Understanding and Confronting Our Mistakes: The Epidemiology of Error in Radiology and Strategies for Error Reduction[1]

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Arriving at a medical diagnosis is a highly complex process that is extremely error prone. Missed or delayed diagnoses often lead to patient harm and missed opportunities for treatment. Since medical imaging is a major contributor to the overall diagnostic process, it is also a major potential source of diagnostic error. Although some diagnoses may be missed because of the technical or physical limitations of the imaging modality, including image resolution, intrinsic or extrinsic contrast, and signal-to-noise ratio, most missed radiologic diagnoses are attributable to image interpretation errors by radiologists. Radiologic interpretation cannot be mechanized or automated; it is a human enterprise based on complex psychophysiologic and cognitive processes and is itself subject to a wide variety of error types, including perceptual errors (those in which an important abnormality is simply not seen on the images) and cognitive errors (those in which the abnormality is visually detected but the meaning or importance of the finding is not correctly understood or appreciated). The overall prevalence of radiologists' errors in practice does not appear to have changed since it was first estimated in the 1960s. The authors review the epidemiology of errors in diagnostic radiology, including a recently proposed taxonomy of radiologists' errors, as well as research findings, in an attempt to elucidate possible underlying causes of these errors. The authors also propose strategies for error reduction in radiology. On the basis of current understanding, specific suggestions are offered as to how radiologists can improve their performance in practice.

Introduction

Diagnostic error in medicine is a major cause of patient harm, with the rate of missed, incorrect, or delayed diagnoses estimated to be as high as 10%–15%. Autopsy studies have identified major diagnostic discrepancies in up to 20% of cases, suggesting that the working or final clinical diagnosis may be wrong in as many as one in five patients overall (1,2).

Because medical imaging constitutes such a large component of modern clinical diagnosis, it is only reasonable to conclude that the high prevalence of diagnostic unreliability (including both incorrect and delayed diagnoses) in medical practice is partly attributable to the errors of radiologists. In fact, the radiologic contribution to diagnostic error overall is likely to be substantial. Radiologists' interpretations constitute an important component of the information available to clinicians when they are formulating their diagnoses, yet the process of radiologic interpretation is subject to a great deal of variability. For example, in a recent study of second readings performed by experienced abdominal imaging radiologists from Massachusetts General Hospital, in which leading radiologists reinterpreted ab-

TEACHING POINTS

- Radiologists' interpretations constitute an important component of the information available to clinicians when they are formulating their diagnoses, yet the process of radiologic interpretation is subject to a great deal of variability.
- Two broad categories of radiologic error have been identified: perceptual errors and cognitive (interpretive) errors. Perceptual errors are far more common, accounting for between 60% and 80% of radiologists' errors.
- The consistency of experimental results on radiologists' perceptual errors reported worldwide, involving radiologists at all levels of training and experience working in a wide variety of clinical settings and across all imaging modalities, argues convincingly against the idea that radiologists who make errors are simply to blame for being careless, sloppy, or negligent or for underperforming in some way; rather, the phenomenon of radiologist underperception and misperception appears to be an unvarying feature of the extremely complex system in which radiologists operate.
- Focused training for radiologists to improve the clarity and effectiveness of their written reports also may be a strategy that can result in fewer errors related to faulty communication between caregivers. This type of communication problem is a known cause of diagnostic errors in medicine, and improving communication between caregivers has long been one of the Joint Commission's National Patient Safety Goals.
- If radiologist errors are indeed inevitable, as they appear to be, then developing the means to enhance the early detection and self-correction of errors is of paramount importance in the fail-safe prevention of harm and risk reduction.

dominopelvic computed tomographic (CT) studies that had been previously interpreted by either themselves or their colleagues, they disagreed with each other more than 30% of the time and disagreed with themselves more than 25% of the time (3). Approximately 1 billion radiologic imaging examinations are performed worldwide annually, and most of the resulting images are interpreted by radiologists (4). If these interpretations carried an average error rate of only 4%, the lowest estimate for the rate of radiologic error, this would translate to approximately 40 million radiologist errors per year.

The topic is made more complex in that the definition of what constitutes an error in radiologic interpretation is subject to debate. Surgically or autopsy-proven diagnoses are generally accepted as an objective reference standard, but these rarely apply. For example, if two radiologists disagree over the presence and meaning of a finding, such as whether a chest radiograph shows the presence of pulmonary edema, can we conclude that at least one of them is making an error? For most purposes (eg, the standard used in radiologist peer review), any discrepancy in interpretation that differs substantially from the consensus of one's peers would be a defensible definition of an interpretive error.

Radiologist Leo Henry Garland (1903–1966) was a pioneer in the study of radiologic error. He conducted rigorous analyses of radiologists' errors in practice and authored several articles on the topic that were published between 1949 and 1959. Garland discovered that even skilled and experienced radiologists failed to note important findings on 30% of chest radiographs that were positive for disease and also had a false-positive rate of approximately 2% for negative cases (5). Since Garland's time, many excellent studies of radiologists' errors have been performed within the United States and abroad that have largely served to confirm and extend his findings; such studies include those of Revesz and Kundel (6), Siegle et al (7), Donald and Barnard (8), and, most recently, Kim and Mansfield (9). These and other studies have helped to elucidate the prevalence and nature of radiologists' errors, have provided a basis for error classification, and have helped guide and inform current research into strategies for error reduction.

Understanding and Categorizing Error in Radiology

Two broad categories of radiologic error have been identified: perceptual errors and cognitive (interpretive) errors. Perceptual errors are far more common, accounting for 60%–80% of radiologists' errors (4,5,8,10,11).

Perceptual errors occur during the initial detection phase of image interpretation. A perceptual error is deemed to have occurred when an abnormality is retrospectively determined to have been present on a diagnostic image but was not seen by the interpreting radiologist at the time of primary interpretation. In general, to be considered a perceptual error, the finding would need to be deemed sufficiently conspicuous and detectable in retrospect by the interpreting radiologist or in the consensus of his or her peers. Clearly not all subtle, insubstantial, or inconspicuous findings that are subsequently found to represent a pathologic process would be considered perceptual errors by this standard. The underlying causes of this type of error remain poorly understood. However, an increased incidence of perception error may be attributable to specific risk factors. These include poor conspicuity of the target lesion on the image; reader fatigue; an overly rapid pace of performing interpretations; distractions, such as phone calls, e-mails, and other Internet-based distractions or interruptions; and a phenomenon known as satisfaction of search, whereby the finding of one abnormality on an image results in a second abnormality being overlooked, ostensibly because the radiologist is satisfied with the results of his or her search. Most perceptual errors, however, lack any obvious cause. All too often, a finding that is readily apparent in retrospect is inexplicably missed (Fig 1).

Various studies have attempted to identify the most common perceptual errors, such as missed lung nodules and metastatic bone disease, on radiographs (8,9); however, there is still no consensus. The consistency of experimental results on radiologist perceptual errors reported worldwide, involving radiologists at all levels of training and experience working in a wide variety of clinical settings and across all imaging modalities, argues convincingly against the idea that radiologists who make errors are simply to blame for being careless, sloppy, or negligent or for underperforming in some way; rather, the phenomenon of radiologist underperception and misperception appears to be an unvarying feature of the extremely complex system in which radiologists operate (5–9).

Cognitive or interpretive errors occur when an abnormality is identified on an image but its importance is incorrectly understood, resulting in an incorrect final diagnosis. This type of error may be secondary to a lack of knowledge, a cognitive bias on the part of the radiologist interpreting the study, or misleading clinical information distorting the apparent pretest probability of disease; it could also simply be a result of a radiologist inadvertently propagating an error made by a colleague in a previous radiology report (sometimes termed an alliterative error or satisfaction of report).

Image interpretation is a human enterprise and is subject to the limitations of human ability. Further, each image contains a great deal of information embedded in a background of high uncertainty, in which nearly every visual feature may or may not represent a potentially useful positive or negative finding. To make a correct diagnosis from "raw data" of this sort, one must use visual detection, pattern recognition, working memory functions—and ultimately cognitive reasoning—to result in a final interpretation of the meaning of what has been perceived. The perceptual and reasoning steps occur as parts of a process that is filtered through the individual practitioner's individual knowledge base, past experience, and cognitive biases. The conclusions derived from this process must then be translated into effective language to be communicated to the clinical providers who will act on the information. Further, for each of the approximately 1 billion imaging examinations performed annually, all of these psychophysiologic and cognitive steps must be performed repeatedly.

Estimates of the true prevalence of radiologic error vary by sample, modality, and patient selection, and range from 4% in a typical representative sample with a substantial percentage of studies with normal findings (12) to around 30% if all studies in the sample have abnormal results

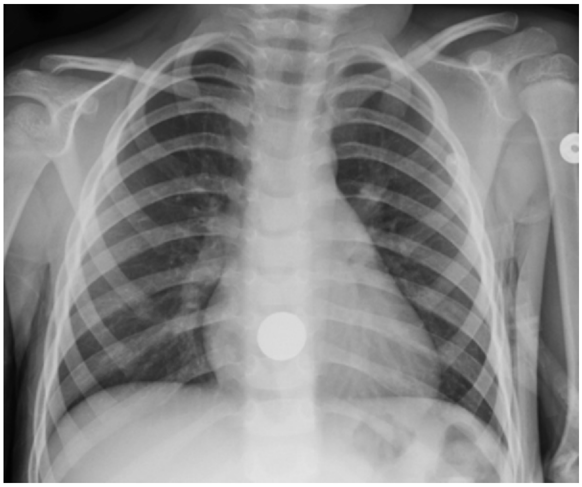


Figure 1. Example of a perceptual error. Anteroposterior radiograph of the chest of a 4-year-old boy. The presence of a swallowed coin within the esophagus was missed twice by a skilled pediatric radiologist. The clinical history provided did not mention the possibility of a swallowed coin.

(12–14). The false-positive rate may be equally high. Moreover, it has been shown that radiologists are prone to make the same errors repeatedly, especially when findings are not detected or when their importance is underestimated (9).

Failure of radiologists to effectively communicate results in a timely manner is a commonly cited vulnerability in the process of diagnostic radiology and represents an important subtype of radiologist error that can contribute to adverse outcomes in patients. It is well understood that patient harm may be prevented by radiologists' urgent and direct communication of critical or unexpected findings to referring physicians, thereby providing new data to the clinician's diagnostic deliberations in a timely manner. The most broadly accepted guideline for this is the American College of Radiology Guidelines for such communications, which advise radiologists to speak directly with the referring physician and document the communication in the radiologist report. Although not as widely recognized, lack of clarity in a radiologist's routine written communications may also be at fault in some cases of misdiagnosis that occur in nonemergency situations, such as cases in which the intended meaning of the radiologist's report is not faithfully conveyed in the report or is not understood by the clinician. From the patient's standpoint, the outcome is the same whether the radiology report omits a key finding or whether the importance of a reported finding is not effectively communicated to the clinician because of confusing report structure, poor organization, poor word choice or vocabulary, or even mistakes in grammar or punctuation.

Classification Scheme for Errors in Diagnostic Radiology

Cause of Error	Explanation	Occurrence (%)
Complacency	A finding is appreciated but attributed to the wrong cause (false-positive finding)	0.9
Faulty reasoning	A finding is appreciated and interpreted as abnormal but is attributed to the wrong cause (true-positive finding misclassified)	9.0
Lack of knowledge	A finding is seen but is attributed to the wrong cause because of a lack of knowledge on the part of the interpreter	3.0
Underreading (missed finding)	A finding is present on the image but is missed	42.0
Poor communication	An abnormality is identified and interpreted correctly but the message does not reach the clinician	0.0
Technique	A finding is missed because of the limitations of the examination or technique	2.0
Prior examination	A finding is missed because of failure to consult prior radiologic studies or reports	5.0
History	A finding is missed because of inaccurate or incomplete clinical history	2.0
Location	A finding is missed because of the location of a lesion outside the area of interest on an image	7.0
Satisfaction of search	A finding is missed because of failure to continue to search for additional abnormalities after the first abnormality was found	22.0
Complication	A complication from a procedure	0.5
Satisfaction of report	A finding was missed because of overreliance on the radiology report from a previous examination	6.0

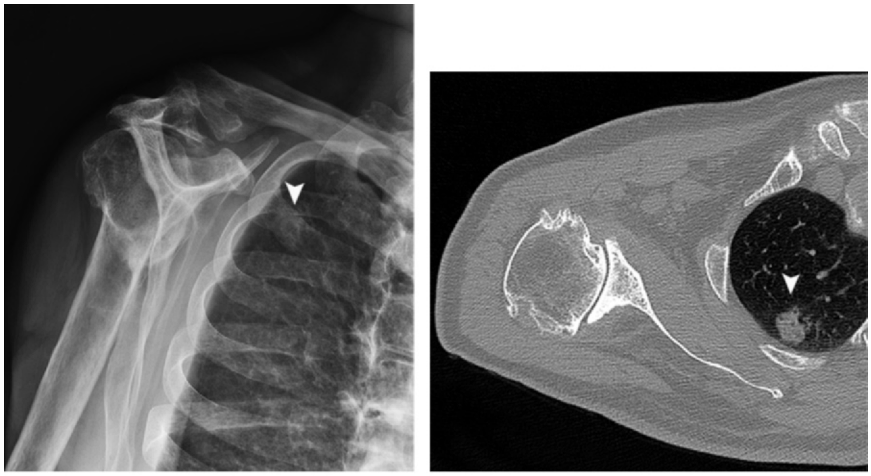
Source.—Reference 9.

Figure 2. Example of a cognitive error. Anteroposterior supine radiograph of the pelvis and hips in a 76-year-old man. The interpreting radiologist correctly identified an abnormal bone around the painful left hip arthroplasty stem and made an incorrect diagnosis of small-particle disease. At reinterpretation, the proximal left femur was noted to be expansile, with cortical and trabecular thickening, and it featured a blade-of-grass advancing edge (arrowhead). These findings were most consistent with a diagnosis of Paget disease. This error might have been due to insufficient knowledge.

Kim-Mansfield Radiologic Error Classification System

Radiologic errors have been categorized somewhat differently by various authors, including Brook et al (15), Pinto and Brunese (16), and Provenzale and Kranz (17). We are partial to the recently proposed 12-category system developed by Kim and Mansfield (9), which extended the simpler scheme developed by Renfrew (18) and may be the most comprehensive model proposed to date. Kim and Mansfield evaluated 1269 errors and separated them into 12 categories by cause (Table).

The first type of error in the Kim-Mansfield scheme is a false-positive error or an error of overreading, in which a clinically unimportant finding is attributed to a more serious cause. The second type of error is an error of faulty reasoning (Fig 2), in which the pertinent finding is detected and correctly interpreted as abnormal but is ultimately attributed to the wrong cause and leads to misdiagnosis. This type of error is particularly prone to cognitive bias, whether from misleading clinical information or an overly limited differential diagnosis. The third type of error is an error



a. b.

Figure 3. Location type error is encountered when the key finding is overlooked because it lies outside the area of focused interest. **(a)** Scapular Y image from a four-view shoulder radiographic examination of a 71-year-old man with a history of well-differentiated lung adenocarcinoma; lung adenocarcinoma (arrowhead) was not identified, even though it was visible. **(b)** The lesion (arrowhead) was discovered 1 week later on this axial CT image of the shoulder when the shoulder surgeon ordered CT for surgical planning before shoulder arthroplasty. Lung findings are frequently overlooked on shoulder radiographs.

that results from lack of knowledge, in which the finding is correctly identified on the image, but its diagnostic importance is missed because of the reader's lack of knowledge.

The most common error in the Kim-Mansfield series was the type 4 error, in which the finding was simply not detected; this finding served to confirm the results of all prior similar studies on radiologist error. This error was termed underreading by Kim and Mansfield. It was the most common error type and constituted 42% of the errors in their study, even though this error type made up a much larger fraction of total errors in several previous studies, as noted previously. Again, in this type of error, the radiographic abnormality was identifiable (often readily identifiable, as in Fig 1) on the image in retrospect, at which time its importance could be clearly understood and appreciated; however, for unknown reasons, it was simply not perceived at the time of primary image interpretation.

Type 5 errors are errors of miscommunication, in which a finding is identified and correctly interpreted, but the message ultimately fails to reach the treating clinician. This may be due to failure of the established channels of communication, or it may be merely due to a failure of the radiology report to effectively transmit the information to the clinician because of unclear writing or other factors (5). Type 6 errors are errors of faulty technique, in which a finding is not detected because of limitations of the radiologic examination or because of poor technique. Type 7 errors are errors of prior examination, in which a finding is missed because of a failure to consult prior radiographic studies or reports that would have guided the radiologist to the correct diagnosis. Type 8 errors are errors due to a faulty clinical history in which an inaccurate, incomplete, or misleading clinical history creates bias that misdirects the interpreting radiologist. Type 9 errors are errors of location (Fig 3), in which a potentially important finding is missed because it is outside the area of interest on an image. This was the fourth most common error in the study by Kim and Mansfield and represented 7% of the total errors in their series. Typical examples include musculoskeletal findings overlooked at chest radiograph interpretation or findings seen on only the first or last of a lengthy series of cross-sectional images in a CT or magnetic resonance imaging study in which the main focus of clinical interest lies on other image sections.

Type 10 errors are described as satisfaction of search, in which a finding is missed because of a failure to continue to search the images after an initial abnormality is discovered. It is believed the radiologist becomes cognitively satisfied after he or she discovers the first finding and prematurely stops evaluating the images. This was the second most common error type and led to 22% of the errors in the Kim and Mansfield study. Ashman et al (19) noted that the detection rate for the first finding in a case that contained multiple findings was about 78%, but the second and third findings were discovered only approximately 40% of the time. Type 11 error is a complication from a procedure. This may include wrong side, wrong patient, and wrong procedure type errors. Type 12 errors are satisfaction of report, representing another unique type of cognitive bias where there is an overreliance on the previous radiologist's opinion of a prior study.

Mechanistic Approach to Understanding Perceptual Error in Radiology

Because perceptual error is the most common type of error, it follows that to substantially reduce the overall prevalence of radiologic error, the underlying psychophysical processes involved in perception must be better understood. To find an abnormality via visual search, one must move his or her eyes around the image to concentrate the central visual field on each of many areas of interest. The radiologist's visual search pattern can be guided by habit, practice, or—ideally—clinical knowledge of the anatomic locations, disease patterns, and types of abnormalities being searched for, and all of these appear to be critical factors. Visual search may also be augmented by detection of an area of interest in the peripheral vision in many cases, and there is evidence that peripheral vision makes a considerable contribution to a radiologist's search, with an interplay observed between foveal and peripheral vision noted as the observer scans an image (4,20).

Certainly, a fraction of perceptual errors in the practice of radiology reflects flaws or biases in the search patterns used by radiologists (eg, whether they do not look in the area of a lesion or do not fixate on a lesion long enough to notice its relevant features); thus, they may be amenable to training and cognitive debiasing. Clearly, some lesions are made subtle by their surroundings or are overlooked because of their location; these errors may be amenable to technologic innovations, such as image processing or computer-aided detection. Many commercially available picture archiving and communication systems, such as the ones used in our own centers, include image-processing algorithms, such as the contrast-limited adaptive histogram equalization (or CLAHE) edge-enhancement algorithm, which has been shown to improve lesion detection on low-contrast images (21). This is easily applied in practice, as it can be toggled on or off with a mouse click at the workstation, and it is commonly used in our practice. Computer-assisted detection is a software-based technology that aims to assist radiologists in detection of abnormalities that might otherwise be overlooked. In computer-assisted detection, a software algorithm is used to identify suspicious features on the image, and it flags these areas to bring them to the attention of the radiologist. In practice, a radiologist would first review the image and then activate the computer-aided detection software. The radiologist would subsequently reexamine any areas marked for concern by computer-aided detection software before concluding his or her interpretation. Several such systems have been used, and their clinical effectiveness remains controversial even though this area holds much promise (22).

Studies that track eye movement are performed by using specialized equipment that detects the location of the viewer's gaze on a target image and can delineate the visual path taken in scanning the image and determine the amount of time spent in each area of the image. In such studies, a radiologist's dwell time in certain areas of a radiographic image seems to be related to the ultimate detection of abnormalities in those areas of the image. Similarly, missed findings are also found in areas of images with relatively longer dwell times. In fact, studies have shown that radiologists' vision may dwell on or frequently return to the area of an image that contains an abnormality that is ultimately missed (23). This observation, which suggests that a perceptual event occurring below the level of conscious awareness may be at work, serves to highlight the complexity of the psychologic, physiologic, and cognitive processes involved. Poorly understood attributes of working memory may also play an important role, whereby abnormalities that are detected visually are not held in working memory long enough to be included in the final written report. If one considers the immense complexity of the radiologist's perceptual task, it would appear that these sorts of errors are most likely inevitable, and we may well worry that their high incidence may indeed be intractable.

Strategies for Error Reduction

In the nearly 70 years since Garland's initial article was published, various efforts have been made to address the problem of radiologist errors, especially errors of omission (misses), the bulk of which we now know are perceptual in origin. Most of these efforts have traditionally focused on intensive education of radiologists-in-training and retraining of practicing radiologists in continuing education, including unknown case reviews, training in pattern recognition, repetition, and drills. Unfortunately, it has become clear that these sorts of strategies, while not without merit, are ultimately insufficient. Similarly, attempts to improve radiologist performance by adjusting work hours to limit fatigue, mitigate pressure to keep up a rapid pace of work, or reduce the number of interruptions and distractions in a radiologist's workday—any of which would be expected to improve performance—have had a negligible effect. To our knowledge, no systematic studies have been performed to evaluate the effects of age or illness on an individual radiologist's performance, nor have any credentialing organizations currently recommended routine visual acuity testing for radiologists, although one might imagine that declining visual acuity could increase the risk for error.

Cognitive Bias and Strategies for Debiasing

Many radiologist errors appear to involve faulty or biased cognitive processes. This is most evident when the importance of a perceived finding is mistaken, but it is noted even in the case of apparent perceptual errors, in which failure to detect a finding may be influenced by bias in the viewer's expectations of which findings are likely and a priori choices regarding what exactly is being searched for on any given image. Accordingly, strategies for cognitive debiasing and metacognitive interventions have been advocated to remediate these types of errors (24), especially for the most common of 40 known cognitive and affective biases that may affect clinical reasoning and information gathering, including the effects of such biases on the actual visual or perceptive search of images and in the interpretation of the meaning of densities encountered visually when the images are viewed.

Biases that may be expected to affect radiologists include *(a)* anchoring bias, in which a diagnostician locks onto some salient feature or features too early in the diagnostic process and discounts conflicting or new information gained subsequently; *(b)* availability bias, in which recent experience with a disease may inflate the future likelihood of its being diagnosed again (conversely, if a disease has not been seen for a long time, it may be underdiagnosed); *(c)* confirmation bias, in which there is a tendency to look for confirmatory evidence to support a diagnostic hypothesis and to ignore or discount evidence that refutes the hypothesis; *(d)* outcome bias, in which there is a preference to opt for diagnostic decisions that will lead the patient to a better final outcome; and *(e)* zebra retreat, in which a rare diagnosis (ie, a "zebra") is actually supported by the patient's history and imaging findings but the diagnostician retreats from making the correct diagnosis because of self-doubt about entertaining such a remote or unusual diagnosis.

The idea of cognitive debiasing has existed for decades and was well described by Wilson and Brekke (25) in 1994 as a form of "mental correction." Efforts since that time have focused on identification of likely biases—over 40 common biases have been named and systematically studied—and development of algorithms to reduce their effect (25). Unfortunately, in recent years, extensive experimental efforts to reduce diagnostic error rates in medical specialties outside of radiology by applying debiasing algorithms have been unsuccessful. For example, in a recent meta-analysis, Graber et al (26) identified 42 published reports that tested interventions to reduce the likelihood of cognitive errors, including *(a)* educational interventions (ie, those meant to improve knowledge and experience), such as improved feedback and focused education; *(b)* interventions designed to improve clinical reasoning and decision making, such as reflective review and error analysis; and *(c)* interventions to provide cognitive help, including integrated decision support and informatics tools to facilitate access to information and expert opinions. Ongoing work is focused on educational interventions, metacognition (eg, "thinking about thinking" techniques, reflection, and mindfulness), slowing-down strategies, group-decision strategies, environmental and cultural interventions, and encouraging physicians to remain skeptical after they believe the correct diagnosis has been determined (27).

Checklists and Structured Reporting

The use of checklists has been shown to reduce errors of omission in a wide variety of fields, including aviation, critical care medicine (28), and presumably radiology; however, their effectiveness remains uncertain. The use of checklists to reduce medical errors has been popularized in the recent best-selling book *The Checklist Manifesto* (29). We have had some encouraging preliminary results in a recent study in which radiologists who interpreted combined positron emission tomographic (PET) and CT studies were asked to review a five-item checklist of the "top five most commonly missed incidental findings on PET/CT," with increased detection of some of the items on the checklist and no additional burden reported by the users who incorporated the checklist into their workflow. The use of this checklist in the interpretation of PET/CT images has now become our standard practice. We also routinely use a semistructured report template in our practice for all cross-sectional studies; this arguably serves as a type of standardized checklist for the interpreting radiologist as well. Our rationale is that a checklist that is well designed and not too lengthy can reduce errors of omission by reminding the radiologist to take a second look at certain aspects, areas, and features of the images. We believe this is the case whether the checklist is overtly placed near the reading station or in the form of a standard set of blanks requiring data entry in a semistructured radiology report. Although the initial results are indeed promising, use of such formal or informal checklists has yet to be fully validated as an error-reduction strategy in the practice of radiology.

Practice Quality Improvement Strategies around Error Reduction

Considerable gains in quality and safety in medical care can be made by merely reducing the variability in processes (ie, standardizing the radiologist's approach or the diagnostic imaging protocol), a fact that has long been recognized. It is widely believed that process improvements applied to a system of care can also lead to reduction of diagnostic errors by individuals working within these systems (15).

The conventional techniques of quality improvement (ie, implementation of the "plan, do study, act" cycle of quality improvement), as described in other articles in this monograph (see the article by Larson et al), may also be brought to bear on the problem of radiologist errors. An important feature is to remove any punitive elements from the process of error analysis and instill a blameless culture. The importance of this approach cannot be overemphasized, as a blameful culture in which individuals are punished or expect they might be punished for human error results in the suppression of error reporting and lost opportunities for process improvement and self-correction of errors (30).

The evolving toolkit of "lean" and Six Sigma strategies as applied to health care (described elsewhere in this monograph) is largely a process to identify and eliminate wasteful or defective variation in health care delivery processes. For complex problems with a large institutional effect that are relatively costly and labor intensive, the lean and Six Sigma processes can often be valuable because successful reduction in process variation has been shown to mitigate error and reduce risk for patient harm.

Focused training for radiologists to improve the clarity and effectiveness of their written reports also may be a strategy that can result in fewer errors related to faulty communication between caregivers. This type of communication problem is a known cause of diagnostic errors in medicine, and improving communication between caregivers has long been one of the Joint Commission's National Patient Safety Goals (31,32).

Information Technology Solutions and Computer-aided Detection

As noted earlier in this article, initial experience with computer-aided detection has not been entirely satisfactory; however, the technology for computer-aided detection continues to evolve and has promise for improving reader performance in the future (33). Technologies based on eye tracking, for example, may someday aid future radiologists by highlighting neglected areas on images or by providing subtle gaze direction in the radiologist's peripheral vision (perhaps by systematically and subtly altering the brightness of regions of the image that the radiologist is currently not focused on, thereby attracting the radiologist's gaze), or even by providing real-time feedback to radiologists, such as by displaying a colorized heat map overlay or other annotations to the image, highlighting areas on an image where the radiologist's visual dwell time suggests that a consciously unrecognized abnormality may be present (34).

Fail-safe Strategies for Harm Prevention and Risk Reduction

If radiologist errors are indeed inevitable, as they appear to be, then developing the means to enhance early detection and self-correction of errors is of paramount importance in fail-safe prevention of harm and risk reduction. Accordingly, in recent years, considerable effort has been placed on developing checks and balances to reduce the potential harm of errors after the fact and to develop trigger tools to facilitate early detection of errors soon after they occur and hopefully before any irreparable harm is done. To reduce the risk for harm caused by ineffective communication between radiologists and clinicians, direct communication of findings to patients, such as that required by the Mammography Quality Standards Act, which prescribes specific direction on communication with patients, can also serve as a fail-safe method and help ensure that proper follow-up occurs.

Conclusion

We ardently hope that future research toward understanding the underlying processes of human perception and overcoming the inevitable cognitive biases that humans bring to their tasks will improve the likelihood that radiologist errors in practice can be reduced. Quality improvement strategies and information technology–based solutions may also provide substantial benefits. Research into how to best tailor radiologists' communications to maximize their effectiveness and overcome the limitations and cognitive biases of their intended audience (ie, referring physicians) is also badly needed. Thus, a multiplexed and intensive effort that includes but is not limited to radiologists will be needed to make a difference in this problem in the years ahead.

Does the proverbial cloud of radiologist error contain a silver lining for radiology in the form of an opportunity for true learning and improvement? We believe that it does but only if the lessons of the past several decades of research into radiologist errors are correctly understood and taken to heart. These include, but are not limited to, *(a)* the need to maintain a state of constant vigilance in interpretation and a healthy degree of skepticism regarding favored diagnoses; *(b)* struggling to overcome all known cognitive biases and pitfalls; *(c)* consistent use of a sufficiently broad range of differential diagnoses when formulating conclusions about unknown cases being evaluated; *(d)* reduction in variation or variability in practice at all levels; *(e)* a program of continuous lifelong learning to prevent knowledge gaps; *(f)* a mindful systematic approach to the search of diagnostic images and to the use of checklists and structured and semistructured reporting strategies, when appropriate; *(g)* cognitive debiasing approaches and metacognition, when appropriate; *(h)* use of effective technologic aids, as appropriate, if any become available; *(i)* consistent focus on clear effective communication, especially clear written communication, so that the radiologist's message is not lost or misunderstood; *(j)* use of harm mitigation and fail-safe strategies to place redundant layers of protection between the radiologist and the patient, including trigger tools to identify errors so that they can be corrected before harm occurs; *(k)* reduction, to the extent possible, of interruptions and distractions; *(l)* attention to individual physician factors, such as illness or advancing age, may be appropriate in some isolated cases to assure that these factors do not significantly affect diagnostic performance; *(m)* systems-level thinking—understanding the individual radiologist's role within the context of the larger health care team and process and empathetically understanding the roles and needs of others within that system; and *(n)* a blame-free and just culture.

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