Fundamentals of Diagnostic Error in Imaging

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Abbreviations: EMR = electronic medical record, HCC = hepatocellular carcinoma, MCC = missed case conference, PACS = picture archiving and communication system, PLC = peer learning conference

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- List the components of a comprehensive process to learn from diagnostic error in radiology.
- Describe the different approaches to identifying cases with diagnostic error.
- Discuss educational and systematic interventions that can reduce diagnostic errors.

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Imaging plays a pivotal role in the diagnostic process for many patients. With estimates of average diagnostic error rates ranging from 3% to 5%, there are approximately 40 million diagnostic errors involving imaging annually worldwide. The potential to improve diagnostic performance and reduce patient harm by identifying and learning from these errors is substantial. Yet these relatively high diagnostic error rates have persisted in our field despite decades of research and interventions. It may often seem as if diagnostic errors in radiology occur in a haphazard fashion. However, diagnostic problem solving in radiology is not a mysterious black box, and diagnostic errors are not random occurrences. Rather, diagnostic errors are predictable events with readily identifiable contributing factors, many of which are driven by how we think or related to the external environment. These contributing factors lead to both perceptual and interpretive errors. Identifying contributing factors is one of the keys to developing interventions that reduce or mitigate diagnostic errors. Developing a comprehensive process to identify diagnostic errors, analyze them to discover contributing factors and biases, and develop interventions based on the contributing factors is fundamental to learning from diagnostic error. Coupled with effective peer learning practices, supportive leadership, and a culture of quality, this process can unquestionably result in fewer diagnostic errors, improved patient outcomes, and increased satisfaction for all stakeholders. This article provides the foundational elements for implementing this type of process at a radiology practice, with examples to help radiologists and practice leaders achieve meaningful practice improvement.

Introduction

The impact of diagnostic error in the United States is considerable. At least 5% of adults seeking outpatient care experience diagnostic errors, which contribute to nearly 10% of deaths annually and up to 17% of adverse hospital events (1). Medical errors also result in wasteful medical spending, with estimated costs ranging from $17 billion to $29 billion annually (2). Approximately 75% of malpractice lawsuits filed against radiologists relate to diagnostic errors (3,4).

In a report titled *Improving Diagnostic Quality and Safety*, the National Quality Forum recently concluded that "while most people will experience at least one diagnostic error in their lifetime, stakeholders in quality measurement and patient safety have largely neglected the issue" (5). Relatively high diagnostic error rates have persisted in radiology despite decades of research and interventions (4,6–8). Nearly every practicing radiologist has experienced a scenario where a finding was not detected in a previous study, resulting in a delay in diagnosis or inappropriate treatment.

TEACHING POINTS

- Developing a comprehensive process to identify diagnostic errors, analyze them to discover contributing factors and biases, and develop interventions based on the contributing factors is fundamental to learning from diagnostic error. Coupled with effective peer learning practices, supportive leadership, and a culture of quality, this process can unquestionably result in fewer diagnostic errors, improved patient outcomes, and increased satisfaction for all stakeholders.
- A fundamental attribute of any successful quality improvement activity is that interventions are designed to address factors that directly or indirectly contribute to failures, hence the inclusion of analysis as an essential component of learning from errors. Categorizing errors into groups can be helpful in identifying trends but is not sufficient, as categories do not provide granular detail about specific contributing factors.
- RCA applied to analysis of diagnostic errors is a highly effective strategy for identifying contributing factors and developing interventions.
- It is critical to understand the types of interventions that drive quality improvement. Interventions relying solely on remediation and increased effort or vigilance are less effective because they assume that errors occur because of individual failures, whereas modern approaches involve viewing errors as the result of organizational and environmental factors. Successful interventions are those designed to help people do the right thing (eg, follow standard workflow and avoid work-arounds) or prevent them from doing the wrong thing (eg, forcing functions and hard stops).
- It is often human nature to assign blame for an error or mistake to an individual or group, especially by administrative staff and leaders who do not understand imaging workflow. However, blaming individuals involved in diagnostic errors when they had no intent to cause harm is ineffective in decreasing the likelihood of a future event and contributes to an unsafe environment by *(a)* discouraging people from reporting errors, *(b)* creating a stigma around discussing and learning from an error, and *(c)* decreasing the likelihood that investments will be made in fixing the system because the "cause" of the error has already been found in an individual.

It may often seem as if diagnostic errors in radiology occur in a haphazard fashion, particularly to those outside our field. A recent example at one of our institutions highlights this observation: An experienced subspecialty-trained abdominal radiologist misses a lower extremity deep venous thrombosis (DVT) at contrast-enhanced CT of the abdomen and pelvis in an emergency department patient with right upper quadrant pain, who is discharged but returns 2 days later with chest pain from an acute pulmonary embolism. In retrospect, the DVT is clearly visible on the CT images (Fig 1).

The emergency department physician must explain to the patient that the DVT was missed during the prior visit and likely led to the acute pulmonary embolism and does not understand how the radiologist could have missed the DVT. "Isn't that one of the 'don't miss' findings?" he asks his colleagues. The patient is angry that the DVT was missed during the prior examination and voices her frustration to Patient Relations, which passes the complaint to the quality officer for the department of radiology. The case is presented at a hospital quality and safety committee meeting, where the quality officer notes that the radiologist "just didn't see" the DVT and that the abdominal radiologists have been instructed to more thoroughly evaluate all abdominopelvic CT studies for DVTs.

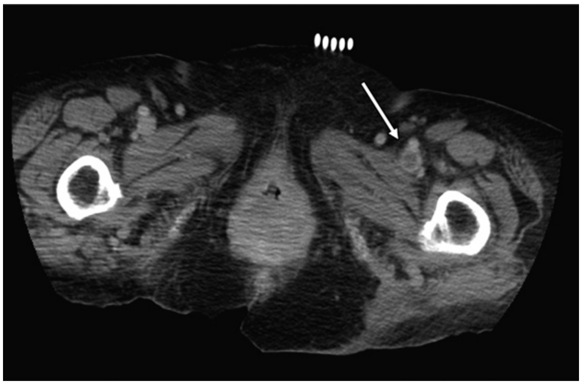


Figure 1. Incidental DVT in an emergency department patient with right upper quadrant pain. Axial contrast-enhanced CT image of the abdomen and pelvis shows an incidental left common femoral DVT (arrow).

In this scenario, an important learning opportunity is missed, and there is no sustainable change in practice that reduces the likelihood that this error will recur. A root cause analysis of the event would reveal a series of systematic factors and cognitive biases that served as latent conditions leading to this error, acting as failures of multiple defenses (like layers of Swiss cheese) aligned in a way to eventually impact the patient (Fig 2) (9).

The radiologist was double-covering hospitals that day because of staffing shortages and had received a telephone call from the emergency department physician asking for a preliminary interpretation for this patient. The radiologist told the emergency department physician that he did not see an abnormality that would account for the patient's right upper quadrant pain, but the telephone call interrupted his search pattern, and he forgot to look at the vascular structures. He used a prefilled template for his report that made it seem as if he had already looked at the vascular structures. Moreover, the indication of "right upper quadrant pain" likely contributed to framing bias, in which his search pattern was influenced by the history and he spent more time looking at the liver and biliary system. Finally, the DVT was visible only on the last few sections of the abdominopelvic CT study, a systematic cause of perceptual error called edge of the film error.

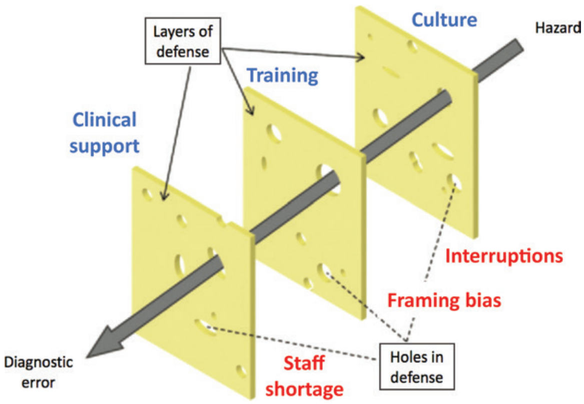


Figure 2. Swiss cheese model of safety. Each slice of Swiss cheese represents a layer of defenses, barriers, and safeguards (9). Holes in each layer represent either latent conditions or active failures that predispose to adverse events. Most hazards are stopped by one of the defenses, but occasionally a hazard passes through all the layers and results in a diagnostic error that negatively impacts patient care. (Adapted and reprinted, with permission, from reference 10.)

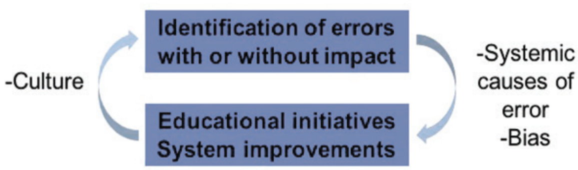


Figure 3. Diagram shows the essential elements of a comprehensive process to identify and learn from diagnostic errors.

One of the primary goals of this article is to emphasize that diagnostic problem solving in radiology is not a mysterious black box and diagnostic errors are not random occurrences. Rather, diagnostic errors are predictable events with readily identifiable contributing factors, many of which are driven by how we think (eg, cognitive biases or errors) or related to the external environment (eg, systematic factors). These contributing factors lead to both perceptual and interpretive errors. More important, identifying contributing factors is one of the keys to developing interventions that reduce or mitigate diagnostic errors.

Developing a comprehensive process to identify diagnostic errors, analyze them to discover contributing factors and biases, and develop interventions based on the contributing factors is fundamental to learning from diagnostic error (Fig 3). Coupled with effective peer learning practices, supportive leadership, and a culture of quality, this process can unquestionably result in fewer diagnostic errors, improved patient outcomes, and increased satisfaction for all stakeholders. In this article, we provide the foundational elements for implementing this type of process at your practice, with examples to help radiologists and practice leaders achieve meaningful practice improvement.

Why Errors Occur

Dual Process Theory and Cognitive Biases

When asked if they remember driving to work in the morning, most people do not specifically recall the event but invariably note that somehow, they arrived unharmed. This is a fitting example of the dual process theory, which describes two distinct cognitive pathways for problem solving in situations where information is incomplete and time is limited (11). This model has important practical applications for understanding the many factors that contribute to diagnostic error and may be used as a template for understanding cognitive biases, as well as a platform for research into methods to reduce these biases.

The model states that there are various approaches to problem solving along a spectrum, with unconscious intuitive approaches at one end and deliberate analytical approaches at the other. The intuitive approach, also known as type 1 or fast thinking, can be characterized as a form of pattern recognition leading to an automatic and immediate diagnosis using heuristics (eg, mental shortcuts) (4,11–15). The deliberate approach, also known as type 2 or slow thinking, occurs when an abnormal pattern or finding is identified but not immediately recognized, requiring deliberate reasoning and problem solving. Underlying both cognitive pathways is the cognitive miser function, which states that there is a tendency to default to a state that consumes fewer cognitive resources (ie, type 1 or fast thinking).

Type 1 thinking depends on mental heuristics and is prone to error caused by various inherent cognitive biases, which are systematic errors in reasoning or judgment that result from failed heuristics and can lead to both perceptual and interpretive errors (Table 1) (15). Cognitive biases have been estimated to account for approximately 75% of diagnostic errors in medicine (16). It is likely that cognitive biases also account for a significant number of diagnostic errors in radiology.

There are numerous examples of how failures in type 1 thinking lead to errors in radiology practice. For example, consider the abdominopelvic CT study of an inpatient with a left ventricular assist device (LVAD) and recent drop in hemoglobin level (Fig 4a). Compared with the prior examination, there is increased perigastric and intra-abdominal hemorrhage. The patient subsequently goes to interventional radiology for embolization of a bleeding gastroepiploic artery.

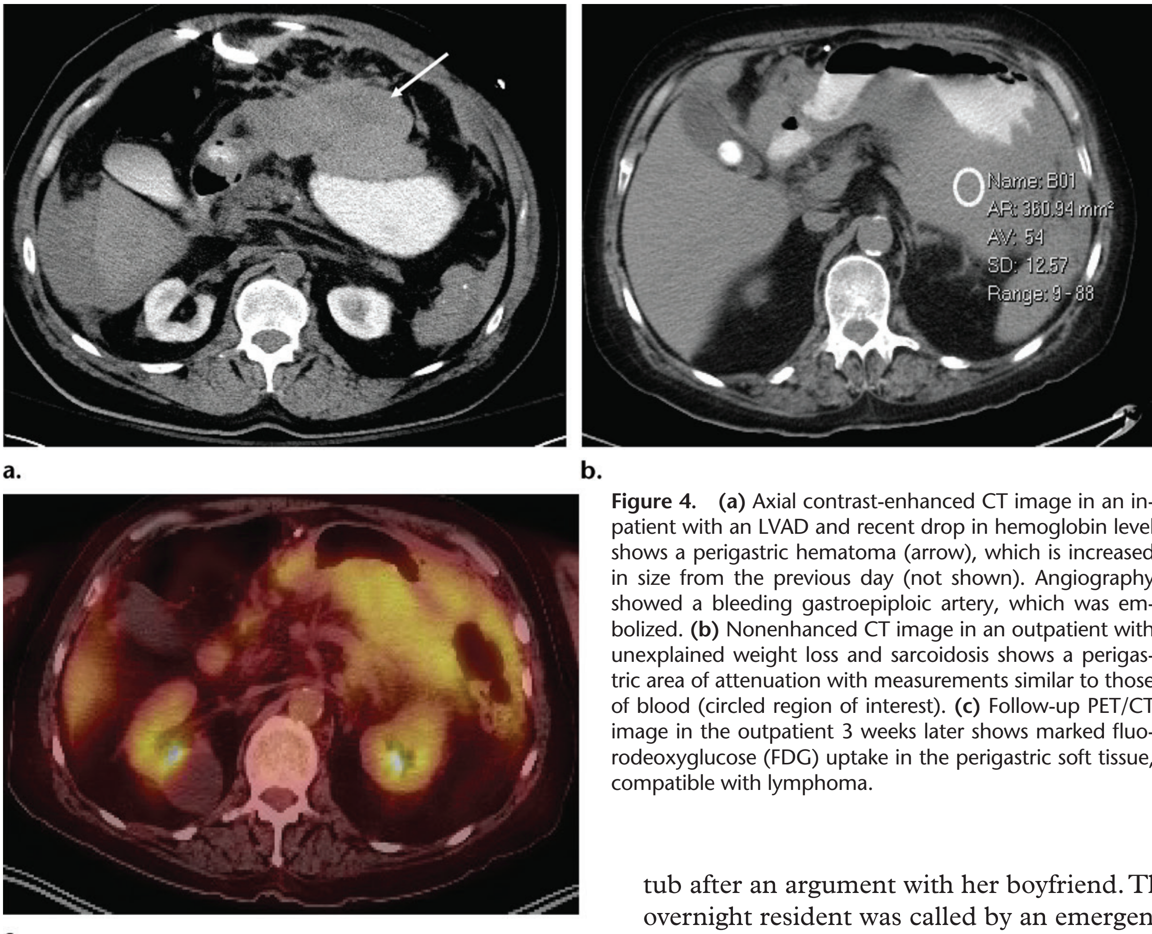
Later that same day, the radiologist who interpreted the inpatient abdominopelvic CT

Table 1: Types of Cognitive Bias with Suggested Interventions

Type of Bias	Definition	Suggested Interventions
Alliterative bias	Influence that one radiologist's judgment can exert on the diagnostic thinking of another radiologist	Consider reviewing prior radiologist reports after rendering an interpretation, so as not to be influence by the prior radiologist's interpretation
Anchoring bias	Undue influence that an initial impression has on evaluation of subsequently collected information	Carefully assess all imaging findings before settling on a diagnosis and objectively consider alternate hypotheses even when confident of a certain diagnosis
Attribution bias	When specific characteristics are attributed to a person or thing simply because it belongs to a certain class	Reviewing imaging studies without knowing the clinical indication or patient demographics Structured report templates can help focus attention on known blind spots to identify uncommon manifestations of diseases
Availability bias	Tendency for diagnostic assessments to be unduly influenced by easily recalled experiences	Reference sources of information beyond one's personal experience, including relevant peer-reviewed publications and second opinions from colleagues
Blind spot bias	When radiologists have a heightened awareness of commonly missed or misinterpreted findings, which may lead to overcalling known types of errors	Metacognition or increased awareness of the tendency to overcall known types of errors
Framing bias	Tendency to be influenced by how a question is asked or how a problem is presented	Initially review the imaging study without knowing the clinical indication or reason for examination, so as to avoid any potential influence from the clinical indication Seek out a more thorough clinical history from the electronic medical record or directly from the ordering provider, given that the indications provided in imaging orders are often incomplete and occasionally spurious
Hindsight bias	Tendency to overestimate the predictability of an event after the event is known	Promoting awareness and a culture of reporting and inquiry that emphasizes why an error was made, rather than who made it
Regret bias	Overestimating the likelihood of a particular disease owing to the undesirability of an adverse outcome from failure to diagnose that disease	Development and use of evidence-based appropriateness criteria and standardized reporting systems to objectively state the probability of certain disease processes based on the presence of an imaging finding, and thus make more unbiased recommendations about whether additional testing is warranted
Satisfaction of search bias	When the visual search pattern is discontinued after identification of an abnormality that can explain the patient's symptom and the interpreting radiologist is satisfied that the diagnosis has been determined	Adopting a systematic approach to image interpretation with report templates designed as checklists, identifying "do not miss" diagnoses Being mindful of known combinations of injuries Promoting awareness so that trainees and staff know to be more vigilant in their search after identifying an initial finding
Scout neglect bias	When radiologists do not expect to find anything meaningful on scout images, which can lead to important diagnoses being missed	Routinely review scout images and include a "scout views" field in the report template

Source.—Reference 15.

study also interprets the abdominopelvic CT study of an outpatient with unexplained weight loss and sarcoidosis (Fig 4b). He notes a new perigastric hematoma extending into the left abdomen and calls the ordering provider to say he is concerned that the patient has new intra-abdominal hemorrhage and recommends CT angiography to evaluate for active vascular extravasation. Several weeks later, the patient undergoes PET/CT, which demonstrates diffusely increased uptake in the perigastric "hematoma," which turns out to be lymphoma rather than hematoma. This is an example of availability bias, which refers to the tendency for diagnostic assessments to be unduly influenced by easily recalled experiences (15).



a. b. c.

Figure 4. **(a)** Axial contrast-enhanced CT image in an inpatient with an LVAD and recent drop in hemoglobin level shows a perigastric hematoma (arrow), which is increased in size from the previous day (not shown). Angiography showed a bleeding gastroepiploic artery, which was embolized. **(b)** Nonenhanced CT image in an outpatient with unexplained weight loss and sarcoidosis shows a perigastric area of attenuation with measurements similar to those of blood (circled region of interest). **(c)** Follow-up PET/CT image in the outpatient 3 weeks later shows marked fluorodeoxyglucose (FDG) uptake in the perigastric soft tissue, compatible with lymphoma.

Systematic Causes of Error

There is another major category of factors that can result in diagnostic error in radiology, generally referred to as systematic factors. Examples include increased workload and understaffing, lack of teamwork, workplace distractions and interruptions, inefficient processes, overly burdensome policies and procedures, technical errors (eg, incorrect protocol, timing of contrast material, or field of view and patient motion), PACS (picture archiving and communication system) and software failure, lack of access to patient information, and various causes of visual and mental fatigue such as long workdays.

While there are numerous examples of how systematic factors contribute to diagnostic error, there are few data showing the impact of these contributing factors, primarily because there is a paucity of methods to accurately measure diagnostic error. Moreover, it is impossible to show that well-designed interventions significantly reduce errors when we cannot accurately measure the frequency of errors at baseline.

Despite these limitations, interventions can and should be implemented to address systematic causes of error. Take for example the case of a 30-year-old woman found lying in the bathtub after an argument with her boyfriend. The overnight resident was called by an emergency department physician to look at the nonenhanced head CT study and issued a preliminary impression of “no acute intracranial abnormality.” The patient’s condition deteriorated 6 hours later, and repeat nonenhanced head CT showed diffuse subarachnoid hemorrhage. The final report on the initial head CT study issued the following morning by the neuroradiology attending physician noted a significant discrepancy and described diffuse subarachnoid hemorrhage, which had been missed by the on-call resident.

It turns out that overnight residents covered two hospitals with separate PACS and separate workstations in the same room. While the resident was looking at an examination from hospital 1, the emergency department physician called, and the resident rolled across the room to look at the emergency patient’s images on the separate PACS workstation for hospital 2. Unfortunately, the default “hanging” protocols for the two hospitals were different in that new studies loaded on the right monitor for hospital 1 and the left monitor for hospital 2. The resident reviewed the patient’s old study, which was normal, and never looked at the new study with diffuse subarachnoid hemorrhage. This is a classic example of a systematic cause of error, for which an effective intervention is to have the same default hanging protocols for the two different PACS.

Education and Training

Another contributor to diagnostic error is inherent in the apprentice-based training approach used for radiology residents and fellows. Although this is not often described in the literature as a cause of error, it has been observed by the authors that case conferences, review books, educational articles, and continuing medical education (CME) activities are biased in showing more classic examples of various pathologic conditions, many of which have pathognomonic features that allow residents and fellows to arrive at the correct diagnosis or at least develop a narrow differential diagnosis. This is coupled with a variable experience during rotations at hospitals ranging from community hospitals to large academic centers, as well as distinct and disparate educational curricula that are created at the level of the individual training program rather than the national level.

Moreover, there is often no formal education or curriculum regarding diagnostic error. The amount of information available and published on a monthly basis makes it impossible to stay up to date in all manners of radiology practice, leading to the "this is how I was trained" approach passed on from faculty to student, which may differ significantly among members of the same division, who have been shown to disagree with each other and even with their own interpretations 25%–30% of the time (17).

Systematic Approach to Learning from Diagnostic Errors

In the following sections, we provide a systematic approach to identifying, analyzing, and learning from diagnostic errors that readers can employ at their own institutions. While there are several high-quality publications providing in-depth overviews of various types of diagnostic errors with strategies to reduce or mitigate them, we believe that meaningful practice improvement occurs locally at the institutional level, with staff and leaders working together to create the infrastructure, policies, processes, and culture necessary to learn from errors and achieve improved performance (4,6,9,12,14,18–45).

Methods of Identifying Diagnostic Error

Developing robust methods of identifying cases with diagnostic error is a critical component of the overall process, as you cannot learn from errors that have not been identified. Absence of error identification is one of the limitations of RADPEER, a program in which radiologists participate to satisfy accreditation requirements but often derive no benefit from, because it is designed to identify underperformers rather than uncover contributing factors leading to errors (32,34,40). RADPEER has traditionally been used as a measure of competency among diagnostic radiologists by providing a discrepancy rate that can be used for benchmarking and comparison, as well as to identify outliers.

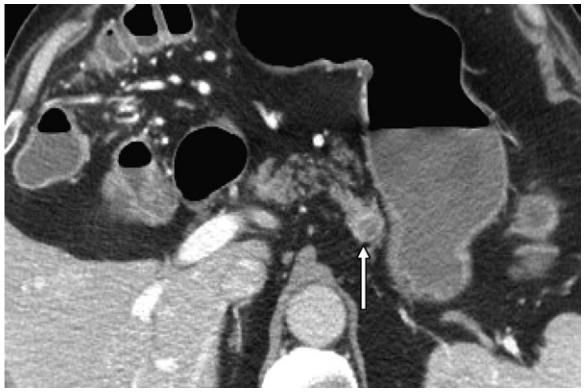


Figure 5. Axial CT image shows an incidental enhancing pancreatic neoplasm (arrow), which was missed during initial interpretation and identified at follow-up by a different radiologist. The lesion represents a neuroendocrine tumor.

The cases identified through RADPEER can be used to learn from diagnostic error, although one of the major problems with RADPEER is significant underreporting of errors, as well as variability in the method used to score errors. In addition, a significant number of cases must be reviewed to find cases with errors (assuming an average error rate of 3%–5%), and more complex examinations such as multiphasic CT and MRI are skipped because they are significantly more time-consuming to review compared with radiography.

There are several more effective methods of identifying cases with diagnostic error that are not overly time-consuming:

Nonrandom Peer Review

This form of peer review refers to any time a radiologist comes across a case of diagnostic error during routine clinical work. For example, a radiologist is reviewing a nonenhanced abdominopelvic CT study to evaluate for renal stones and notices a pancreatic lesion, which was missed by the previous interpreting radiologist on a recent prior study (Fig 5). Creating formal policies and processes that both facilitate and encourage radiologists to submit these types of cases into a nonrandom peer review queue for analysis and group discussion has great potential for identifying valuable cases of diagnostic error.

In our study that compared random and nonrandom peer review processes at a single academic center within the same cohort of abdominal radiologists, we found significantly more cases of diagnostic error using the nonrandom process compared with the traditional random process (46). Moreover, we were able to identify trends

Figure 6. Axial contrast-enhanced CT image, obtained in a patient with abdominal pain in the emergency department, shows small peritoneal implants (arrows). The interpreting radiologist was subspecialty trained in musculoskeletal imaging and interpreted abdominopelvic CT studies only when on call over the weekend. That radiologist correctly identified a pancreatic mass (not shown) but did not report the peritoneal implants.

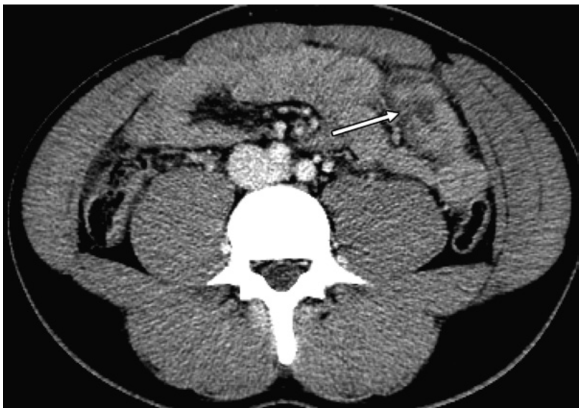


Figure 7. Axial contrast-enhanced CT image in an emergency department patient with trauma. The interpreting radiologist did not see the full-thickness laceration involving the jejunum in the left abdomen (arrow).

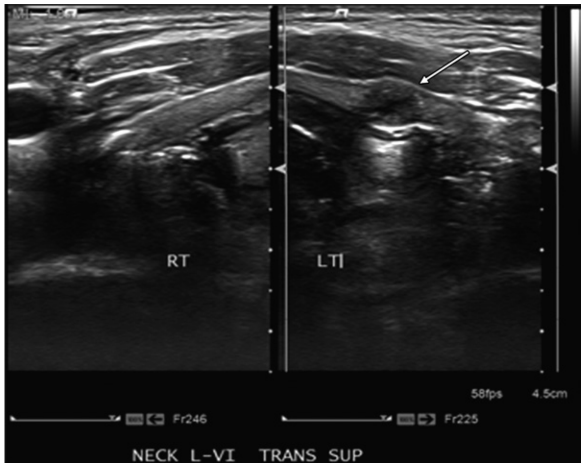


Figure 8. Misdiagnosed recurrent thyroid cancer in a 24-year-old man who had differentiated papillary thyroid carcinoma. US image 2 years after thyroidectomy shows a focal hypoechoic lesion in the left strap muscle (arrow), which was reported by the interpreting radiologist as "concerning for recurrent disease." Fine-needle aspiration demonstrated myxoid acellular debris with no papillary carcinoma seen. (Reprinted, with permission, from reference 47.)

and implement educational and systematic improvements to address contributing factors. One of the factors that made the nonrandom process successful in identifying cases with error was the arrangement of peer learning conferences (PLCs) using best practices to minimize bias and create a nonpunitive environment (32,34).

Tumor Boards and Multidisciplinary Conferences

These conferences are a form of double reading in which another radiologist, often more experienced and with additional clinical information not available to the original interpreting radiologist, essentially reinterprets imaging studies in an interdisciplinary setting with the goals of refining diagnosis and tailoring treatment/management. For example, during a hepatobiliary tumor board conference, a subspecialty-trained abdominal imaging radiologist identifies peritoneal implants related to pancreatic cancer (Fig 6) that were missed by the original interpreting radiologist, who was a musculoskeletal imaging–trained radiologist reading abdominopelvic CT studies over the weekend while on call.

The tumor board radiologist knows from experience that peritoneal implants are often subtle and one of the most frequent misses in the tumor board setting, so he has developed a specialized search pattern and added a field to the abdominopelvic CT report template specifically addressing the peritoneal surface to ensure adequate evaluation for peritoneal implants, particularly in patients with known abdominal malignancies.

Radiologic-Surgical and Radiologic-Pathologic Correlation

This approach has the advantage of reference to a standard (pathologic analysis or surgery) that allows identification of errors using a process that is more objective than peer review. In a retrospective review of abdominopelvic CT studies of patients with a diagnosis of bowel trauma (eg, laceration or perforation) identified during surgery, the authors found several cases with diagnostic errors including missed bowel laceration (Fig 7), bowel wall thickening, hemorrhage surrounding injured bowel, and active vascular extravasation. In a separate retrospective review of patients with differentiated papillary thyroid cancer who underwent thyroidectomy and radioiodine ablation, the authors found several cases of postsurgical scar and normal lymph nodes misdiagnosed as recurrent thyroid cancer (Fig 8) (47).

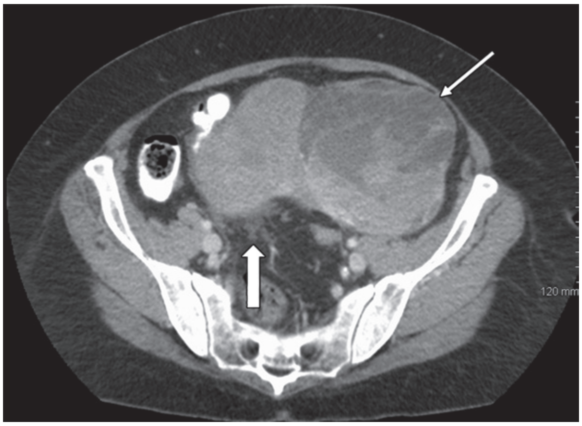


Figure 9. Axial contrast-enhanced image from abdominopelvic CT performed at an outside hospital. The interpreting radiologist identified a mass (thin arrow) in the left pelvis but incorrectly attributed it to an exophytic fibroid. The imaging appearance is not characteristic of a fibroid, and the interpreting radiologist missed small implants in the right dependent pelvis (thick arrow). The patient was eventually referred to gynecology-oncology at an academic hospital; the findings proved to represent ovarian cancer.

Figure 10. Coronal contrast-enhanced image (bone window) from abdominopelvic CT performed in an emergency department patient with left lower quadrant pain. He also had a history of prostate cancer. In the report, the interpreting radiologist stated that "metastatic lesions [arrow] in the proximal femurs are suspicious for impending pathologic fractures." The patient was imaged on a Friday, and orthopedic surgery performed bilateral hip replacement over the weekend, while the patient's oncologist was out of town. When the oncologist returned the following week, he contacted the radiology department to say that the patient's disease had been in remission for years and he should not have undergone hip replacement. Pathologic specimens obtained during the hip replacement did not show residual malignancy.

A major limitation of this approach is the need for resources in terms of staff to review cases and compare imaging results with those of surgery or pathologic analysis, as well as the IT (information technology) infrastructure and software necessary to search the various EMR (electronic medical record) databases. A significant opportunity exists for software vendors to incorporate features into PACS and RIS (radiology information system) software that automate the process of tracking radiologic-surgical and radiologic-pathologic correlation for a variety of diseases that are frequently imaged and subsequently go to biopsy or surgery. Radiologic-pathologic correlation will likely play a significant role in quality and outcome measure development for diagnostic radiologists in the near future.

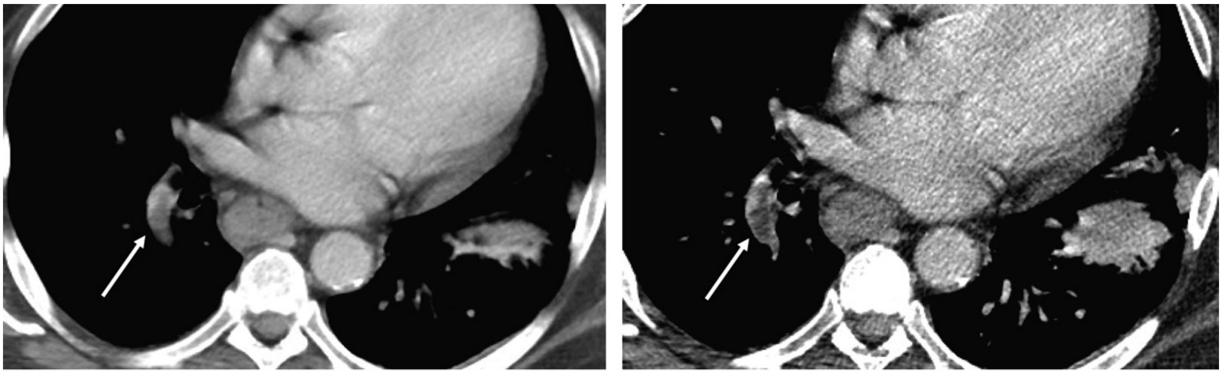
Reinterpretation of Outside Studies

This is another variation of double reading in which an imaging study performed outside of your institution is submitted for reinterpretation (Fig 9). This practice is becoming more common, as significant discrepancies are documented during reinterpretation of imaging studies, particularly when imaging is originally performed in the community and patients are referred to academic centers for specialized care (43,48–50). In our experience, there are similarities in the types of errors across settings and levels of training/specialization such that many radiologists miss the same entities for the same reasons. Therefore, we believe there are significant learning opportunities that can be achieved by identifying and analyzing the errors of radiologists at other practices.

The benefits of requiring formal reinterpretations for outside imaging studies include improved accuracy, a formal report issued and available in the EMR that avoids the communication errors and liability inherent in unofficial "curbside" consultations, and an opportunity to identify and track potentially significant diagnostic errors. At one of our practices, we have added a dedicated field to our outside study report templates called "category," where 1 indicates agreement, 2 indicates a nonurgent but clinically significant change, and 3 indicates an urgent clinically significant change. Reports can then be retrospectively searched to identify and review cases with *2*'s and *3*'s for educational initiatives such as missed case conferences (MCCs) (Fig 9).

Patients and Referring Physicians

Both patients and referring physicians can be valuable resources for identifying cases with diagnostic error. Many patients are highly involved in their care, and with increasing access to medical



a. b.

Figure 11. Missed pulmonary embolus in a 44-year-old man with Crohn disease who underwent contrast-enhanced CT in the emergency department for abdominal pain and concern for obstruction. Axial images of 5-mm **(a)** and 1.25-mm **(b)** section thickness show an incidental pulmonary embolus in the right lower lobe (arrow), which is more apparent on the 1.25-mm-thick section.

records and radiology reports, can identify errors in radiology reports if given the opportunity. Similarly, referring physicians often have more information regarding patients and can identify errors in radiology reports (Fig 10).

One major barrier is that many patients and referring physicians do not have an easy way to pass on information to interpreting radiologists, particularly if the radiologist and referring physician are not part of the same health system. One potential strategy to promote patient- and referring physician–reported errors is to create a hyperlink or QR (quick response) code in radiology reports that allows reporting of errors or discrepancies in the reports. Another strategy is to include an e-mail address in the report. However, the added steps of logging into an e-mail system and composing an e-mail message could be a barrier for people reporting errors.

Another related barrier is lack of a nonpunitive culture within the department/institution and formal peer review processes. Referring physicians are more likely to notify a radiologist of a diagnostic error if they know the process by which the case should be handled and there is a nonpunitive culture.

Analysis of Errors

The next key step in the process is analysis of identified errors to elucidate contributing factors. A fundamental attribute of any successful quality improvement activity is that interventions are designed to address factors that directly or indirectly contribute to failures, hence the inclusion of analysis as an essential component of learning from errors. Categorizing errors into groups can be helpful in identifying trends but is not sufficient, as categories do not provide granular detail about specific contributing factors. For example, determining that 20% of diagnostic errors are related to technical factors such as wrong protocol, incorrect field of view, or poor timing of contrast material does not clearly identify targets for improvement.

More important to the process is identifying contributing factors specific to an error. For example, consider the case of a 44-year-old man with Crohn disease undergoing contrast-enhanced abdominopelvic CT in the emergency department for abdominal pain and concern for obstruction, in which an incidental right lower lobe pulmonary embolus is missed (Fig 11). Analysis of this error reveals that the radiologist does not routinely check the lower lobe pulmonary arteries for pulmonary embolus and that the embolus was poorly visible on a single image from a soft-tissue reconstruction study with 5-mm-thick sections. Interventions specific to this error include adding a dedicated field to the abdominopelvic CT report template for "lower lobe pulmonary arteries" and generating 1.25-mm-thick sections for all abdominopelvic CT studies, which makes the pulmonary embolus more conspicuous.

Root cause analysis (RCA) is a method of *(a)* identifying factors that underlie variation in performance or predispose an event toward undesired outcomes and *(b)* allows development of effective strategies to decrease the likelihood of similar adverse events occurring in the future (42). RCA applied to analysis of diagnostic errors is a highly effective strategy for identifying contributing factors and developing interventions. RCA has three components: *(a)* consideration and identification of factors most directly associated with the event; *(b)* analysis and prioritization of these factors to plan the introduction of effective strategies to prevent them from recurring; and *(c)* introduction, management, and—when possible—dissemination of effective countermeasures (42). During the analysis of contributing factors, it is helpful to use an Ishikawa diagram or causal tree (Fig 12) to develop a comprehensive

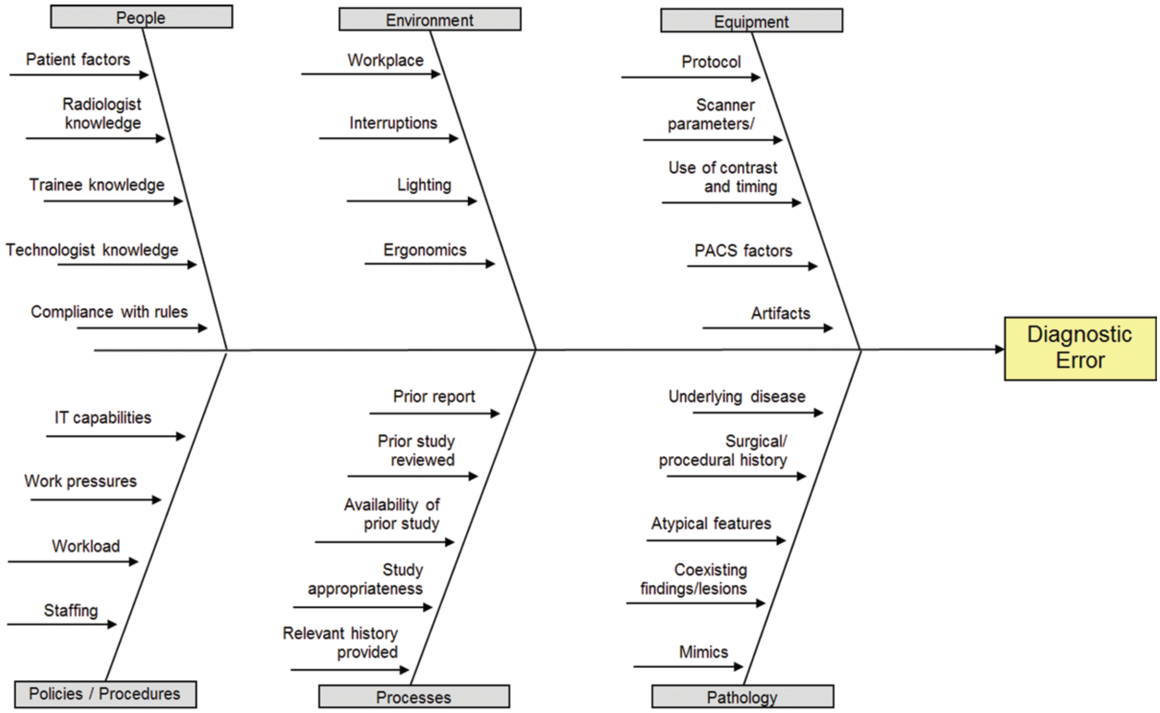


Figure 12. Ishikawa or causal diagram. The interpretive error causal tree is arranged according to six major categories (gray), and contributing factors are assessed to determine if they contributed to the diagnostic error undergoing analysis. *IT* = information technology.

list, given that many diagnostic errors have more than one contributing factor (42).

An exceptional example of how to use RCA to analyze diagnostic errors and develop interventions was published by Siewert et al (33), in which the authors performed RCA on 250 diagnostic errors involving missed lesions at abdominal oncologic CT and describe a series of interventions to reduce the likelihood of these errors recurring. We have encountered many of the same types of errors described by the authors, illustrating the systematic nature of many diagnostic errors (Fig 13).

Table 2 provides examples of contributing factors derived from RCA of errors involving missed peritoneal implants at both CT and MRI (Figs 14, 15).

In terms of categorization of "misses," we have found that grouping similar errors together according to the organ and/or disease process (eg, missed liver metastasis) is helpful in identifying trends. In our study that compared random versus nonrandom peer review methods for identifying errors in an abdominal imaging section (46), we found that the most frequent errors occurred in oncology patients and included missed liver metastases (11%), missed peritoneal implants (9%), and missed osseous metastases (7%). This type of information can be incorporated into a Pareto chart, allowing limited resources to be focused on the most frequent and/or impactful errors.

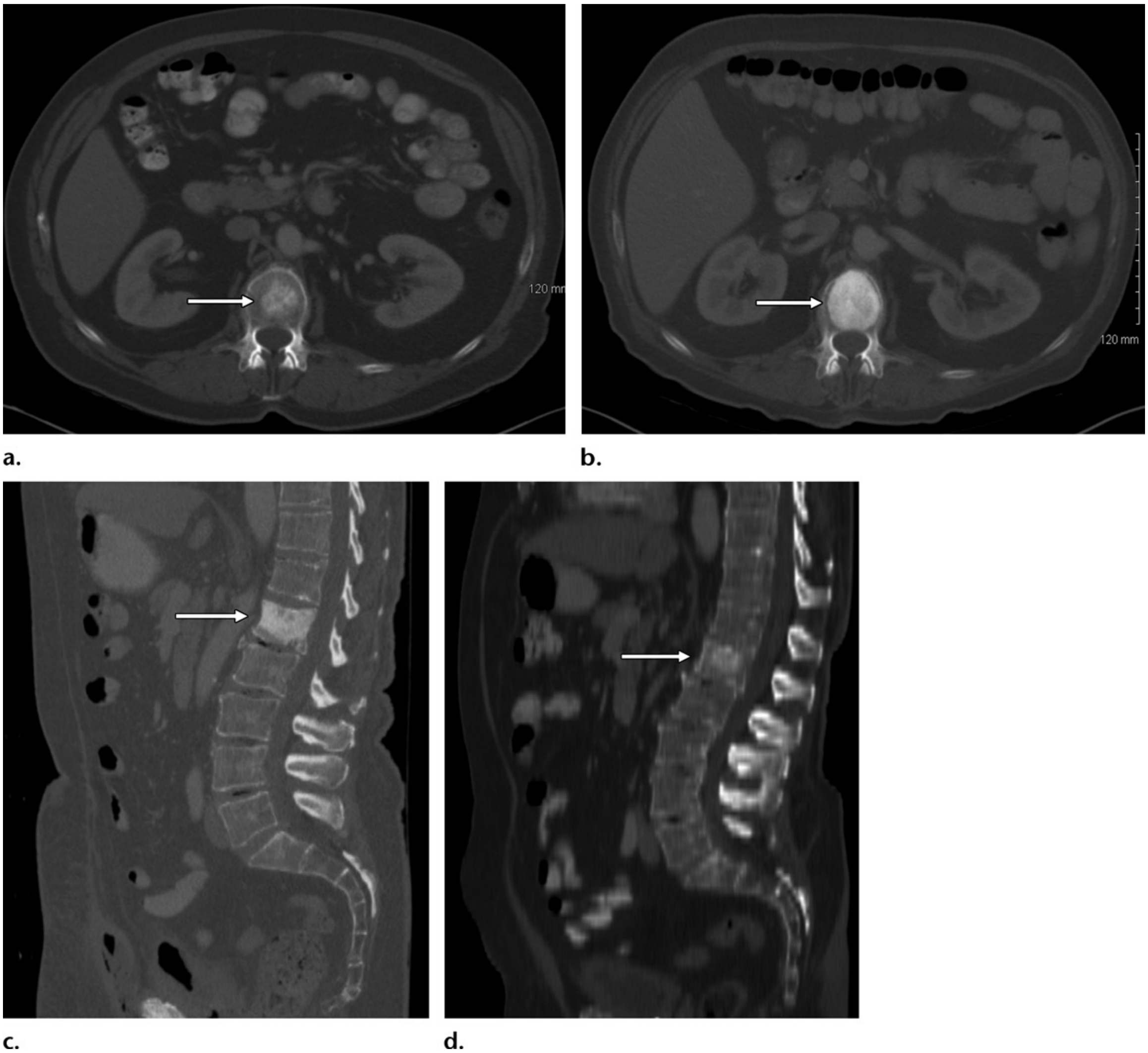
As a result of this approach, we determined that many missed liver and osseous metastases were subtle on 5-mm-thick axial sections and better visualized on 1.25-mm-thick axial sections; therefore, 1.25-mm-thick axial reconstructions were added to all abdominal CT examinations (Fig 16). To address missed peritoneal implants, a dedicated field called "peritoneal surface" was added to all abdominopelvic CT report templates.

Educational Interventions

The value of educational interventions related to diagnostic error cannot be overstated. First, effective educational initiatives can increase the number of cases identified by radiologists, as participants begin to see the value of the process. When participants use the information from these educational activities to improve their performance and avoid making errors because of cases discussed during error-related case conferences, you gain their buy-in. Educational efforts are also key to establishing a culture of quality and inquiry, provided that case conferences are nonpunitive and focus on why errors occur rather than who made the error.

Finally, focused MCCs have been shown to significantly decrease the frequency of common and important errors. In a study that evaluated the impact of focused MCCs, the authors found a 66% decrease in errors related to interpretation of musculoskeletal radiographs obtained in the emergency department setting (45). After the

Figure 13. Missed metastasis in a 65-year-old man with prostate cancer and rising prostate-specific antigen (PSA) level. **(a)** Axial 5-mm-thick CT section shows a subtle sclerotic lesion that appears to be at an end plate (arrow). It was interpreted as degenerative change. **(b, c)** Follow-up axial **(b)** and sagittal **(c)** CT images approximately 1 year later show that the lesion (arrow) has grown and represents an osseous metastasis from prostate cancer rather than degenerative change. **(d)** Sagittal image reconstructed later from the original 5-mm-thick axial sections shows that the lesion (arrow) could have been diagnosed as a metastasis during the original examination; however, sagittal reconstructions were not routinely performed at that time.



focused MCCs, residents had significantly fewer errors related to interpretation of musculoskeletal radiographs compared with board-certified fellows, who did not attend the MCCs.

When discussing cases during MCCs, efforts should be made to go beyond “show-and-tell” and include discussion of contributing factors with possible interventions. Moreover, faculty or attending physician errors should be presented at the department or division/section level, whereas resident and fellow errors should be presented in a trainee-only setting. Presenting resident and fellow errors at departmental quality conferences is perceived as punitive regardless of how these are arranged. Moderators and presenters should focus on providing information about cases and encouraging discussion between participants that revolves around what can be learned from each case and what changes may serve as meaningful interventions. We have also found that starting MCCs with our personal “misses” helps create a nonpunitive environment with open discussion.

Resident and fellow MCCs are almost universally perceived as a high-yield educational activity and from our perspective should be a core component of residency training program curricula. These conferences can serve several purposes: addressing deficiencies in the predefined educational curriculum, reducing variability and improving accuracy in preliminary interpretations issued while on call, incorporating evidence-based recommendations and guidelines, and highlighting some of the limitations of various imaging techniques that lead to variability in diagnoses and recommendations.

RadioGraphics

Table 2: Factors Contributing to Missed Peritoneal Implants at CT and MRI

CT	
	Wrong protocol (pancreatic cancer staging performed only as CT of abdomen with implants in the pelvis)
	Excessive workload due to staff shortages
	Peritoneal implants uncommon for type of cancer (transitional cell carcinoma)
	Satisfaction of search
	Lack of experience (HCC) (Fig 14)
MRI	
	Radiologist reliance on DWI for cancers that do not typically restrict diffusion (HCC) (Fig 15)
	Radiologist did not review diffusion-weighted images for cancers that restrict diffusion
	Patient motion
	Lack of experience

Note.—DWI = diffusion-weighted imaging, HCC = hepatocellular carcinoma.

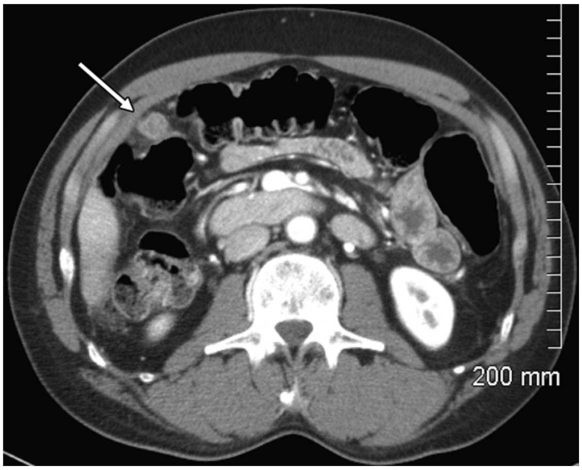


Figure 14. Missed peritoneal implants in a patient with a rising α-fetoprotein level after biopsy and percutaneous ablation for hepatocellular carcinoma (HCC). Axial contrast-enhanced CT image shows a peritoneal implant in the omentum (arrow), which was missed by the original interpreting radiologist. The interventional radiologist who performed the procedure noticed these implants and reviewed the case with the interpreting radiologist, who noted that he didn't realize that HCC could spread into the peritoneal space.

For example, we identified a need to review examples of free air and pneumatosis for junior-level residents beginning to take independent call (Fig 17). Other MCCs have focused on ovarian torsion, appendicitis and rupture, and acute cholecystitis. MCCs can be resident led with support from faculty or moderated by a faculty member who is experienced in discussing and analyzing errors in an open nonpunitive manner. Residents and fellows can help significantly in identifying errors to support the process of learning from diagnostic errors.

Another important activity is regular PLCs within divisions and sections. A key difference between MCCs and PLCs is that MCCs are designed to present cases with diagnostic errors to an audience with information about why the error occurred and what can be done to avoid or mitigate the error in the future. PLCs are an open forum to learn from error cases where the participants discuss and debate the contributing factors and possible interventions. A typical MCC can include 20–30 cases with teaching points and discussion, whereas a PLC typically involves in-depth review of five to 10 cases with extensive discussion and chart review. By their nature, MCCs are more of a didactic activity.

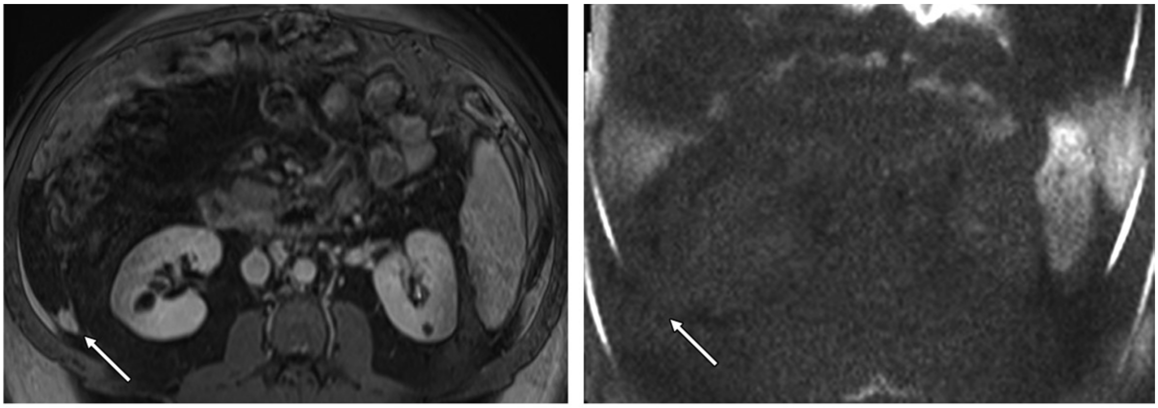
We have incorporated best practices in the review of cases with diagnostic error by anonymizing cases in the PACS and making these available to members of the division at least 2 weeks before the PLC (32). The information available to the original interpreting radiologist is provided in a separate document, and participants provide an impression anonymously using SurveyMonkey (San Mateo, Calif) before the meeting.

One of the goals of PLCs is to demonstrate the value of identifying and analyzing errors by showing radiologists cases identified through peer review processes to facilitate identification of interventions for practice improvement. During PLCs, each case is reviewed and discussed in a blinded manner, with follow-up imaging, surgery, and pathology results provided when available. We do not attempt to score or grade the severity of errors or determine impact on patient care, as we believe that this does not provide additional value. PLCs at the section level are particularly valuable for discussion of interpretive errors, interobserver variability in interpretations, and system-related errors.

The last form of educational intervention to consider is implementation of a curriculum about diagnostic error. This does not have to be a formal curriculum with goals and objectives, assessments, evaluations, and extensive resources/reading lists. Rather, we recommend starting with 15–20-minute presentations on various aspects of diagnostic error and peer review at departmental quality assurance/improvement meetings, where all radiologists, residents, and fellows have an opportunity to attend. This article and associated references can serve as the basis for this curriculum, supplemented by cases from the local institution illustrating the various types of errors, contributing factors, and proposed interventions.

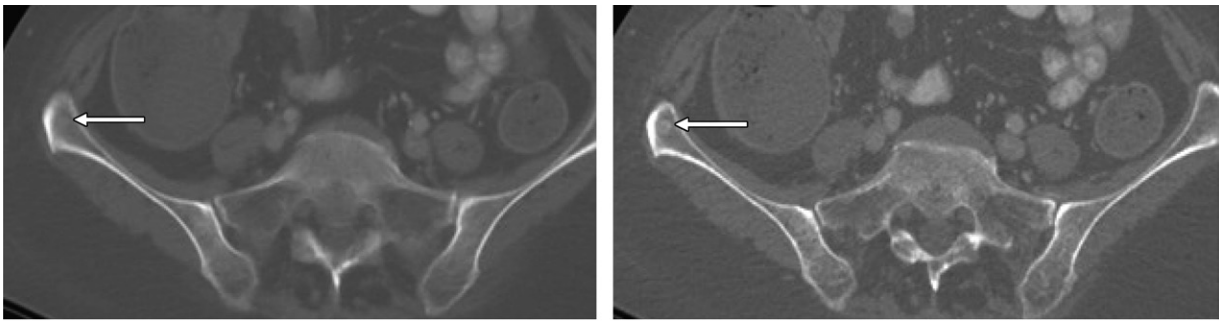
Systematic Interventions

The second major output of a comprehensive process to reduce diagnostic errors is systematic interventions designed to reduce or mitigate con-



a. b.

Figure 15. Missed peritoneal implants in a patient with multifocal HCC and a rising α-fetoprotein level. **(a)** Axial contrast-enhanced T1-weighted image with fat saturation shows a peritoneal implant in the right paracolic gutter (arrow), which was missed by the original interpreting radiologist. A different radiologist reviewing a subsequent imaging study identified the implants, which had grown in size. This radiologist reviewed the case with the radiologist who interpreted the prior imaging study, who noted that he used diffusion-weighted imaging (DWI) to evaluate for peritoneal disease. **(b)** On an axial high *b* value diffusion-weighted image, the multifocal HCC and peritoneal implants do not demonstrate restricted diffusion and are imperceptible (arrow).



a. b.

Figure 16. Axial contrast-enhanced abdominopelvic CT images in a patient with lung cancer show that a small osseous metastasis is imperceptible on a 5-mm-thick section (arrow in **a**) but more conspicuous on a 1.25-mm-thick section (arrow in **b**).

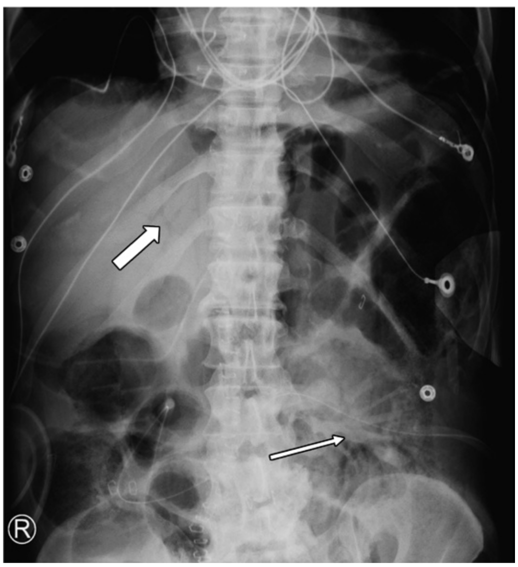


Figure 17. Missed pneumatosis and portal venous gas in a 63-year-old man who experienced cardiac arrest with cardiopulmonary resuscitation after total gastrectomy with esophagojejunostomy and placement of a jejunostomy tube. The indication was "assess for free air." The resident on call did not identify pneumatosis in the left lower quadrant bowel (thin arrow) and portal venous gas overlying the right upper quadrant (thick arrow). The patient died overnight before a final interpretation was issued.

tributing factors identified during error analysis. It is critical to understand the types of interventions that drive quality improvement. Interventions relying solely on remediation and increased effort or vigilance are less effective because they assume that errors occur because of individual failures, whereas modern approaches involve viewing errors as the result of organizational and environmental factors. Successful interventions are those designed to help people do the right thing (eg, follow standard workflow and avoid work-arounds) or prevent them from doing the wrong thing (eg, forcing functions and hard stops) (9). This approach should also be used in developing interventions to reduce diagnostic errors, acknowledging that education and training are complementary and beneficial.

Excessive workload and fatigue are often cited as systematic causes of diagnostic error, serving as

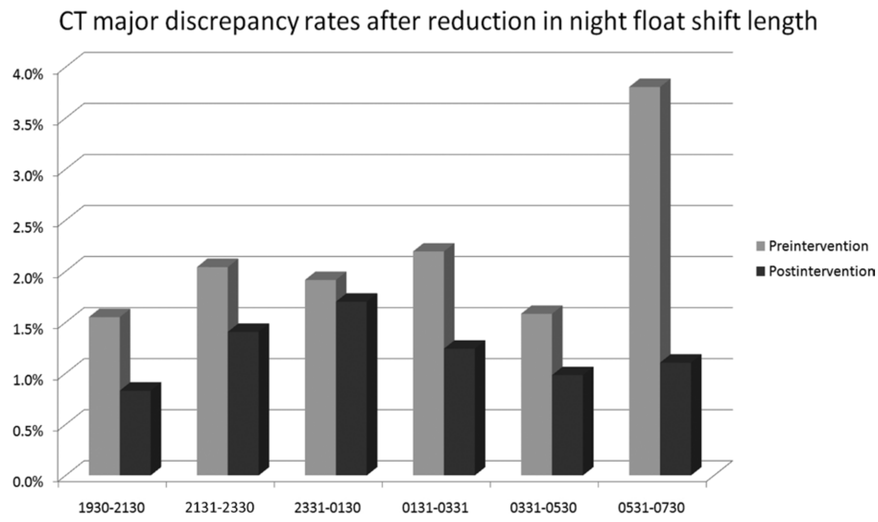


Figure 18. Graph shows a statistically significant increase in major discrepancies for residents working overnight call shifts during the final 2 hours of the shift (light gray) (51). Starting the call shift 2 hours later, effectively shortening the call shift by 2 hours, resulted in a statistically significant decrease in major discrepancies for CT and US, with a peak no longer observed during the last 2 hours (dark gray).

latent conditions that predispose radiologists to errors. There is a paucity of data providing evidence of a direct link between workload and errors for several reasons: *(a)* accurately measuring errors is difficult and subjective without a standard of reference, *(b)* low error rates averaging between 3% and 5% require a large number of cases to be reviewed, and *(c)* powering research studies to find statistically significant differences in error rates between low- and high-volume days in practice requires a substantial number of cases to be reviewed.

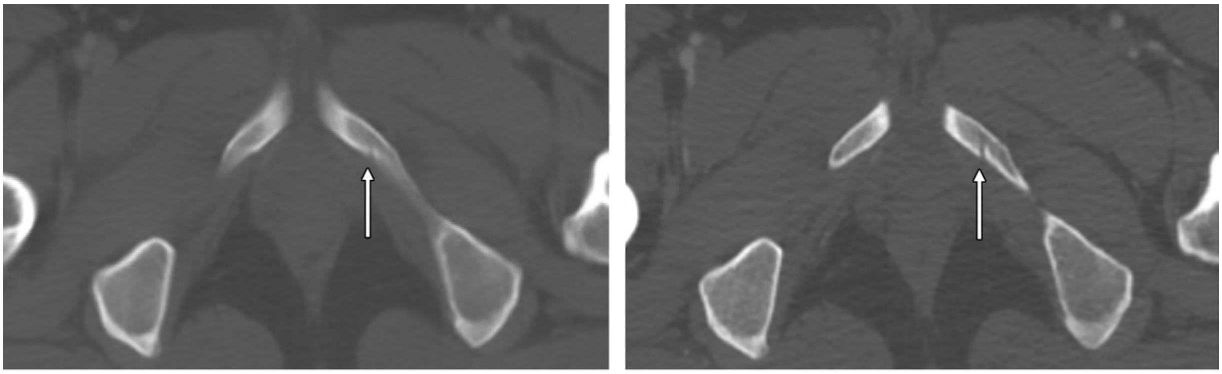
In a study that evaluated determinants of error in interpretation of abdominal CT studies, the authors noted an increase in errors when radiologists interpreted more than 20 CT studies per day, although the increase was not statistically significant (30). A study that evaluated the relationship between error rates among trainees during overnight call shifts and shift length identified a statistically significant increase in error rate during the last 2 hours of 12-hour shifts (51). The intervention in this group was to shorten shift length to 10 hours, resulting in a significant decrease in major discrepancies for CT and US, and the peak during the last 2 hours was no longer observed (Fig 18).

Another systematic intervention described earlier was including 1.25-mm-thick axial sections with all abdominopelvic CT studies regardless of protocol or indication. We observed several types of errors that would benefit from thin-section imaging, including subtle and nondisplaced pelvic fractures missed by residents on call (Fig 19), missed osseous metastases (Fig 16), missed pulmonary emboli (Fig 11), and missed hepatic metastases.

While CT studies are acquired volumetrically and 1.25-mm-thick axial sections can be reconstructed from the original data as needed, depending on the indication and findings on 5-mm-thick sections, we implemented this protocol change for all abdominopelvic CT studies to remove the barriers of having to call the technologist to request 1.25-mm-thick sections and waiting until those reconstructions had been produced and sent to the PACS. This would have represented a significant disruption of workflow; hence, we implemented an intervention that removed these barriers. In addition, we presented the protocol change with a rationale and representative cases to residents and fellows during a dedicated resident MCC, as well as to faculty throughout the department during a departmental quality improvement MCC.

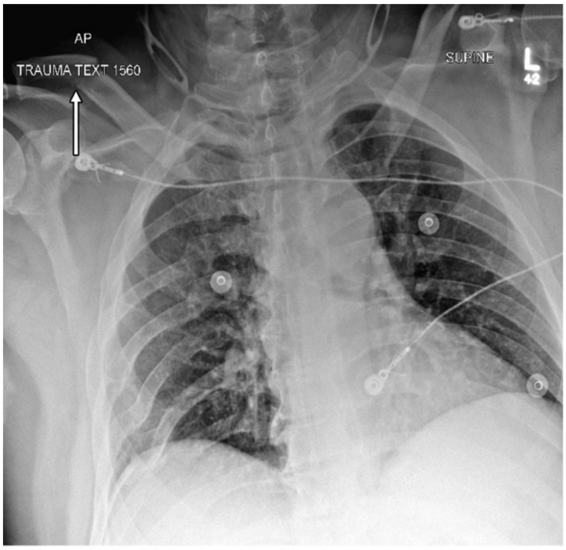
In our analysis of 190 diagnostic errors in abdominal imaging identified through nonrandom peer review (46), we developed several modifications to standard report templates to address specific types of errors (Table 3, Figs 20–22). The intent of these modification fields was to ensure that interpreting radiologists evaluated images that were not routinely viewed in all patients (eg, scout views for CT and diffusion-weighted images for MRI) or addressed known blind spots (eg, peritoneal surface in the setting of intra-abdominal malignancy and lower lobe pulmonary arteries for incidental pulmonary emboli). Leaving the field blank with brackets requires an active statement, which serves as a forcing function to ensure that individuals do not simply skip the field, as would be the case if the field was prepopulated.

In our analysis of errors, we also found several examples of alliterative bias, in which one radiologist's judgment exerts significant influence on the thinking of another radiologist (Fig 23). This can happen when radiologists start their review of an imaging study with the report of another radiologist, and that interpretation influences their own interpretation. There were other errors related to subtle findings in known blind spots missed by the interpreting radiologist but identified by other radiologists during prior imaging

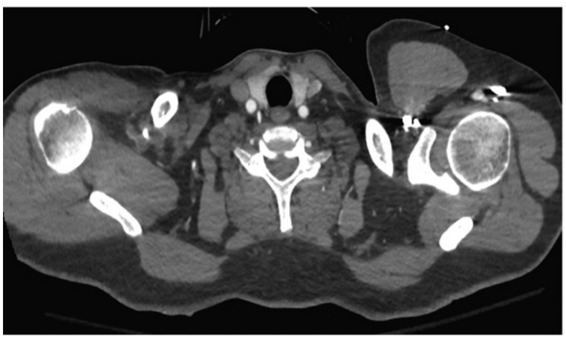


a. b.

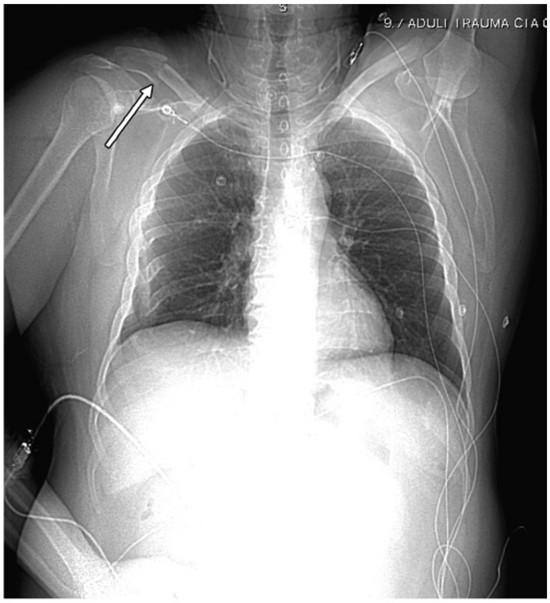
Figure 19. Missed pelvic fracture in a 43-year-old woman after trauma. **(a)** Axial contrast-enhanced CT image (5-mm section thickness) shows a nondisplaced left inferior pubic ramus fracture (arrow), which is barely perceptible and was missed by the resident on call. To confirm the subtle finding, the interpreting radiologist had the technologist reconstruct the examination using 1.25-mm section thickness. **(b)** Axial 1.25-mm-thick CT section shows the fracture more clearly (arrow).



a.



b.



c.

Figure 20. Missed clavicle fracture in a 24-year-old man imaged in the emergency department after trauma. **(a)** Chest radiograph shows the right clavicle fracture (arrow). The finding was missed by the interpreting radiologist, likely because it is obscured by unnecessary text. **(b)** Axial contrast-enhanced chest CT image at the top of the image stack does not include the right clavicle fracture in the field of view. **(c)** Scout view for the abdominopelvic CT study shows the right clavicle fracture (arrow), which was correctly identified by the resident on call.

studies, indicating that the interpreting radiologist did not review the prior radiologist's report. Our intervention to mitigate both of these errors was to instruct radiologists to first review the current and prior imaging studies, then look at the prior radiologist's report. This approach minimizes the influence of alliterative error and allows interpreting radiologists to formulate their own diagnosis or differential diagnosis before reviewing the prior report, but not miss subtle findings described in the prior report.

There are many other interventions described elsewhere (12,33,39). While we have focused on interventions related to radiologists and interpretation workflow, there are errors related to technologists performing imaging studies involving all modalities. Radiology practices should also have processes in place to identify, analyze, and

Table 3: Dedicated Fields Added to Standard Report Templates for CT and MRI as a Systematic Intervention

Added Fields by Imaging Modality*	Figures
CT	
Scout []	20
Lower lobe pulmonary artery []	11
Peritoneal surface []	6, 9, 14, 15
MRI	
Localizer/coronal T2W []	21
DWI []	22

*DWI = diffusion-weighted imaging, T2W = T2-weighted.

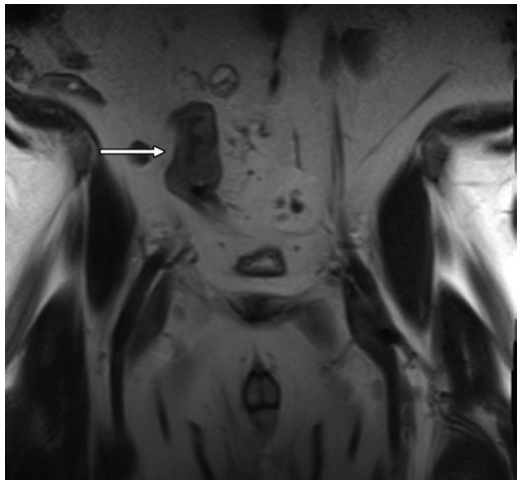


Figure 21. Missed synchronous colon cancer in a patient with known anal cancer. Initial coronal T2-weighted image obtained with a rectal cancer staging protocol shows the known synchronous sigmoid colon cancer (arrow), which was missed by the interpreting radiologist.

learn from technologist errors. For example, the chest radiograph in Figure 20a could be submitted to a technologist review system so that the technologists and supervisors could educate all technologists about the potential consequences of obscuring anatomic structures with text, as well as develop systematic interventions to ensure that these types of errors do not recur.

Open-source Web-based software enabling radiologists to electronically notify both technologists and modality supervisors of imaging errors has been described (52). The robust process developed in that practice also includes random review of imaging studies by other technologists in the department with the goal of continuous quality improvement. These processes are particularly important for sonographers, as the quality of US studies is highly operator dependent.

Culture

Creating a supportive culture is the final essential component of an effective process to identify and learn from diagnostic errors. It is often human nature to assign blame for an error or mistake to an individual or group, especially by administrative staff and leaders who do not understand imaging workflow. However, blaming individuals involved in diagnostic errors when they had no intent to cause harm is ineffective in decreasing the likelihood of a future event and contributes to an unsafe environment by *(a)* discouraging people from reporting errors, *(b)* creating a stigma around discussing and learning from an error, and *(c)* decreasing the likelihood that investments will be made in fixing the system because the "cause" of the error has already been found in an individual (9,53).

Random peer review with scoring of errors is perceived as punitive, undermining participation and degrading a culture of openness and trust (40). Transitioning away from traditional peer review processes such as RADPEER to alternatives that emphasize peer feedback, learning, and improvement has been advocated (34). A culture that supports learning from diagnostic error must also be a "just culture," which balances the focus on systems-level issues with individual accountability (54).

Creating a supportive culture around diagnostic error does not happen by accident. Characteristics of a supportive culture include the following (53,54):

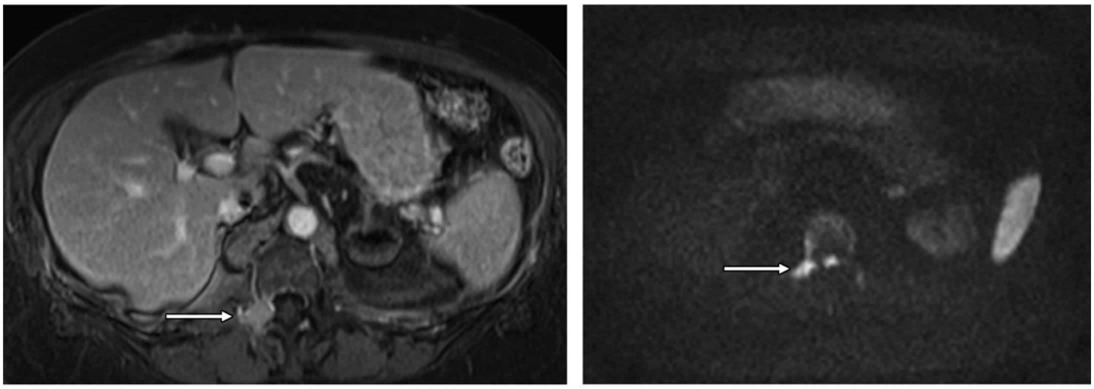
1. Every individual involved in patient care is held accountable and expected to report potential errors.
2. Open communication is vital to allow discussions about errors to occur in a blame-free and transparent fashion with an emphasis on improvement.
3. Discussion of errors focuses on why errors occur and how they can be prevented, rather than who made the error.
4. Cultural change can be achieved through educational activities such as departmental missed case and lessons learned conferences.
5. Learning from diagnostic error is an organizational priority supported by leadership.
6. Care delivery systems are redesigned rather than individuals remediated.

Other Strategies to Reduce Diagnostic Error

Metacognition

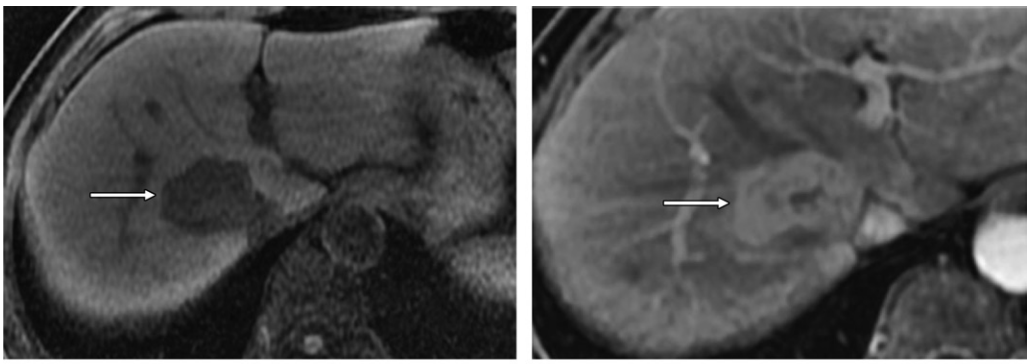
The term *metacognition* refers to "thinking about thinking" or the concept that individuals can consciously evaluate their own thought processes. This multifactorial process involves *(a)* acknowledging

Figure 22. Missed vertebral metastasis in a 58-year-old woman with renal cell carcinoma who underwent contrast-enhanced MRI of the abdomen for surveillance. The interpreting radiologist missed the right L1 pedicle metastasis (arrow), which appears subtle on a postcontrast T1-weighted image with fat saturation **(a)** but is significantly more conspicuous on a high *b* value diffusion-weighted image **(b)**.

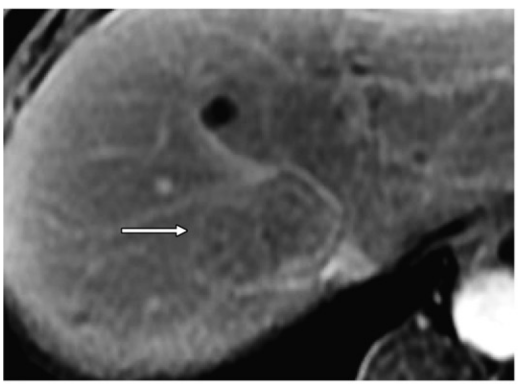


a. b.

Figure 23. HCC in a 67-year-old woman with hepatitis C and a liver mass who underwent MRI of the abdomen at an outside institution. The indication on the outside report was "hepatocellular carcinoma." The outside report impression read "enhancing liver lesion demonstrates enhancement pattern and signal morphology, which is commonly seen with FNH." The study was reinterpreted at our institution, with our impression reading "a 4.0 cm lesion with constellation of findings favoring focal nodular hyperplasia." **(a)** Axial T1-weighted image shows a lesion (arrow) with signal intensity atypical for FNH and most consistent with HCC. **(b)** Contrast-enhanced image shows arterial enhancement of the lesion (arrow), which can be seen in both FNH and HCC. **(c)** On an equilibrium phase image, the lesion shows washout and a pseudocapsule (arrow), which are diagnostic of HCC in the setting of cirrhosis. Biopsy demonstrated HCC. The radiologist reinterpreting the study was influenced by the original radiologist's report, representing an alliterative error.



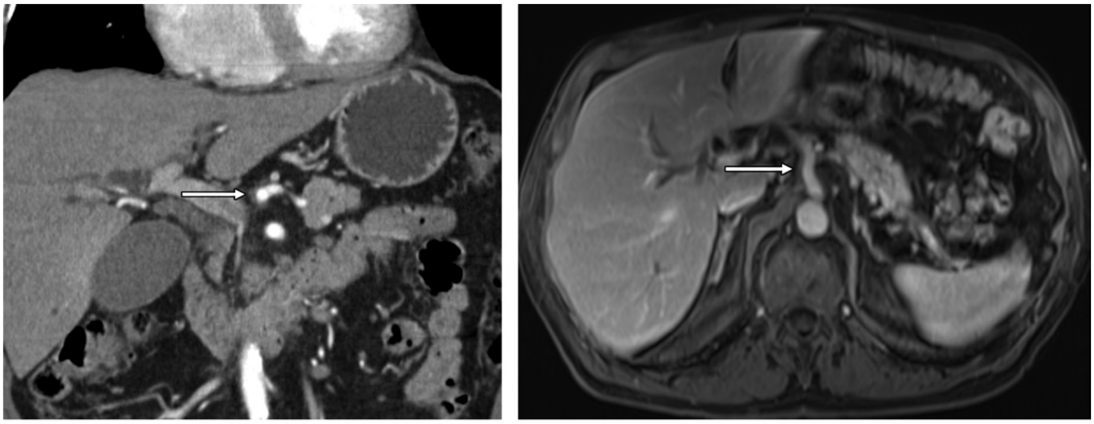
a. b.



c.

the limitations of memory, *(b)* seeking perspective while making decisions, *(c)* being able to self-critique, and *(d)* choosing strategies to prevent cognitive errors (4). This approach has been proposed as a means to reduce or mitigate cognitive biases in medicine, although no systematic method to teach or train radiologists to be more aware of their own heuristics and biases has been described.

Cognitive errors tend to occur when type 1 thinking predominates in interpretation of an imaging study, and the real difficulty with metacognition is in consciously identifying when the automatic process of pattern recognition and mental shortcuts has failed. One clue is when the interpreting radiologist has the sense that "something doesn't quite fit," which is an opportunity to engage type 2 thinking processes such as creating a differential diagnosis (rather than settling on a single diagnosis) or searching the patient's chart for more information. Other strategies to



a. b.

Figure 24. Missed vascular involvement in a 55-year-old woman with pancreatic cancer. Axial CT **(a)** and MR **(b)** images show soft-tissue encasement of the celiac artery (arrow), which was missed at preoperative staging. The patient proceeded to pancreatectomy; within 3 months of surgery, she was found to have progression. Had this finding been identified preoperatively, the case would have been considered unresectable and the patient would have undergone only chemoradiation therapy. Unnecessary surgery in this case negatively impacted the patient's quality of life. It is possible that double reading could have identified this finding before surgery and spared the patient unnecessary surgery.

address cognitive biases have been described (3,11–14,18,28,39,55).

Double Reading

There are numerous studies evaluating the impact and cost of double reading imaging examinations in radiology, with most studies unable to demonstrate improvements in accuracy that justify the cost and resources of double reading (38,56–64). Given that 60%–80% of diagnostic errors are perceptual errors (initially missed but visible in retrospect), we believe that prospective double reading may still be a promising approach to reduce the impact and frequency of diagnostic errors. This approach is standard practice at most academic radiology departments, with attending radiologists overreading studies initially interpreted by residents and fellows. It is interesting to consider that the shift toward 24/7 final interpretations in academic radiology practices without resident preliminary interpretations may have the unintended consequence of increasing perceptual errors, and this is worth studying.

In a retrospective analysis of the clinical importance of changes to radiology reports driven by radiologist-initiated double reading of abdominal CT studies, the authors found that 14% of report changes were clinically important, 3% were major (implying a change in treatment), and 0.3% were critical (demanding immediate action) (38). Allowing the double-reading process to be driven by the interpreting radiologist is a fundamentally different approach that may increase the yield of double reading. Another strategy is application of double reading to specific scenarios—such as trauma or cancer staging—in which the correct initial interpretation may have a significant impact on management and/or treatment (Fig 24).

Deep Learning

A promising approach to reduce diagnostic error is use of deep learning, which is a class of machine learning gaining considerable popularity in radiology (65). Deep learning algorithms can be applied to images to perform pattern recognition, similar to radiologists, except that deep learning algorithms are not susceptible to various types of cognitive biases or environmental factors such as fatigue. Using this approach during real-time interpretation of imaging studies can work similar to how computer-assisted detection programs are currently incorporated into the workflow, assisting radiologists. Deep learning algorithms can also be used to create predictions based on existing data from similar cases, providing a type of radiologist decision support to help develop a probability-based differential diagnosis using patient-specific information.

Another potential application is to use deep learning algorithms retrospectively to identify diagnostic error for analysis and development of interventions. For example, deep learning algorithms could be used on EMR data to identify changes in diagnosis and escalations/de-escalations in care that may indicate a diagnostic error has occurred (5). Another application of deep learning is to optimize interpretation workflow by extracting relevant information such as laboratory test values, surgical history, and pathology results from the EMR for radiologists to review during interpretation, rather than having to search manually.

Infrastructure and Support

Like any comprehensive system in health care, an effective process to identify and learn from diagnostic error requires resources, infrastructure, and support. One of the major barriers to securing the support necessary for this process is the predominantly fee-for-service payment model, which reimburses for imaging volume rather than quality. Another barrier is the lack of quality measures that can be used for reimbursement in the new value-based model, particularly measures reflecting diagnostic accuracy. There are considerable costs related to diagnostic error incurred by payers and health care systems that are difficult to track back to diagnostic errors.

For these reasons, it may be difficult to define a return on investment that justifies the financial investment necessary to develop and support the activities described in this article. However, with increasing research being published about the prevalence and impact of diagnostic error in radiology, as well as recognition of the substantial consequences of diagnostic error by major organizations such as the National Quality Forum and the Centers for Medicare & Medicaid Services (CMS), many radiology departments and leaders are realizing that an effective process to identify and learn from diagnostic error will be critical for success in the new value-based health care model.

Protected Time

Academic radiology departments are typically organized according to individual divisions or sections defined by anatomy or organ system, such as thoracic imaging, breast imaging, and neuroradiology. With this organization, the functional learning unit is the individual division/section, and there should be members within that group who have primary responsibility for collecting cases with diagnostic error, organizing regular PLCs, and working with other members of the department on implementing the educational activities and systematic interventions described earlier. These individuals should have protected nonclinical time ranging from 5% to 10% on average, depending on the size of the division/section and responsibilities. In smaller academic departments and private practices that are not organized strictly by anatomy or organ system, subgroups should be organized composed of members who interpret similar types of imaging studies, so that discussion of cases is relevant to all members.

Training

It is desirable for individuals involved with this process to have formal training in quality improvement, change management, and other aspects of quality and safety, in the form of workshops or courses. The skills and tools learned can be broadly applied to identification and analysis of diagnostic errors, as well as development and implementation of interventions. There are workshops specific to radiologists and online resources described elsewhere (54). There are also numerous articles in the radiology literature reviewing various aspects of the process, most notably in the Practice Policy and Quality Initiatives section of *RadioGraphics* and the Quality Matters section of the *Journal of the American College of Radiology*.

Information Technology Needs

Information technology (IT) tools play an important role in supporting an effective process to learn from diagnostic errors, including facilitating reporting and tracking of errors, providing a platform for multiple subspecialists to anonymously review cases with diagnostic error, anonymizing cases for analysis and PLCs, and providing timely feedback to interpreting radiologists about diagnostic errors. Implementing interventions to reduce errors may also depend on IT capabilities and support, such as making information more easily accessible at the time of interpretation (radiologist portal) and modifying standard report templates. Retrospective review of cases may require access to a data repository that combines EMR and RIS (radiology information system) data in an easily searchable manner, and operationalizing processes for radiologic-surgical and radiologic-pathologic correlation also requires IT resources to implement and support. We believe that these are major opportunities for IT vendors.

Leadership

Do not assume that leadership will support efforts at developing and sustaining a system to learn from diagnostic errors. Both radiology and hospital leadership should be engaged in developing the system and should understand the ultimate goal: practice improvement and high-quality patient care. We suggest using a data-driven approach with specific examples of diagnostic error that highlight the potential benefits of a comprehensive system.

We compared random and nonrandom processes for identifying cases with diagnostic error and found that our nonrandom process yielded substantially more cases with educational and practice improvement value (46). After presenting these data to departmental leadership, we proposed replacing participation in random peer review with participation in PLCs as the primary peer review metric. Radiology and hospital leadership would receive a summary from each PLC highlighting the anonymized cases reviewed, teaching points, and systematic interventions along with participating radiologists. We believe that this approach clearly demonstrates the value of our new approach compared with the established random review process.

Incentivizing Participation

Participation in RADPEER and other random peer review processes is incentivized in many radiology departments, either to encourage participation or to punish those who choose not to participate. When a radiology department develops an effective process to learn from errors and supports this process with adequate resources and time, we believe that radiologists will willingly participate without the need for financial inducements.

This process inherently creates value for patients and their family members, health care team members, payers, and hospital systems; attaching often trivial amounts of money to participation devalues the process and certainly does not improve its effectiveness. One approach to measuring the effectiveness of the process, as well as the engagement of residents, fellows, and radiologists, is to track participation in terms of how many staff members contribute cases and how many radiologists participate in PLCs.

Conclusion

We have provided a description of the foundational elements of a comprehensive process to learn from diagnostic errors using specific examples to illustrate how the components of this system work together. It is critical to understand that diagnostic errors are predictable events with readily identifiable contributing factors, which lead to both perceptual and interpretive errors. Identifying contributing factors is key to developing interventions that reduce or mitigate diagnostic errors.

The components of this process include identifying diagnostic errors, analyzing errors to discover contributing factors and biases, and developing effective interventions based on these contributing factors. Coupled with effective peer learning practices, supportive leadership, and a culture of quality, this process will result in fewer diagnostic errors, improved patient outcomes, and increased satisfaction for all stakeholders.

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