building expertise with the use of scientific improvement methods among radiologists	Array of educational resources sponsored by radiology organizations, such as ACR and the Radiology Society of North America (RSNA)	ACR Learning Network Quality and Safety + Informatics Conference Quality Improvement | RSNA
ACR Appropriateness Criteria® (AC), Practice Parameters (PP), and ACR Reporting and Data Systems (RADS)	Development of evidence-based guidance to standardize and optimize imaging ordering for specific clinical scenarios (AC), radiology practice (PP) such as management of contrast reactions, and follow-up recommendations rendered by radiologists	Approximately 650 AC, 33 PP, and 17 RADS updates or new documents have been published since 2015; tremendous volunteer effort by radiologists	ACR Appropriateness Criteria - Search Results - PubMed ACR Practice Parameters - Search Results - PubMed Reporting and Data System JACR - Search Results - PubMed

interactions with patients and colleagues, fighting uphill battles to improve patient access to advanced imaging and faster diagnosis, continued need for metacognition and improvement capacity to minimize errors, provider burnout contributing to error as well as staffing shortages, and finding ways to more effectively and efficiently manage patient care where imaging is involved within increasingly complex systems (Figure 1).

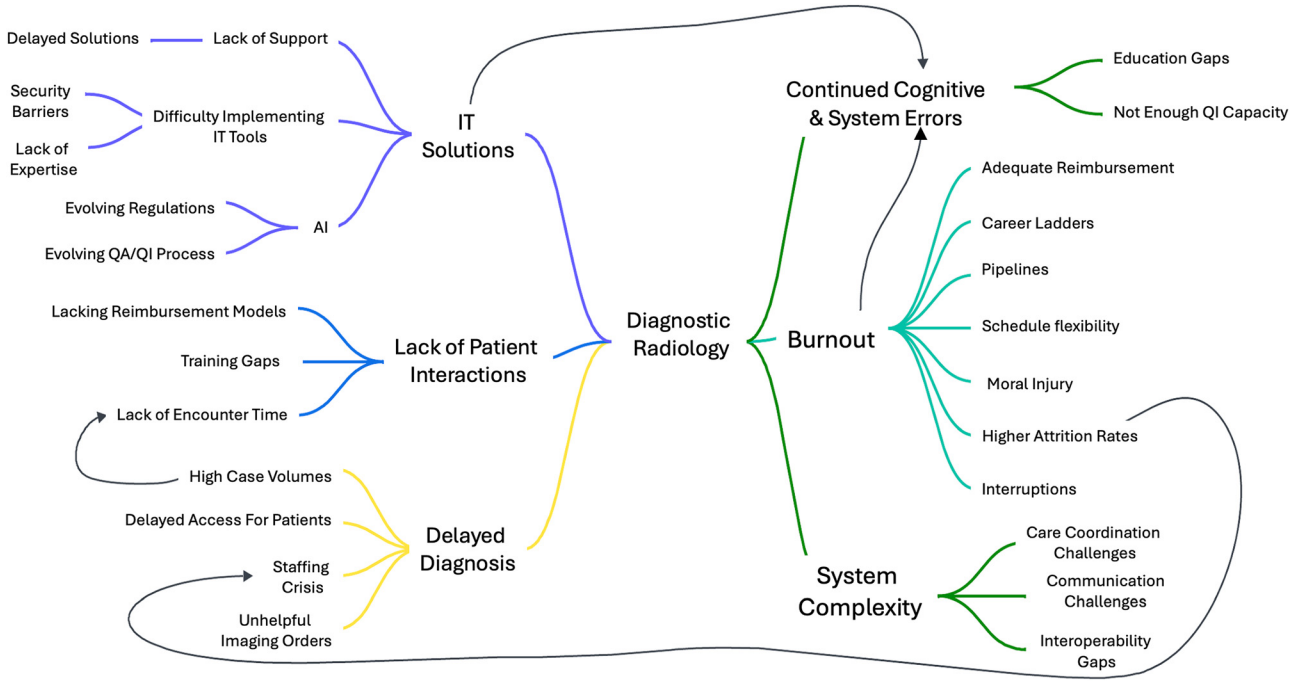

Figure 1: Simplified mind map highlighting a few of the many problems that remain to be addressed in diagnostic radiology, as they pertain to diagnosis error.

3 What are the topic priorities moving forward?

Evolving AI technology currently poses an opportunity as well as a threat to radiologists. It can be argued that radiologists can best demonstrate their value as humans by focusing on tasks that require human intelligence, compassion, advocacy, trust, and creativity. We propose such a focus can be by aligning radiology efforts to decrease diagnosis error with the patient journey (Figure 2).

The clinical patient journey encompasses symptom awareness, treatment consideration, seeking medical care, treatment/diagnosis, and recovery or ongoing care [28]. The adapted radiology patient journey encompasses awareness, imaging considerations, access to imaging, service, and ongoing care (Figure 1). The radiology value chain [29] comprises steps in the imaging process, such as imaging appropriateness, insurance matters, patient access, patient preparation, imaging protocol, image acquisition & processing, image review, image interpretation, reporting, result communication, error detection, error mitigation, and ongoing learning (Figure 1). We describe gaps and possible mitigation strategies using this blended framework:

Awareness. The patient journey starts with the awareness of something being wrong, observing signs and symptoms and gathering more information, initially often from internet sources [30]. While online sources provide ease of access, it is often difficult for patients to discern which content is current and reliable [31]. Radiology societies are sponsoring a patient-directed informational website (RadiologInfo.org); however, on this website patients can mainly search for information based on imaging findings/diagnoses, and less so based on symptoms that they may be experiencing. This offers a key strategic opportunity for improvement. Providing symptom-based information in radiology may help prevent patient harm by prompting patients to engage with a healthcare provider sooner [32].

Consideration. Patients who have engaged with a healthcare provider may face several decisions related to imaging: Do I want imaging? If so, what type of imaging do I want? Which imaging service provider should I use? What is the cost to me?

Imaging considerations are usually addressed by patients in conjunction with a clinical provider, who may not be as well-versed as a radiologist in matching a clinical scenario with an appropriate imaging modality and technique, and who may not be able to offer evidence-based guidance, i.e., the relevant pros and cons to help patients in their decision-making between available imaging options. Suboptimal imaging decisions can potentially cause harm to patients, such as delays in care, unnecessary exposure to ionizing radiation and intravenous contrast, as well as the identification of incidental findings which may unnecessarily trigger additional diagnostic

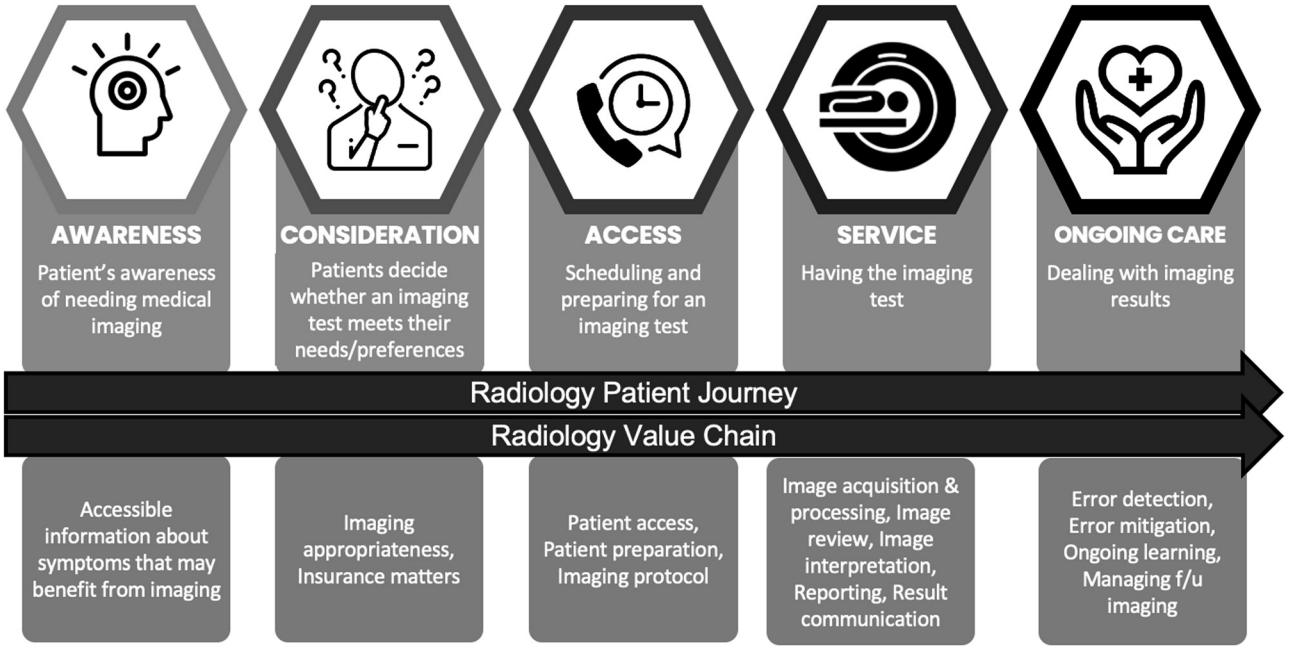

Figure 2: Framework for radiology diagnosis errors combining the patient journey and radiology value-chain.

tests and anxiety [33], and/or unnecessary treatments with additional risks and personal/societal cost [34]. Conversely, if patients decline recommended imaging based on their own beliefs and preferences, including for reasons related to social determinants of health, this can also lead to delayed diagnosis and interval disease progression which may ultimately lead to poorer outcomes, as well as incur higher downstream cost [35].

Key strategies to address these gaps include wider adoption of patient decision aids (PDA) in radiology and aid patients with choosing a provider by sharing standardized relevant performance measures.

PDAs can serve as a powerful vehicle for conveying evidence-based pros/cons related to imaging decisions for specific clinical scenarios, as well as detailed information on general pros and cons for specific imaging modalities and techniques [36, 37]. Radiology PDAs can help patients understand when imaging is necessary, clarify potential risks (e.g., radiation exposure, contrast reactions), and discuss alternatives (e.g., clinical observation, ultrasound vs. CT, etc.). Radiology PDAs thus have the potential to improve imaging utilization appropriateness, enhance patient engagement, and reduce unnecessary use of medical services [38]. While PDAs are well-established in other medical domains (e.g., surgery, oncology, cardiology) and represent a proven strategy for avoiding errors at the earliest stages of the patient journey, their adoption in radiology remains very limited.

Patient could benefit from learning about the importance of certain features when choosing an imaging provider, such as indicators of competence, adequate equipment, and a practice environment that promotes safety culture, which all play a role in diagnostic error in radiology [39]. Radiology practices have a strategic opportunity to define such indicators and how they are measured and share this information with patients [39]. Greater price transparency and patient-centric tools for calculating out-of-pocket costs would also assist patients in their decision-making [40].

Access. Delayed access to an imaging test and insufficient patient preparation can create additional opportunities for diagnostic error in the patient's journey. Delayed access can result from resource and/or capacity limitations, could result from a drawn-out insurance pre-authorization process, or could be due to patient's concerns pertaining to out-of-pocket costs [41–43]. Imaging cost transparency and financial support tools at this stage of the patient journey can enhance the likelihood that patients complete their exams so that delays in diagnosis are avoided [44]. Scheduling barriers also play a role in delayed care [45]. In radiology, no-shows and cancellations of existing appointments are common, often due to socioeconomic factors [46] or the length of time between the date the exam was scheduled and the appointment date [47]. Without sufficient notice of a cancellation, filling imaging slots from a patient wait-list can be challenging, so missed appointments effectively reduce a facility's capacity to provide service, compounding access delays to other patients. Appointment reminders and greater flexibility in re-scheduling can assist patients with

keeping appointments [47]. Several artificial intelligence (AI) applications can accelerate image acquisition as well as shortening image processing times leading to earlier access and diagnoses [48, 49] and aid with reconciliation of outside facility imaging studies that require upload for a second opinion interpretation [50].

Patients with scheduled imaging tests will want to learn what is involved with the test and how to prepare for it, and they prefer to receive this information from the provider who ordered the test for them [51]. Having access to imaging test information can decrease anxiety [52] and contribute to successful test completion with high diagnostic image quality. Well-informed patients may be better prepared to cooperate despite possible experiencing pain or discomfort, decreasing motion artifacts or other technical limitations that could negatively impact diagnostic accuracy [53].

Service. For patients, undergoing an imaging test is very much about the experience of the service delivery and satisfaction with the service, but there is currently no conclusive evidence linking an imaging experience with diagnosis errors or patient outcomes [54].

Service quality from the perspective of the imaging facility is highly defined by technical factors and equipment operator skills. Having equipment quality assurance programs in place is crucial in maintaining technical efficacy [55]. Radiological technologists need to be onboarded and trained continually to advance and maintain their skills as an important factor in acquiring high-quality images [56]. Creating educational resources for technologists may aid in improving image quality and diagnostic accuracy [57]. One current challenge in maintaining consistently high image quality are commonly high staff attrition rates among skilled technologists, related to an ongoing workforce crisis [58].

Performing the wrong imaging exam and/or using the wrong imaging technique for a given clinical scenario can also commonly result in error [59]. Radiologists volunteering with the American College of Radiology (ACR) continue to develop evidence-based guidelines for appropriate imaging use [60]. These have been integrated into clinical decision support (CDS) software applications that can guide ordering providers' selection of imaging exams, including advising users when imaging is not likely to be helpful. While CDS use can lead to improvement in imaging utilization appropriateness [61], many barriers have slowed wide adoption and are worth addressing, such as lacking skills to use CDS tools, disagreeing with weak evidence that informs the decision tool, disregard for the value of imaging to the patient regardless of appropriateness, perceived infringement on physician autonomy, and organization commitment to CDS implementation, among others [62].

Even with the appropriate imaging protocol/technique and optimal image quality, diagnosis errors deriving from an incorrect radiologist interpretation can result in missed, delayed, and inaccurate diagnoses. Radiologists' interpretations are subject to perceptual (missed findings) and interpretive (misinterpreted findings) errors [63]. The ability to perceive or accurately interpret images varies among radiologists and depends on factors such as training, ongoing continuing medical education, certifications status, and experience level [64]. The radiologist's interpretative quality is also influenced by external factors, such as imaging processing errors, interruptions and disruptions in the reading room environment, shift volumes and shift length [59, 63, 64].

Common cognitive biases leading to interpretive errors, especially anchoring bias, satisfaction of search, and confirmation bias can lead radiologists to overlook critical findings or misinterpret imaging studies [59, 63]. Efforts to address these issues include structured interpretation frameworks, training in cognitive bias recognition, and strategies such as mandatory breaks and workload optimization to reduce fatigue-related errors [57, 61]. The implementation of dual reading systems and peer review programs enhances diagnostic reliability and mitigates the impact of both randomly-occurring perceptual errors and individual cognitive biases [63].

Structured reporting (as opposed to unstructured narrative text) can decrease interpretive error by providing a built-in search pattern/checklist, especially for budding radiologists [65]. Specialists have expressed a preference for structured and contextualized reporting, to provide them with specific information needed for patient management [66]. AI technologies can now automatically generate a structured report and impressions from dictated findings [67]. Large language models (LLMs) can identify potential discrepancies within reports (e.g., reporting a "normal prostate" in a biologically female patient), across sections of a structured report (e.g., reporting "No visualized pulmonary embolism" in the findings and "Visualized pulmonary embolism" in the impression due to a dictation omission error) [68] as well as flag laterality errors. AI triage models identify potentially emergent imaging findings and mark these studies for priority interpretation [69]. AI models can reduce variability in image interpretation [70]. AI image interpretations can provide "diagnostic complementarity", acknowledging different strength and limitations between human and machine image interpreters, and evidence that the combined performance is better than either performance alone [71].

AI-powered screening opportunities can predict future development of disease using signals already present within

imaging examinations obtained for unrelated indications "opportunistic screening" [72]. For example, identification of coronary calcium on unenhanced chest CTs can be used for cardiovascular risk stratification [73]. Quantification of bone mineral density from CT can identify patients with osteopenia or osteoporosis who have not undergone bone densitometry assessment [74]. Radiomics and radiogenomics can be used to develop precision diagnostic and therapeutic approaches for a variety of conditions [75].

Ongoing care. Communicating results to patients is a pillar of the diagnostic process, and failure to communicate effectively with patients constitutes a diagnosis error [1].

Traditionally, radiologists have been reporting results exclusively to other health care providers and insurance companies. It is still considered highly unusual today that radiologists would directly contact patients with results, with exception of the State of Pennsylvania, where it was mandated in 2018 [76] for radiology practices to notify patients by mail of outpatient findings on cross-sectional imaging that will likely require follow-up. The enactment of the 21st Century Cures Act as of January 1, 2022, has also aided in getting imaging results to patients by making radiology test results available through electronic patient portals. Offering 1:1 consultation with patients, whether in person or virtually, is less common among radiologists, but is feasible [77–79]. Other interventions can be as simple as radiologists including their phone number in the report [80] or establishing a call-center for patient inquiries [81] and can be as sophisticated as creating video reports for patients highlighting findings on their imaging studies and narrated by their radiologist [82].

Errors in result communication can have minor and major impacts on patient care [83]; examples of major impact include delayed diagnosis of malignancy, delayed diagnosis and treatment of emergent findings, and unnecessary surgical procedures [83]. The idea of patient-centered reporting or consultations between radiologists and patients only evolved during the mid-2010s. One of the first approaches was the use of hyperlinks that explain technical language in the report with the addition of anatomy images as visual aids [84], which has since been transformed into a commercial tool that greatly enhances patients' understanding of their radiology reports [85].

Radiology departments throughout the country are increasingly focusing effort on building communication systems for actionable incidental findings to further decrease diagnosis delays, to help assure that evidence-based follow-up recommendations are being completed [2, 86, 87], as is further discussed below. Prior to the advent of AI, many innovative approaches were developed to identify actionable findings on radiology reports, including using structured reporting [88, 89]. More recently, natural-language processing technology, coupled with large language models, have successfully been used to identify actionable findings in radiology reports without the need for structured reporting [90]. Advanced generative AI may eventually support radiologists by automatically incorporating recommended guidelines when certain diagnoses are mentioned in radiology reports or the electronic medical record (EMR) [91]. While automated solutions for closing the follow-up loop enable scaling to large numbers of findings and patients, hybrid solutions with a human in the loop to nudge clinicians when follow-up remains incomplete remain important [92].

Whether AI tools are used specifically to enhance communication of radiology results, or more generally for quality and safety improvements in healthcare, the human-machine interface must be optimized to achieve optimal performance. We envision that human-factors and systems-engineering principles will be of paramount importance in designing future AI-augmented human workflows in radiology's future [93].

Radiology e-consults with referring providers can also be part of a multifaceted strategy to improve communications between caregivers, enhance diagnostic accuracy, and reduce errors and misunderstandings [94]. E-consults can be implemented by a small group of radiologists that triage and manage many questions across an enterprise using asynchronous communication tools [94]. Clearly defined workflow steps for primary care providers (PCPs) and radiologists are necessary for an e-consult service [94].

While not apparent to patients, a radiology provider's ongoing quality assurance (QA) and quality improvement (QI) programs, which are designed to improve the quality, consistency and patient experience, as well as to continually decrease diagnostic errors, also fall into this final stage of the patient's imaging journey.

Technology is also evolving to aid with skill-building among radiologists and technologists. AI applications offer improvements to radiologists' education by identifying gaps in training pertaining to specific imaging modalities and diagnoses so that the trainee assignments can be adjusted accordingly [95, 96]. Contemporary picture archiving and communication systems (PACS) feature integrated tools that allow radiologists to exchange feedback on image quality with technologists, greatly enhancing learning opportunities and skill-building among technologists [97].

A key pillar for improving performance is through ongoing measurement of key performance indicators (KPIs). Common KPI metrics in Radiology include such things as report turn-around times (RTAT), callback and radiographic repeat rates. There is currently an opportunity in radiology

to reach a new consensus on KPIs with the specific goal of reducing diagnosis error. Current systems typically focus on tracking incidents of patient harm, but do not emphasize measuring or tracking errors in diagnosis. In fact, radiologists only rarely become aware of their errors. The Measure Dx resource can help to guide radiologists towards uncovering specific sources for discovery of diagnosis errors, such as existing quality and safety event reporting systems, soliciting feedback from clinical providers who are aware of radiology errors involving their own patients, leveraging patient feedback regarding diagnosis errors, and uncovering discrepancies of radiology diagnoses with other diagnoses in the health records, such as surgical and pathology results or final episode diagnosis codes [98]. As a first step in providing feedback to radiologists on diagnostic errors, radiology departments are increasingly moving to peer learning, which is a formalized approach where discrepancies in interpretation are discovered by other radiologists and then used to provide content for regularly-occurring peer learning sessions [5, 6].

4 What are the key groups and agencies and what should be their role?

Similar to other medical specialties, diagnostic radiology depends on a number of key agencies with specific roles in advancing the care we deliver:

Professional radiology organizations. The American College of Radiology (ACR) coordinates health policy, economics, and quality efforts affecting radiology, and coordinates a slew or volunteer efforts, such as developing and updating practice parameters and appropriateness criteria.

Government agencies. The Food and Drug Administration (FDA) regulates imaging devices, AI/ML diagnostic tools, and contrast agents to ensure safety and efficacy in reducing errors. The Centers for Medicare & Medicaid Services (CMS) tie reimbursement to quality metrics to incentivize reporting and error reduction strategies (MIPS, APMs).

Accreditation & quality bodies. The Joint Commission (TJC) sets standards for diagnostic imaging safety and communication; require reporting of sentinel events related to delayed/missed diagnosis. The ACR accredits imaging facilities by modality, thereby driving the reporting of quality metrics to its registries.

Technology & informatics bodies. The ACR data Science Institute plays a crucial role on the ongoing integration of AI solutions in radiology. The ACR Recognized Center for Healthcare-AI (ARCH-AI) sets the guidelines for AI use in imaging interpretation and ensures radiology facilities are using AI safely and effectively.

Conclusions

The integration of the patient journey with the imaging workflow provides a broad, comprehensive framework for identifying and mitigating diagnostic errors in radiology. Addressing human factors, fostering a culture of continuous learning, and leveraging advanced technological solutions are critical steps toward improving diagnostic accuracy and enhancing patient safety. Although the adoption of AI is still in the early stages in radiology, AI technologies are already transforming the practice of radiology in many ways, by offering a range of tools that can collectively enhance human performance and can mitigate common failure modes in radiology. As AI continues to evolve, its integration into radiology workflows is expected to further reduce diagnostic errors, enhance communication between radiologist, providers and patients, and improve patient outcomes.

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