Heuristics and Cognitive Error in Medical Imaging

OBJECTIVE. The field of cognitive science has provided important insights into mental processes underlying the interpretation of imaging examinations. Despite these insights, diagnostic error remains a major obstacle in the goal to improve quality in radiology. In this article, we describe several types of cognitive bias that lead to diagnostic errors in imaging and discuss approaches to mitigate cognitive biases and diagnostic error.

CONCLUSION. Radiologists rely on heuristic principles to reduce complex tasks of assessing probabilities and predicting values into simpler judgmental operations. These mental shortcuts allow rapid problem solving based on assumptions and past experiences. Heuristics used in the interpretation of imaging studies are generally helpful but can sometimes result in cognitive biases that lead to significant errors. An understanding of the causes of cognitive biases can lead to the development of educational content and systematic improvements that mitigate errors and improve the quality of care provided by radiologists.

The error rate for practicing diagnostic radiologists generally ranges from 3% to 6% [1–13]. A meta-analysis of discrepancy rates in the interpretation of CT examinations in adults found an average major discrepancy rate of 2.9%, with major discrepancies being defined as a discrepancy that would potentially adversely affect patient care [14]. Given the volume of imaging studies performed in the United States, it is not surprising that tort claims for negligent diagnostic errors result in billions of dollars in payouts annually [15]. Approximately 75% of medical malpractice claims against radiologists are related to diagnostic error [16].

Errors in radiology are broadly classified into perceptual errors and interpretive errors. Perceptual errors account for 60–80% of errors and occur when an abnormality is present on a diagnostic image but not seen by the interpreting radiologist [7, 10, 17, 18]. Interpretive errors constitute the remaining 20–40% of errors and occur when an abnormality is identified on an image but its meaning or importance is incorrectly interpreted [7]. Cognitive factors have been reported to contribute to diagnostic error in 74% of cases [15, 19]. There are several types of cognitive biases that contribute to both perceptual and interpretive errors in diagnostic radiology, which can result from failed heuristic principles [15, 20].

Definitions

A heuristic is a mental shortcut that allows rapid problem solving based on assumptions and past experiences. Cognitive bias is a systematic error in reasoning or judgment that can be the result of failed heuristics. Cognitive biases can lead to both perceptual and interpretive errors. Perceptual error is an error that occurs when an abnormality is present on a diagnostic image but not seen by the interpreting radiologist. Interpretive error is an error that occurs when an abnormality is identified on an image but its meaning or importance is incorrectly interpreted. Diagnostic error is defined as a diagnosis that is missed, wrong, or delayed, which can be the result of either perceptual or interpretive errors.

Heuristics and Biases

Radiologists rely on heuristic principles to reduce complex tasks of assessing probabilities and predicting values into simpler judgmental operations [21]. A heuristic is any approach to problem solving, learning, or discovery that uses a practical method that is usually sufficient for the immediate goal but not perfect or optimal [22]. In more general terms, a heuristic is a mental shortcut that

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allows rapid problem solving based on assumptions and past experiences. Physicians rely on these shortcuts (heuristics) in reasoning to minimize delay, cost, and anxiety in our clinical decision making [15].

Heuristics used in the interpretation of imaging studies are generally helpful but can sometimes result in cognitive biases that lead to errors. For example, an abdominal radiologist identifies enlargement of the pancreatic head with biliary and pancreatic duct dilation in an older patient with right upper quadrant pain and jaundice. This radiologist works at an academic center with a busy pancreaticobiliary service that receives numerous referrals for patients with pancreatic cancer and recently interpreted a follow-up study for a different patient with adenocarcinoma of the pancreatic head resulting in dilation of the biliary and pancreatic ducts. The radiologist concludes that enlargement of the pancreatic head is suspicious for pancreatic adenocarcinoma. After multiple biopsies and a subsequent Whipple procedure, the patient receives a diagnosis of autoimmune pancreatitis. Although the conclusion of pancreatic head cancer may have been correct for most patients, failed heuristics led the radiologist to overlook the possibility of the less common diagnosis of autoimmune pancreatitis, in which the morbidity and mortality associated with the Whipple procedure could have been avoided.

There are several common cognitive biases that result from failed heuristics, which will be reviewed in this article (Table 1).

### TABLE 1: Types of Cognitive Bias With Suggested Interventions

<table>
<thead>
<tr>
<th>Bias</th>
<th>Intervention</th>
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<tbody>
<tr>
<td>Availability bias refers to the tendency for diagnostic assessments to be unduly influenced by easily recalled experiences</td>
<td>Reference sources of information beyond one’s personal experience, including relevant peer-reviewed publications and second opinions from colleagues</td>
</tr>
<tr>
<td>Alliterative bias represents the influence that one radiologist’s judgment can exert on the diagnostic thinking of another radiologist</td>
<td>Consider reviewing prior radiologist reports after rendering an interpretation, so as not to be influenced by the prior radiologist’s interpretation</td>
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<tr>
<td>Anchoring bias reflects the undue influence that an initial impression has on the evaluation of subsequently collected information</td>
<td>Carefully assess all imaging findings before settling on a diagnosis and objectively consider alternate hypotheses even when confident of a certain diagnosis</td>
</tr>
<tr>
<td>Framing bias results from a tendency to be influenced by how a question is asked or how a problem is presented</td>
<td>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</td>
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<tr>
<td>Attribution bias occurs when specific characteristics are attributed to a person or thing simply because it belongs to a certain class</td>
<td>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</td>
</tr>
<tr>
<td>Blind spot bias occurs when radiologists have a heightened awareness of commonly missed or misinterpreted findings, which may lead to overcalling known types of errors</td>
<td>Reviewing imaging studies without knowing the clinical indication or patient demographics may help address attribution bias</td>
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<td>Regret bias refers to overestimating the likelihood of a particular disease because of the undesirability of an adverse outcome from a failure to diagnose that disease</td>
<td>Structured report templates can help focus attention on known blind spots to identify uncommon manifestations of diseases</td>
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<td>Satisfaction of search bias occurs 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</td>
<td>Metacognition or increased awareness of the tendency to overcall known types of errors is one potential strategy to minimize the effect of this type of bias</td>
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<td>Hindsight bias refers to the tendency to overestimate the predictability of an event after the event is known</td>
<td>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</td>
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<td>Scout neglect bias occurs when radiologists do not expect to find anything meaningful on the scout images, which can lead to important diagnoses being missed</td>
<td>Adopting a systematic approach to image interpretation with report templates designed as checklists, identifying do-not-miss diagnoses</td>
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<td>Being mindful of known combinations of injuries</td>
<td>Being mindful of known combinations of injuries</td>
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<tr>
<td>Promoting awareness so that trainees and staff know to be more vigilant in their search after identifying an initial finding</td>
<td>Promoting awareness and a culture of reporting and inquiry that emphasizes why an error was made, rather than who made the error</td>
</tr>
<tr>
<td>Routinely review the scout images and include a field in the report template labeled “Scout views”</td>
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on the diagnostic thinking of another radiologist. This bias commonly occurs while interpreting an imaging study with a prior comparison study that was interpreted by a colleague (Fig. 2). Reading the colleague’s report can influence how a radiologist interprets the follow-up imaging study. In many cases, knowledge of the prior report can be diagnostically useful and make interpretation of the follow-up study more efficient. However, if the radiologist’s colleague made an error interpreting the prior comparison study, there is a greater chance that the radiologist will make the same error when interpreting the follow-up study. Radiologists should not become overly reliant on prior reports and keep an open mind to diagnostic possibilities other than those that have already been suggested [20, 23].

With the growing implementation of electronic medical records, alliterative errors can take a more direct and obvious form—namely, those that occur when a clinician copies and pastes a prior report into the current report. Such practice can cause the rapid propagation of inaccurate information within the medical record, and close vigilance for such errors should be maintained [24].

**Anchoring Bias**

Anchoring bias reflects the undue influence that an initial impression has on the evaluation of subsequently collected information. Anchoring bias can cause a clinician to prematurely settle on a diagnostic hypothesis based on initially gathered information and thereafter downplay alternative diagnostic possibilities. This is also known as the primacy effect, wherein earlier information has a greater effect on interpretation than later information [21, 25, 26]. A closely related bias is confirmation bias, which refers to the tendency to collect and evaluate information in a manner that supports an initial or preexisting hypothesis [22, 27]. In radiology, these biases can have a powerful effect on image interpretation. During the evaluation of an imaging study, initially detected findings may elicit a differential diagnosis that unduly biases the interpretation of subsequently detected imaging findings in support of that differential diagnosis (Fig. 3). Subsequent evidence that points to an alternative diagnosis may be downplayed or misinterpreted. To help avoid these tendencies, it is important for radiologists to carefully assess the totality of the imaging findings and objectively consider alternate hypotheses.

**Framing Bias**

Framing bias results from a tendency to be influenced by how a question is asked or how a problem is presented. For radiologists, framing bias commonly results from the influence that the clinical history or reason for examination has on image interpretation (Fig. 4). Dilated small bowel seen on a radiograph of a patient with a history of small-bowel obstruction will likely result in an interpretation attributing dilated small bowel to obstruction. However, if the indication also noted that the patient underwent surgery 2 days ago for small-bowel obstruction, then the interpretation would more likely attribute the dilated bowel to adynamic ileus in the setting of recent surgery. There are competing views on how best to mitigate framing bias. One strategy is to first review the imaging study without knowing the clinical indication or reason for examination, so as to avoid any potential influence from the clinical indication [15]. A contrasting strategy is to 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.

**Attribute Bias**

Attribute bias occurs when specific characteristics are attributed to a person or thing simply because it belongs to a certain class [28]. Several examples of attribution bias affecting radiologic interpretation have been described [22]. Consider the interpretation of CT and MRI of the abdomen in patients with cirrhosis and hepatocellular carcinoma. Commonly described routes of extrahepatic spread of hepatocellular carcinoma include the lung, abdominal lymph nodes, bones, diaphragm, and adrenal glands [29]. Radiologists who interpret these examinations may not know that hepatocellular carcinoma can disseminate into the peritoneum and can subsequently miss peritoneal implants because this cancer is not typically associated with intraperitoneal spread, as opposed to cancers of the ovary, pancreas, and stomach (Fig. 5). Reviewing imaging studies without knowing the clinical indication or patient demographics may help address attribution bias. In addition, structured report templates can help focus attention on known blind spots to identify uncommon manifestations of diseases such as peritoneal spread of tumor (e.g., including the field “Peritoneal surface and intraperitoneal space” in the report template).

**Blind Spot Bias**

The practice of reinterpretting imaging examinations performed at outside institutions is becoming commonplace at academic centers because of a relatively high rate of discrepancies affecting patient care [30–32]. Error rates as high as 41% have been reported during the reinterpretation of outside CT and MRI examinations in patients with head and neck cancer at an academic center [31]. In that study, discrepancies identified during reinterpretation altered treatment for 98% of patients and affected the prognosis for 95%. In a study evaluating clinically important changes in radiology reports with double reading of abdominopelvic CT, the most common changes were related to cancer, and most changes resulted in increased severity, indicating that the presence or extent of cancer had been unrecognized or underappreciated [33]. This illustrates a common theme among studies characterizing the effect of reinterpretting imaging examinations in patients with cancer: most errors relate to undiagnosed cancer or metastatic disease. Given a knowledge of this trend, radiologists at academic centers may have a heightened awareness of missed cancers and may be prone to attributing findings to cancer or metastatic disease (and fail to recognize their own bias), representing blind spot bias [34] (Fig. 6). Awareness of the tendency to overlook known types of errors is one potential strategy to minimize the effect of this type of bias.

**Regret Bias**

Regret bias refers to overestimating the likelihood of a particular disease because of the undesirability of an adverse outcome from a failure to diagnose that disease [12] (Fig. 7). Regret bias relates to the commonly understood practice of defensive medicine. So as to not miss a potentially life-threatening disease, physicians will recommend and order additional diagnostic tests, even if the pretest probability of the disease is exceedingly low. There are some instances when such practices might be acceptable, especially if the diagnostic test is low cost and low risk and the potential benefit of detecting a particular disease is high. However, such practices can lead to multiple negative consequences, including significant patient anxiety, patient risk from additional procedures, and unnecessary health care costs. One method that helps reduce the effects of regret bias is the development and use of evidence-based appropriateness criteria and
standardized reporting systems. Such practices can allow radiologists to objectively state the probability of certain disease processes on the basis of the presence of an imaging finding, and thus make more unbiased recommendations about whether additional testing is warranted [22].

Satisfaction of Search

It has been observed that the detection rate for second and third abnormalities after one abnormality has been detected can decrease to approximately 50%, a cognitive bias termed “satisfaction of search” [35] (Fig. 8). This bias occurs 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 [20, 35–38]. A variation of this bias can be seen in the setting of quaternary care hospitals with complex patients who have multiple ongoing medical issues in the ICU (i.e., exhaustion of search), in which there is an increased risk of missing several significant and often unexpected findings. Strategies to reduce the risk of satisfaction of search include adopting a systematic approach to image interpretation with report templates designed as checklists, identifying do-not-miss diagnoses (e.g., pneumoperitoneum on a chest x-ray), being mindful of known combinations of injuries (e.g., search for findings of active vascular extravasation when an intramuscular hematoma is identified), and promoting awareness of satisfaction of search so that trainees and staff know to be more vigilant in their search after identifying an initial finding [15, 39].

Hindsight Bias

Hindsight bias refers to the tendency to overestimate the predictability of an event after the event is known. This is commonly referred to as the “knew-it-all-along” bias. The analysis of a decision after the fact is influenced by the added knowledge that has been gained since the decision was originally made. Hindsight bias reflects a tendency to selectively recall past information in a manner that conforms to the subsequently proven event. In the radiology setting, it is difficult to objectively gauge the diagnostic uncertainty faced by a radiologist who prospectively interprets an imaging study after additional information related to the study becomes known. Hindsight bias can have several deleterious effects. Foremost, hindsight bias can hinder educational opportunities related to error cases. If the pretest probability of a missed diagnosis is overestimated in retrospect, there may be a tendency to assert that the individual radiologist who missed the diagnosis should have known better. Such a tendency might shift attention away from more salient systemic factors and, thus, hinder efforts to reduce similar errors in the future (Fig. 9). Hindsight bias also has serious effects in the medicolegal setting. In medicolegal cases, jurors are instructed to determine negligence according to whether the accused physician practiced the standard of care, regardless of outcome. However, there is substantial evidence that jurors are, in fact, highly influenced by the outcome of cases and that hindsight bias tends to increase with the severity of a negative outcome [40, 41].

Scout Neglect Bias

The primary purpose of scout views on cross-sectional CT and MRI examinations is to prescribe the imaging slices and display slice locations. For this reason, radiologists often ignore the scout images. However, it is not unusual for a pathologic abnormality to be visible on the initial scout images but then excluded from the subsequent diagnostic images, often because of the relatively larger FOV of the scout images. Scout views have been shown to contribute significantly to diagnosis [42]. A systematic neglect of the scout views on cross-sectional imaging studies can result in important diagnoses being missed (Fig. 10). A simple and effective remedy for this type of bias is to routinely review the scout images and include a field in the report template labeled “Scout views.”

Metacognition and Interventions to Reduce the Effect of Cognitive Biases

One theoretic model of cognitive processing during the interpretation of radiographic images is the dual-process theory of reasoning, which defines type 1 (automatic) and type 2 (deliberate) processes [6]. Type 1 processing can be characterized as a form of pattern recognition (i.e., shortcut or heuristic) leading to an automatic and immediate diagnosis, whereas type 2 processing occurs when an abnormal pattern is identified but not instantly recognized, requiring deliberate reasoning and problem solving. The experienced radiologist relies on type 1 processing, which is a useful and time-saving technique but can lead to a replicable pattern of error due to cognitive biases. One approach to minimizing type 1 errors is to learn deliberate type 2 forcing strategies that override type 1 thinking, an approach termed “metacognition” [15, 43]. The difficulty, however, lies in identifying when the automatic process of pattern recognition has failed. Aside from metacognition, corrective strategies to the biases reviewed in this article have been described elsewhere [6, 15, 39].

We think that a comprehensive departmental strategy is necessary to reduce the effect of cognitive biases and to learn from diagnostic errors. The key components of this strategy are processes to identify errors, analysis of errors for systematic causes and biases, using what is learned from these errors to develop educational content and systematic improvements, and developing a culture of quality that promotes reporting and learning from errors. Implementing an educational curriculum for trainees, radiologists, and staff is a foundational element of this strategy, because awareness is arguably one of the most effective tools we have to reduce errors. Awareness that errors occur and are often the result of systematic causes (rather than person failures) is a requisite to having a robust and effective reporting system to identify errors. The analysis of errors, educational content, and systematic improvements work synergistically to develop a culture that understands and learns from these errors.

Conclusion

Diagnostic errors commonly arise from faulty heuristics and cognitive biases that all radiologists share. Such biases can produce predictable patterns of misdiagnoses. Awareness of the spectrum of cognitive biases is an important step toward a comprehensive strategy to learn from diagnostic errors and ultimately improve patient care.

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(Figures start on next page)
Fig. 1—Availability bias. A and B, 27-year-old woman. Axial contrast-enhanced magnetization prepared rapid acquisition gradient recalled-echo sequence (A) shows round centrally enhancing mass in posterior fossa. Neuroradiologist correctly identified mass as giant aneurysm, as proven on subsequent angiogram (B). C and D, 45-year-old woman. Same neuroradiologist interpreted pituitary MRI in different patient later that same day. Coronal (C) and sagittal (D) contrast-enhanced T1-weighted images show enhancing sellar-suprasellar mass causing right lateral displacement of pituitary stalk (C) and smooth remodeling of sella turcica (D), imaging features that are characteristic of pituitary macroadenoma. However, neuroradiologist also included possibility of giant aneurysm in differential diagnosis and recommended angiographic imaging study. Neuroradiologist was likely influenced by recently interpreted case of posterior fossa aneurysm. Sellar-suprasellar mass proved to represent macroadenoma after resection.

Fig. 2—Alliterative bias. 3-month-old boy with respiratory distress. Frontal chest radiograph shows relatively increased opacity of right upper lobe (black arrow) and relative lucency and hyperinflation of right middle lobe (white arrow). Radiologist interpreted findings as representing right upper lobe atelectasis. Multiple radiologists interpreted subsequent chest radiographs in this patient as “unchanged right upper lobe atelectasis,” influenced by initial radiologist’s report. Patient was ultimately found to have surgically proven congenital lobar emphysema involving right middle lobe.
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Fig. 3—Anchoring bias. 37-year-old man with left frontal lobe mass. A, Contrast-enhanced T1-weighted image shows ring enhancing left frontal lobe mass. B, DW image shows central diffusion restriction. On basis of these findings, in particular restricted diffusion, radiologist interpreted this mass to represent cerebral abscess. C and D, However, mass also showed marked hyperperfusion on perfusion-weighted image (C) and infiltration of corpus callosum on FLAIR image (D), findings that were subsequently detected but downplayed by interpreting radiologist. These latter findings supported actual diagnosis of glioblastoma multiforme.

Fig. 4—Framing bias. 36-year-old woman. Portable anteroposterior view of abdomen with indication of “SBO” (small-bowel obstruction) was interpreted as dilated loops of small bowel representing obstruction. Radiologist did not recognize surgical staples overlying midline abdomen, reflecting recent surgery for small-bowel obstruction. Dilated bowel loops in fact reflected postoperative ileus.
Fig. 5—Attribution bias. 13-year-old boy with seizures. A–C, MRI examinations show enhancing left frontal lobe mass on contrast-enhanced T1-weighted image (arrow, A) with hyperperfusion on perfusion-weighted image (arrow, B) and hemorrhage on susceptibility-weighted image (arrow, C). Radiologist provided differential diagnosis of pediatric CNS neoplasms, influenced by patient age, including “ganglioglioma, DNET [dysembryoplastic neuroepithelial tumor], pleomorphic xanthoastrocytoma, or oligodendroglioma.” This proved to represent glioblastoma multiforme. Diagnosis of glioblastoma, albeit rare in pediatric patients, was concordant with imaging findings of contrast enhancement, hyperperfusion, and hemorrhage.

Fig. 6—Blind spot bias. 56-year-old man with pancreatic adenocarcinoma. A, Contrast-enhanced CT image of abdomen obtained after patient received neoadjuvant chemotherapy shows focal area of low attenuation in inferior right hepatic lobe (arrow). Outside interpretation did not describe this focal lesion. Radiologist at our institution who reinterpreted this case determined that lesion was consistent with metastasis and assumed this represented another missed metastatic lesion by outside radiologist. B and C, Patient subsequently underwent MRI of abdomen, and in-phase (B) and out-of-phase (C) images of lesion (arrows) show loss of signal on out-of-phase imaging, which is diagnostic of focal fat rather than metastatic disease.

Fig. 7—Regret bias. 29-year-old woman with primary bone tumor of left femur. CT of abdomen and pelvis was performed to assess for metastatic disease. Interpreting radiologist believed that sclerotic lesion in right iliac bone (arrow) was benign. However, for fear of missing metastasis in young patient, he decided to recommend pelvic MRI and bone scan for more definitive characterization. Follow-up bone scan and MRI (not shown) showed stable lesion in right ilium with benign features, consistent with bone island.
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Fig. 8—Satisfaction of search. 28-year-old man with hand pain after punching wall. A and B. Frontal view radiograph of hand obtained in emergency department shows fracture of fourth metacarpal (arrow, A). Interpreting radiologist did not notice additional hamate fracture seen only on oblique view radiograph of hand (arrow, B), classic example of satisfaction of search.

Fig. 9—Hindsight bias. 30-year-old woman who presented to emergency department (ED) after being found down in bathroom after argument with her boyfriend. Axial image from current CT examination is on left, and prior CT examination is on right. Overnight resident interpreted current head CT as “No acute abnormality.” Attending physician reviewed case 6 hours later and changed preliminary report to “diffuse subarachnoid hemorrhage.” Case was discussed at quality assurance meeting, where ED physician stated that “this should never have been missed” and “this is why we need 24/7 final interpretations by attending physicians.” However, at root cause analysis it was determined that primary contributing factor to this misinterpretation was different hanging protocols between two hospitals covered by residents overnight. At one hospital, new studies were loaded on right, whereas at other hospital, new studies were loaded on left. Resident had mistakenly looked at old study when issuing his interpretation.

Fig. 10—Scout neglect bias. 38-year-old woman with abdominal pain who had undergone hemicolectomy. A and B. Scout (A) and axial (B) oral contrast agent–enhanced CT images of abdomen and pelvis are shown. Retained surgical sponge (arrows) was missed on multiple consecutive CT examinations, likely because interpreting radiologists did not evaluate scout view (A), which clearly shows radiopaque sponge in left lower quadrant. Retained sponge and resulting gossypiboma were misinterpreted as oral contrast agent within colon on subsequent CT images.