Donald L. Renfrew, MD • Edmund A. Franken, Jr, MD • Kevin S. Berbaum, PhD
Frank H. Weigelt, MA • Monzer M. Abu-Yousef, MD

Error in Radiology: Classification and Lessons in 182 Cases Presented at a Problem Case Conference[1]

The authors review and classify errors in 182 cases that were presented at problem case conferences between August 1986 and October 1990. Errors were classified by means of a system developed 20 years ago and by means of a system developed within the past several years. The authors found that sources of error have changed very little. Errors usually involved failure to consult old radiologic studies or reports, limitations in imaging technique, acquisition of inaccurate or incomplete clinical history, location of a lesion outside the area of interest on an image, lack of knowledge, failure to continue to search for abnormalities after the first abnormality was found, and failure to recognize a normal biologic variant. Errors included 126 perceptual errors (64 false-negative, 15 false-positive, and 47 misclassification errors) and 56 mishaps, including 38 complications and 18 communication errors. In seven cases nonperception errors occurred because established departmental routines were not followed, and in nine cases a new departmental routine was established after a complication occurred. Departmental policy exerts less effect on perception and interpretation errors.

Index terms: Diagnostic radiology, observer performance • Radiology and radiologists, departmental management • Quality assurance

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Table 1
Classification of Error

Class	Cause of Error	Explanation and Examples	Decision-Analysis Term
I	Complacency	Errors of overreading and misinterpretation, in which a finding is appreciated but is attributed to the wrong cause.	False-positive error
II	Faulty reasoning	Errors of overreading and misinterpretation, in which the finding is appreciated and interpreted as abnormal but is attributed to the wrong cause. Misleading information and a limited differential diagnosis are included in this category.	True-positive reading, but misclassification
III	Lack of knowledge	The finding is seen but is attributed to the wrong cause because of a lack of knowledge on the part of the viewer.	True-positive reading, but misclassification
IV	Underreading	The finding is missed. Underreading may result from failure to isolate important material or from satisfaction of search.	False-negative error
V	Poor communication	The lesion is identified and interpreted correctly, but the message fails to reach the clinician.	...
VI	Miscellaneous	The lesion was not present on the image obtained, even in retrospect. This may be secondary to limitations of the examination or to an inadequate examination.	False-negative error
VII	Complications*	Untoward events happened during the course of examination, which was most frequently encountered during invasive procedures.	...

Source.—Adapted from Smith (4).
* We have added this class, which was not in Smith's scheme.

ERROR occurs frequently in the practice of medicine (1). In addition to the mistakes common to all areas of medicine, perceptual error in diagnostic radiology is particularly prevalent, as the human perceptual system is imperfect. That perceptual error is common in diagnostic radiology has been recognized for years (2), with errors noted in over one-third of cases of interpretation of ambiguous diagnostic images. This article presents an analysis of perceptual errors and other mishaps that occurred in the diagnostic radiology department at our institution over a 4-year period.

MATERIALS AND METHODS

Since August 1986, problem case conferences have been held by the Department of Radiology at the University of Iowa; the conferences, on the model of Wheeler (3), are held 10 times per year. Subspecialty divisions within the department (pediatric radiology) are assigned to present cases on a rotating basis, so that each division contributes approximately four cases per year.

[1] From the Department of Radiology, the University of Iowa College of Medicine, Iowa City. Received May 17, 1991; revision requested June 21; final revision received October 17; accepted November 4. **Address reprint requests to** D.L.R., Department of Radiology, Rush-Presbyterian-St Luke's Medical Center, 1653 W Congress Pkwy, Chicago, IL 60612.

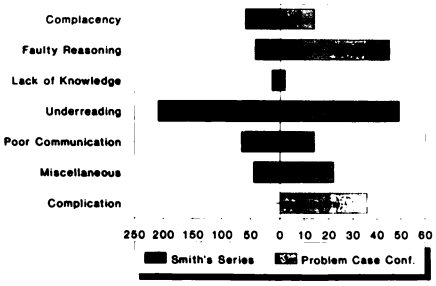


Figure 1. Graph depicts distribution of errors in Smith's original 437 cases (4) and in our 182 cases.

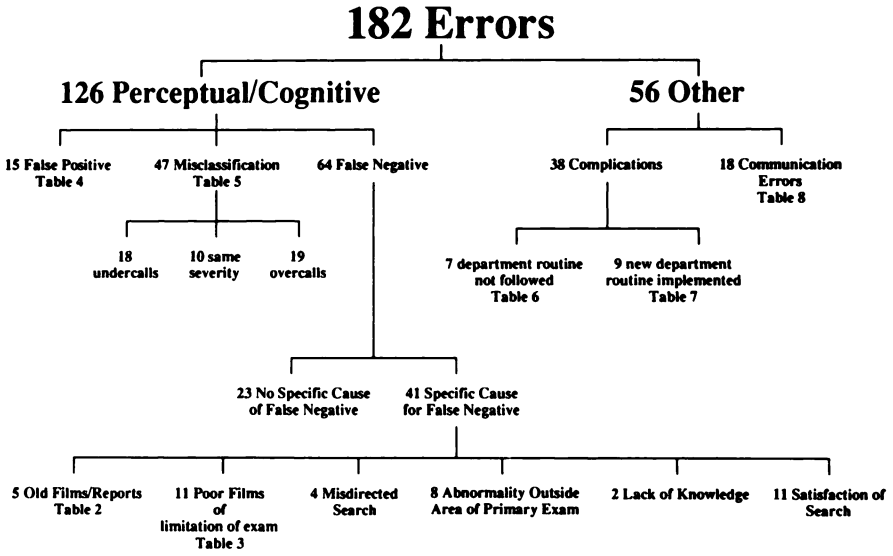


Figure 2. Flow chart depicts classification of 182 errors on the basis of contemporary methods.

Problems are identified from a variety of sources. The review of prior imaging examinations that occurs when cases are interpreted often discloses errors. Advanced modalities such as magnetic resonance (MR) imaging may demonstrate abnormalities that are apparent "in retrospect" on routine radiographs. Clinical colleagues are often helpful in pointing out errors. A logbook compiled from each conference provides a brief history of the patient, information about the radiologic examination with interpretations and associated errors, any mortality and/or morbidity that resulted from the error, and steps that were taken to minimize the chance of recurrence of the error.

Two radiologists (D.L.R., E.A.F.) independently classified the 182 cases presented at problem case conferences between August 1986 and October 1990 according to the single most important cause of error. In the few cases in which the radiologists disagreed on the single most important cause of error, they chose a single cause after discussion of the case. The radiologists classified the cases according to two classification systems.

1. One scheme, developed by Smith in 1967 (4) for errors in the practice of general radiology, classified 437 errors that occurred during a special 2-year study of Smith and his colleagues in private practice. Smith and his colleagues did not perform nuclear medicine, most of what we now call interventional radiology, and imaging with newer modalities. Table 1 summarizes Smith's classification system; we added the category "complications" to his scheme.

2. Classification was also made on the basis of contemporary methods such as decision analysis to classify perceptual-cognitive error. Such classification involved dividing cases into perceptual-cognitive error (false-positive, false-negative, or misinterpretation error) and other error (complications and communication errors). Table 1 also indicates the closest equivalent to Smith's classes that exists in decision-analysis terminology.

The 182 cases reported herein occurred during a 4-year period in which over 700,000 radiologic examinations were performed in the radiology department of our institution. Although case selection was arbitrary and therefore necessarily not representative of all error in the department, the series does represent those incidents that were considered by the staff radiologists and by our clinical colleagues to be the most serious errors.

Table 2
Errors Caused by Limitations of Examination or Technique

Case*	Description
5	Fracture of the scaphoid was not apparent on plain radiographs; interpretation was qualified; a nuclear medicine study was performed, and the fracture was demonstrated.
12	Imaging after administration of three water-soluble contrast material enemas did not show a transverse colon tumor.
18	Intracerebral aneurysm was missed on first arteriogram because of failure to perform selected internal carotid arteriography.
30	Disk abscess and erosion of the spine was missed at MR imaging because of the types of imaging sequences chosen.
77	Hepatic venoocclusive disease was not diagnosed on initial Doppler studies because the Doppler beam and the vessel were almost perpendicular, a situation with an inherently large margin of error.
85	Water-soluble esophogram failed to show a leak; the clinician refused to have barium administered, and a leak was missed.
94	Computed tomography (CT) failed to demonstrate an intraabdominal abscess, which was documented with labeled white blood cell study.
144	Salter-Harris undisplaced type I fracture was missed on initial radiograph.
156	Postoperative upper GI examination was interpreted as negative for leak, but abdominal CT demonstrated the leak.
171	Plain radiographs showed normal findings in a neonate with hypoplastic left heart syndrome.
188	Eight-millimeter-thick sections acquired on an ultrafast chest CT scan failed to show a double aortic arch.

* These are the case numbers in our logbook and are used for anonymous identification of patients. Although there were 182 errors classified in this study, 191 cases were presented in the conferences, and, thus, the case number is occasionally greater than 182.

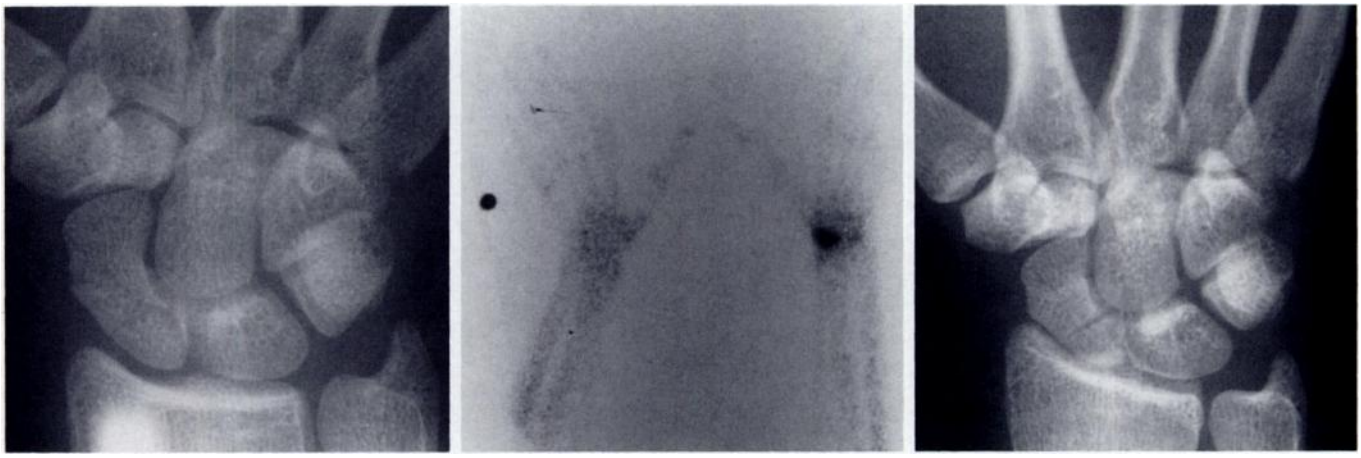
RESULTS

Figure 1 presents classification of Smith's data, as well as our own, by means of Smith's scheme. Reclassification on the basis of contemporary methods of perceptual-cognitive classification demonstrated 126 cases of perceptual error and 56 mishaps attributed to other causes. Figure 2 presents the classification of our 182 errors on the basis of contemporary methods.

Perceptual-Cognitive Errors

The 126 cases of perceptual-cognitive error included 64 false-negative, 15 false-positive, and 47 misclassification errors.

False-negative error.—A classic example of a false-negative error is a pulmonary nodule that is visible in retro-



a. b. c.

Figure 3. Limitation of technique. Images are of an 18-year-old gymnast who came to a sports medicine clinic with exquisite tenderness in the anatomic snuff box. **(a)** Ulnar-deviation oblique radiograph of the scaphoid fails to demonstrate a fracture. **(b)** Nuclear medicine scan shows intense increased radiotracer localization in the region of the scaphoid, consistent with an acute fracture. **(c)** Follow-up radiograph obtained 2 weeks after the injury demonstrates a fracture of the scaphoid.

Figure 4. False-negative error. Lateral plain radiograph of the ankle in a 22-year-old man was obtained after ankle sprain. Radiograph was interpreted as normal, despite the fact that there is an obvious fracture of the anterior process of the calcaneus (arrows). The observer may have been unaware of the existence of fractures in this location.

spect but that was not detected on the initial radiologic evaluation. Further study showed 41 cases in which a specific cause could be identified.

1. In five cases error occurred because old radiologic studies or reports were not consulted. For example, a pulmonary nodule was missed that had been demonstrated on a prior chest radiograph and had been reported correctly.

2. In 11 cases, limitation of technique caused the error (Table 2). In some cases poor quality of images led to the lesion being missed, whereas in others the lesion was not visualized despite performance of an adequate radiologic examination (Fig 3).

3. Misdirected search was noted in four cases in which the lesion was missed because of inaccurate, incomplete, or misleading clinical history. For example, radiographs of the wrist were obtained for the evaluation of possible hemochromatosis in a patient with hepatomegaly and wrist pain. The fact that the patient had lung cancer was not noted on the requisition. A metastatic lesion of the distal ulna was missed.

4. In eight cases the abnormality was outside the area of primary examination; for example, an abnormality of the chest was visible on an abdominal radiograph but was overlooked.

5. Lack of knowledge was a very unusual cause of error, accounting for two cases in our series. Assigning cases to the category of "lack of knowledge" was difficult because of the inability to separate this cause of error from simple underreading. Figure 4 shows an example of a false-negative error that may have occurred because of a lack of knowledge or because of simple underreading.

6. "Satisfaction of search" refers to the circumstance in which the radiologist recognizes one abnormality but fails to see a second lesion. This was noted in 11 cases.

False-positive error.—This less frequent cause of error was noted only 15 times (Table 3). Figure 5 shows an example of a false-positive error.

Misclassification.—In these 47 cases the abnormality was recognized but was given an incorrect interpretation. Errors were divided among those called lesser disease (undercalls) (n = 18), disease of the same severity (n = 10), or a more severe ailment (overcalls) (n = 19). An example of an undercall is an adenocarcinoma of the mesentery that was seen on a CT scan of the abdomen and was interpreted as scarring. An example of a misinterpretation with the wrong diagnosis having an equivalent disease severity is a herniated nucleus pulposus of C5–6 misdiagnosed as a herniated nucleus pulposus of C4–5. An example of an overcall—in which gynecomastia was misinterpreted as possible malignancy—is presented in Figure 6.

Other Mishaps

Fifty-six mishaps were attributed to problems other than perceptual error. These included 38 complications and 18 communication errors.

Complications.—In this group of 38 cases, seven were specifically noted to have occurred because established departmental standards were not followed (Table 4). In nine cases a new departmental practice was established because of the incident involved (Table 5).

Communication errors.—In 18 cases communication errors included radiologic examinations obtained of the wrong patients; incorrect examinations performed on the correct patients; delayed diagnosis because radiologic images were allowed to be taken from the radiology department before they were interpreted; and failure to alert attending physicians of important, unsuspected findings on images. Most of these errors could have been prevented if established departmental routine had been followed.

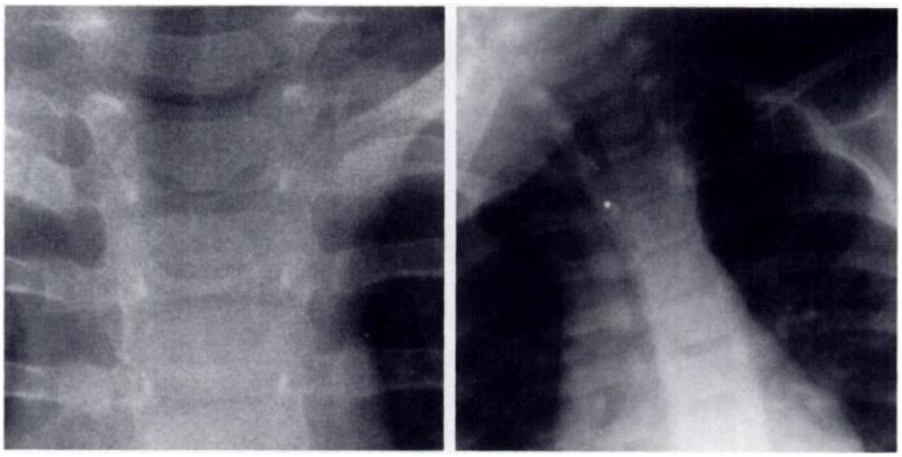


Figure 5. False-positive error. Images are of a 1-year-old baby girl who had been playing unsupervised with buttons and began gagging. **(a)** Detail from anteroposterior chest radiograph was read as demonstrating a 2-cm-diameter foreign body in the mid-esophagus. A barium swallow study was obtained, which was interpreted as normal. **(b)** Oblique spot radiograph of the chest was obtained after placement of a metallic pellet on the manubrium. The pellet was used to demonstrate that the "foreign body" actually represented a center of prominent manubrial ossification.

a. b.

DISCUSSION

Others (3) have shown the value of a problem case conference to create awareness of perceptual error and other mishaps in diagnostic radiology and to initiate measures to reduce such problems in the future. It is of some interest that, other than the category of "complications," sources of error in diagnostic radiology have changed very little for many years; our results parallel those of Smith (Fig 1).

Mishaps not due to errors in perception and interpretation represent problems that are more readily and easily addressed by changes in departmental policy or by enforcement of existing policy. It is of value, particularly in errors of complications and communication, to reeducate physicians about departmental practice standards or to establish new standards when required.

It is less clear how to reduce perceptual-cognitive errors (ie, mistakes of interpretation). Departmental standards can be developed to ensure an optimal environment for detecting abnormality. Examples include insistence on technically satisfactory images, on review of prior images, and on acquisition of appropriate clinical information.

It may be that by confronting perceptual errors made by ourselves and our colleagues, radiologists will recognize these pitfalls and others like them when they reoccur in the radiology reading room. Whether this is actually true is difficult to establish. At the very least, group discussion ought to lead to better calibration of the findings of different observers relative to each other and to clinical truth. In principle, by frequently providing standards of comparison, the number of underreading errors that are the result of overt decision making should be reduced (5).

Kundel (5) distinguished between perceptual and cognitive errors. He believed a perceptual error occurred when image features, though recorded, were not appreciated. A cognitive, or reasoning, error occurred when image features, though appreciated, led to wrong conclusions. Perceptual error occurred because of a faulty *covert* decision to attribute a specific meaning to the features. Cognitive error occurred because of a faulty *overt* decision, as a result of either response bias or flawed diagnostic logic. In reviewing quantitative studies of error in chest radiography (6,7), Kundel (5) noted that perceptual error occurs four times more frequently than cognitive error. For our data, as in all nonlaboratory studies, the distinction between these subcategories is difficult.

Most perceptual or cognitive errors

Table 3
False-Positive Errors

Case*	Description of Case
31	Barium meal study was read as probable malrotation with volvulus in an infant with intermittent vomiting. Subsequent surgery showed no abnormality.
38	Patient with ovarian cancer had a metastatic deposit according to reading of a chest radiograph. This finding was subsequently proved to be the result of a shallow inspiration rather than a pulmonary nodule.
67	One-year-old patient possibly swallowed a button. Manubrial ossification center was misinterpreted as being a foreign body, which resulted in performance of endoscopy and a barium swallow examination.
79	T-5 fracture was read because of slight wedging of the vertebral body at plain radiography; the patient had marked point tenderness. Subsequent CT scan was read by some staff members as normal and by others as showing a fracture.
98	Vague shadows on screening mammogram were read as mass lesion; follow-up mammography failed to demonstrate lesion.
99	In a patient with dilated biliary system, endoscopic retrograde cholangiopancreatograph was read as showing a cutoff in the pancreas indicative of a mass. Surgery demonstrated an accessory pancreatic duct and a normal main pancreatic duct.
100	In a patient with laboratory evidence of hyperparathyroidism, ultrasound (US) scan showed "9 × 9 × 11-cm isoechoic mass suspicious for parathyroid adenoma." Results of preoperative laboratory tests were normal. At surgery, normal parathyroid tissue was found, as well as a lymph node from the right inferior lobe of the thyroid.
103	Clinicians were informed that findings on a nuclear medicine study confirmed brain death when in fact the scan showed some intracerebral activity.
104	An 8-mm-diameter appendix was interpreted as demonstrating appendicitis, but a normal appendix was noted at surgery and on subsequent pathology reports.
112	Nodular opacity in left upper lobe was identified on a chest radiograph. A CT scan obtained 10 days later failed to demonstrate nodule, and repeat plain radiography also failed to demonstrate nodule.
116	Nodule or polyp of the colon seen on a single constrast material–enhanced barium enema study was read as suspicious for tumor. At surgery, no tumor was found.
133	Injection technique resulted in misreading of area of lower attenuation at intravenous cholangiography as a thrombosis.
160	Right hilar mass was seen on CT scan. Repeat CT scan obtained later showed no mass to be present.
165	Ultrafast CT scan showed a column of contrast material adjacent to the aorta that was probably the result of partial volume effect but that was read as dissection. This reading was later excluded on the basis of findings at thoracic aortography and MR imaging.
170	Nonvisualization of gallbladder at US was interpreted as probable gallbladder disease. Agenesis of the gallbladder was demonstrated at surgery.

* These are the case numbers in our logbook and are used for anonymous identification of patients.

Table 4
Complications That Resulted from Failure to Follow Existing Departmental Policies

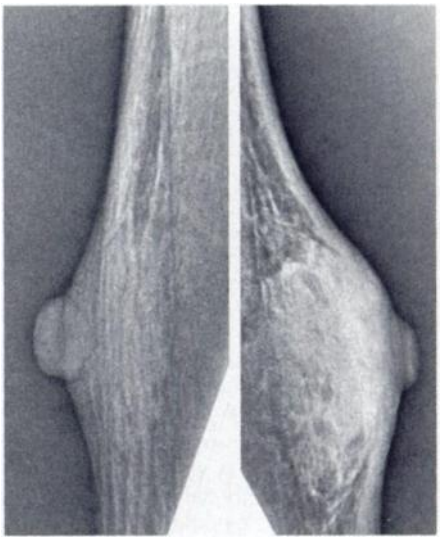
Case*	Description	Violated Departmental Standard
117	Patient suffered cardiac arrest while undergoing MR imaging.	A proper monitor cuff was not in use during the examination.
122	Hematoma developed following angiography.	Inadequate compression was applied following the procedure.
123	A pneumothorax that had been correctly diagnosed on a chest radiograph was not noted prior to angiography.	Patient's records and studies were not reviewed, and heart and lungs were not auscultated prior to angiography.
125	Subacute bacterial endocarditis followed angiography in a patient who had undergone mitral valve replacement.	Adequate antibiotic therapy should be administered to patients who undergo heart valve replacement.
135	Sepsis resulted after a barium enema study in a neutropenic patient.	Barium enema study should have been avoided, or antibiotic coverage should have been provided.
136	Hypoxia occurred during esophageal dilation.	In patients with a vascular ring, anomaly, or tracheomalacia, this complication should be anticipated prior to dilation.
142	The cerebellar tonsils were punctured during a tap to obtain cerebrospinal fluid.	Review of the MR image prior to the tap would have prevented this problem.

* These are the case numbers in our logbook and are used for anonymous identification of patients.

Table 5
Complications That Resulted in New Departmental Standards

Case*	Description	New Departmental Standard
8	A colon stricture ruptured during attempted dilation.	Dilate colon strictures only in the rectum.
42	Pneumothorax was apparent at radiography 4 hours after a lung biopsy, but a second follow-up radiograph was not obtained until 14 h after biopsy.	If the 4-h radiograph demonstrates pneumothorax, obtain a second examination at 6 h.
43	T-tube injection resulted in septicemia, probably secondary to overdistention of the biliary system.	A change in technique was instituted whereby the contrast material is allowed to drip in under the force of gravity instead of being injected.
47	During an epidural injection for pain relief, the thecal sac was initially punctured. Spinal anesthesia resulted from this injection, and hospitalization was required.	If the thecal sac is punctured during epidural injection, discontinue the procedure and reschedule at least 1 wk later.
59	Transvaginal placement of a drainage catheter was unsuccessful because of prior hysterectomy.	Do not attempt transvaginal catheter placement in patients who have undergone a hysterectomy.
109	Insulin reaction occurred in a patient during a gastric emptying study.	Perform gastric emptying studies in diabetic patients only in the morning. In addition, an intravenous catheter should be in place for rapid administration of glucose or other drugs, if necessary.
118	A contrast material reaction occurred after administration of gadopentetate dimeglumine.	Have epinephrine available in the MR imaging center for treatment of contrast material reactions.
151	Augmentation mammoplasty prosthesis ruptured because of compression during mammography.	Warn the patient of this possibility prior to performance of the examination.
173	A patient undergoing treatment with radioactive iodine had a greater dose to the thyroid gland than calculated because of retention of dose as a result of renal failure.	Calculate whole-body clearance of I-131 with the 2-μCi diagnostic dose.

* These are the case numbers in our logbook and are used for anonymous identification of patients.



a. **b.**

Figure 6. Misclassification. Images are of a 40-year-old male alcoholic patient who had noticed a small increase in the size of his right breast over the past few weeks. Mammograms show **(a)** the left breast and **(b)** the right breast. The asymmetry present on these images was interpreted as suspicious for malignancy. Pathologic diagnosis after surgery was of gynecomastia.

encountered in this series were the result of underreading or misclassification. We found that underreading (false-negative errors) occurred more than five times more frequently than overreading (false-positive errors). Our findings agree with those of prior studies (8–12) that noted failure to detect lesions in 25%–32% of cases, but a rate of false-positive interpretations of truly negative radiographs of only 1.6%–2.0%.

A variety of explanations are given for false-negative errors. Many have an aura of negligence, such as faulty imaging techniques, social pressure, carelessness, and lack of clinical data. The courts occasionally treat false-negative errors as if they were errors of negligence (13–15). However, false-negative errors occur even when these potential sources of error and others, such as poor viewing environment (eg, glare, noise, distractions) and fatigue, can be discounted. Most of these potential error sources are either untested or have not produced the effects in the laboratory that could have been expected. Of course, many of these factors are very difficult to study in the laboratory partly because the behavior of human subjects changes when they are observed.

For false-negative errors, it is frequently alleged, after retrospective review, that lesions should have been noted prospectively. There is, however, an interesting psychophysical explanation for improved retrospective perception of lesions. Two basic methods for discovering perceptual thresholds are the method of increasing limits and the method of decreasing limits. In the former, stimulus energy is increased until an observer reports that the stimulus becomes detectable; in the latter, the stimulus energy is decreased until an observer reports that the stimulus has become undetectable. The threshold of detectability established with the former method is invariably higher (more energy is required) than the threshold established with the latter. Viewing of serial radiographs prospectively is essentially a method of increasing limits, whereas viewing of a series of radio-

graphs retrospectively is essentially a method of decreasing limits. Assuming that stimulus energy is analogous to lesion size and contrast, it would make sense that more lesions are perceived retrospectively. Studies of detection of lung nodules support this thesis (16).

There are several primary ways to reduce the number of false-negative diagnostic errors. Increased education has been advocated. Development of and adherence to practice standards such as insistence on technically satisfactory images, review of prior examinations, and acquisition of appropriate clinical information are of obvious importance. Another way is to improve imaging technology so that abnormalities are more easily discovered. To a large extent this recommendation has been accomplished, and we are now considering a new class of errors. For example, until the newer modalities were used, even large pancreatic abnormalities were seldom discovered. Now we are concerned about the misclassification of recognized small pancreatic lesions.

A major but underemphasized approach to error reduction is to conduct further research on the perceptual and intellectual aspects of the human interpretive process as applied to diagnostic images. As we better understand some of the foibles of human perception, we can theoretically design imaging methods that use the more efficient aspects of the human perceptual system. Conversely, we may be able to develop methods such as analysis with artificial intelligence to substitute for defective aspects of the human eye-brain system.

Multiple areas of research may be productive in addressing the problem of false-negative readings. In addition to "satisfaction of search," research could investigate visual time and its effect on accuracy, fixation clusters and dwell time, dual reading, availability of clinical history and comparative images, application of artificial intelligence, and selection of superior observers. The potential benefit of tort procedures or tort reform to reduce such error is undetermined; such procedures consume considerable resources.

Failure to report multiple lesions has been noted in several studies (17–19). Satisfaction of search is a type of underreading error that occurs when some abnormalities remain unreported when multiple abnormalities are present in an image. Tuddenham (18) believed that a quest for meaning had been satisfied when the first positive finding was recognized, after which the image was not searched for additional findings. Although plausible, this explanation has recently been found to be inaccurate after laboratory investigations (19).

In false-positive errors, the radiographic finding is appreciated but is attributed to disease rather than to a normal physical variant. Despite the considerable increase in knowledge in recent years of what is normal in a radiologic examination, false-positive error occurs with the same frequency. As Smith (4) stated, "More emphasis should be placed on the teaching of normal anatomic and physiologic variants."

Regarding misclassification of lesions, Smith found that the acquisition of more clinical information and the conscious attempt to expand the differential diagnosis helped decrease such errors. It must be emphasized that there is a limit to the usefulness of expanding the differential diagnosis. For instance, Felson and Reeder (20) list eight common and 30 uncommon disease processes in the differential diagnosis of a solitary pulmonary nodule that is less than 4 cm in diameter, but most of the time it serves no purpose to include such a list in the radiographic report. More important than the histologic accuracy of diagnosis in a given case is patient outcome. In this regard, radiographic misclassification of disease in our series was often to a diagnosis of similar severity to the patient's true diagnosis. Misclassification of more or less severe disease occurred with roughly equal frequency. Thus, it appears that there is no systematic bias in over- or undercalling severity of disease in misclassification.

Current methods of evaluation of perceptual error leave certain areas unstudied. Analysis of receiver operating characteristic curves has been the basis for the interpretive process, particularly regarding judgment calls. This technology as currently defined is not helpful in understanding cases of misinterpretation, which is a major source of perceptual error in clinical situations. The data indicate a need to develop better experimental and formal methods of analysis of perceptual error.

In conclusion, study of the errors presented at problem case conferences demonstrated that perceptual errors continue to constitute the bulk of errors made by radiologists and that false-negative errors are the most frequently committed perceptual-cognitive mistakes. Errors secondary to complications have resulted in the establishment of several effective departmental policy changes. ■

References

1. Leape LL, Brennan TA, Naird N, et al. The nature of adverse events in hospitalized patients: results of the Harvard medical study practice II. New Engl J Med 1991; 324:377–384.
2. Yerushalmy J, Harkness JT, Cope JH, Kennedy BR. The role of dual reading in mass radiography. Am Rev TB 1950; 61: 443–464.
3. Wheeler PS. Risk prevention, quality assurance, and the missed diagnosis conference. Radiology 1982; 145:227–228.
4. Smith MJ. Error and variation in diagnostic radiology. Springfield, Ill: Thomas, 1967.
5. Kundel HL. Perception errors in chest radiography. Semin Respir Med 1989; 10: 203–210.
6. Herman PG, Hessel SJ. Accuracy and its relationship to experience in the interpretation of chest radiographs. Invest Radiol 1975; 10:62–67.
7. Rhea JT, Potsaid MS, DeLuca SA. Errors in interpretation as elicited by a quality audit of an emergency radiology facility. Radiology 1978; 132:277–280.
8. Birkelo CC, Chamberlain WE, Phelps PS, Schools PE, Zachs D, Yerushalmy J. Tuberculosis case finding: a comparison of the effectiveness of various roentgenographic and photofluorographic methods. JAMA 1947; 133:359–366.
9. Garland LH. On scientific evaluation of diagnostic procedures. Radiology 1949; 52:309–328.
10. Garland LH. Studies on the accuracy of diagnostic procedures. AJR 1959; 82:25–38.
11. Newell RR, Chamberlain WE, Rigler L. Descriptive classification of pulmonary shadows: revelation of unreliability in roentgenographic diagnosis of tuberculosis. Am Rev TB 1954; 69:566–584.
12. Yerushalmy J, Garland LH, Harness JT, et al. An evaluation of the role of serial chest roentgenograms in estimating progress in patients with pulmonary tuberculosis. Am Rev TB 1951; 64:225–248.
13. Berlin L. Does the "missed" radiological diagnosis constitute malpractice? Radiology 1977; 123:523–527.
14. Berlin L. Malpractice and radiologists. AJR 1980; 135:587–591.
15. Berlin L. Is a radiologic "miss" malpractice: an ominous example. AJR 1983; 140: 1031–1034.
16. Muhm JR, Miller WE, Fontana RS, et al. Lung cancer detected during a screening program using 4-month chest radiographs. Radiology 1983; 148:609–615.
17. Tuddenham WJ. Visual search, image organization, and reader error in roentgen diagnosis. AJR 1962; 78:694–704.
18. Tuddenham WJ. Problems of perception in chest roentgenology: facts and fallacies. Radiol Clin North Am 1963; 1:227–289.
19. Berbaum KS, Franken EA, Dorfman DD, et al. Time course of satisfaction of search. Invest Radiol 1991; 26:640–648.
20. Felson B, Reeder MM. Gamuts in radiology: comprehensive lists of roentgen differential diagnosis. 2nd ed. Cincinnati: Audiovisual Radiology of Cincinnati, 1987.