# Errors in Emergency and Trauma Radiology

Michael N. Patlas
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*To my parents, Ludmila and Dr. Natan Patlas, who showed me the way. To my wife Nataly who made me to believe in myself and continues to inspire me. To my children Michal and Jessica who make me happy and proud.*

***Michael N. Patlas***

*To Sebastian Isaiah, who will encounter some pitfalls and will probably make some errors along the way, but whom Darienne and I are confident will find the correct path, and who will have a great journey in life.*

***Douglas S. Katz, MD***

*To my parents, Pietro and Ida, for their encouragement, support, and love.*

***Mariano Scaglione***

# Foreword

Over the past half century, emergency radiology has come into being as a subspecialty on its own. Corresponding to a dynamic period in CT technology, the evolution of the specialty has been profound. What originally began as an area of interest for some has morphed into a discipline with a potential to make a vital difference in the care of acutely ill patients and victims of trauma.

As a radiologist who trained in the late 1990s, I witnessed firsthand how imaging made major inroads in the care of the emergency department (ED) patient. When I started residency in 1995, we routinely performed angiography for the evaluation of the potentially injured aorta. Some thought that CT would never achieve the accuracy needed for this potentially lethal injury. Over two decades later, it is hard to imagine diagnosing traumatic aortic injury without CT. With the added reliance on imaging, we all became aware of potential pitfalls. Of course, we all wished to be sensitive in our diagnoses but in the ED patient, specificity is equally as important. Chasing an artifact to exclude aortic injury can potentially be lethal in the setting of a pelvic fracture or grade 5 liver laceration.

CT for pulmonary embolism (PE) provides another such example. As a resident, angiography was rarely performed, and ventilation perfusion scintigraphy was the standard for the evaluation of a patient with suspected pulmonary embolism. CT was not felt to be ready to meet this challenge. Boy, how times have changed! A night in the ED rarely passes without at least one PE CT ordered. As with any widely accepted protocol, indication creep occurs and the number of truly positive studies for PE decreases. Understanding of the potential errors helps the reading radiologist make sure they find the unusual PE and prevent overdiagnosis.

In *Errors in Emergency and Trauma Radiology*, Drs. Patlas, Katz, Scaglione, and colleagues address the potential errors and pitfalls in the ED patient. By covering all organ systems, they bring together in one place all of the ways imaging can mislead us in the care of the ED patient. Specific chapters on select patient populations are also incredibly helpful in avoiding the traps of imaging in the ED. For the experienced ED reader, this work will serve as a nice review with creative approaches to reinforce techniques to improve accuracy. For the general reader, it helps put imaging findings in context so that the radiologist may make a meaningful difference and provide effective care in some of our most vulnerable patients.

Anyone taking call will appreciate *Errors in Emergency and Trauma Radiology* as a valuable, concise resource that will help diagnostic accuracy in the ED. Drs. Patlas, Katz, Scaglione, and colleagues deserve much credit for bringing these potential errors together in one place. These chapters represent a compendium of learning in the past half century that will help increase our value in the next half.

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# 1 Errors in Emergency and Trauma Radiology: General Principles

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In 2016, researchers estimated that more than 251,000 patients die in US hospitals annually as a result of preventable errors, ranking medical error as the third most common cause of death in the USA [1]. Many of these preventable deaths are due to diagnostic errors. Multiple large autopsy studies dating from 1957 [2] describe diagnostic error rates across all medical specialties ranging from anywhere between 5% and 47% [2–7]. Diagnostic errors in medicine are a major source of patient harm, and result in death more often than other medical errors including drug-related errors [8]. In addition to affecting patient morbidity and mortality, diagnostic errors also account for the leading type of paid claims (28.6%) and the highest proportion of total payments (35.2%) in malpractice lawsuits, with a 25-year sum of diagnostic-related payments in the USA totalling $38.8 billion [8].

A diagnostic error is defined as a medical error related to a missed, incorrect, or delayed diagnosis that is discovered by subsequent findings or tests [9, 10]. As medical imaging is central to the overall diagnostic process, it is logical to conclude that the incidence of diagnostic error (missed, incorrect, and delayed) is attributable, at least in part, to radiology-related errors [11]. For example, in a review of closed malpractice claims in the USA, diagnostic radiology was the sixth more frequent specialty involved [12], while approximately three out of four malpractice claims against radiologists mention errors in interpretation resulting in missed diagnoses [5, 13].

Radiology, similar to many other highly complex visual perception-based activities including air traffic control or operating nuclear power plants, relies on a sophisticated interplay of numerous psychophysiological factors and visual perception and is therefore prone to human error [14–17]. Radiological diagnosis also involves decision-making under conditions of often significant uncertainty in which the availability of clinical information, prior examinations, or use of proper technique may be variable [18]. These conditions are amplified in the fast-paced and high-stress environment of emergency and trauma centers in which the acuity of polytrauma patients, involvement of a large multidisciplinary team, and the need to make quick

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life-saving decisions all predispose the radiologist to interpretive error. Under such conditions of uncertainty, all diagnostic decisions therefore have inherent error rates [19].

In the first landmark study of its kind, in 1949, California radiologist L.H. Garland published an article entitled, “On the Scientific Evaluation of Diagnostic Procedures,” in which he demonstrated a surprising degree of inaccuracy in numerous clinical, laboratory, and radiological tests [20]. Regarding radiological examinations specifically, Garland discovered a 33% retrospective error rate among radiologists interpreting positive chest radiographs and a 2% overcall rate for normal examinations [21]. This retrospective experimental error rate translates into an error rate of approximately 3–5% when evaluating the prospective interpretation of all examinations during a routine clinical day [5]. Nearly 70 years later, despite remarkable technological advances in medical imaging, Garland’s findings on the incidence of radiological error remain nearly identical. From the 1950s to the present day, studies have repeatedly demonstrated the incidence of diagnostic error in radiology to be approximately 3–5% [17, 19, 22–30].

Unlike physical examination findings, radiological examinations are now easily accessible electronic databases which are available for subsequent scrutiny and analysis. Because of the accessibility and relative permanence of radiological examinations, the extensive collection of examinations also provides a robust data source from which not only to assess inter- and intraobserver variation, but also to retrospectively detect patterns in errors or discrepancies for educational purposes. As dozens of studies have repeatedly shown, radiological errors follow predictable patterns [5, 14, 18, 22, 30–35]. By analyzing these patterns, individual and system-wide measures may be enacted to help prevent similar errors from being made in the future.

## 1.1 General Errors in Radiology

Radiological errors may be categorized in multiple different ways [5, 11, 30, 32, 33, 36–42]. In the broadest terms, the cause of interpretive error may be either internal (specific to the individual radiologist) or external (due to larger systemic failures). To subdivide these categories further, internal factors include both perceptual and cognitive errors. Among internal sources of error, perceptual errors account for approximately 60–80% of missed or delayed diagnoses in radiological interpretation [5, 11, 36–38]. A perceptual error occurs during the first step of image interpretation. For an error to be categorized as a perceptual error, the imaging finding must be deemed sufficiently conspicuous and detectable in retrospect by the initial radiologist or in the consensus of his or her peers [11]. As such, not all subtle or inconspicuous findings that are subsequently identified and found to represent a pathological process would be classified as perceptual errors [11]. Considering that the radiological error rate has remained stable at 3–5% for nearly 70 years as noted, it is reasonable to assume that every radiologist has committed a perceptual error: a miss that, in retrospect, may appear obvious to both the original radiologist and to her or his peers.

The psychophysiologic and cognitive processes by which an obvious abnormality can simply go unseen when it is so clearly seen in retrospect have yet to be fully explained to anyone’s satisfaction. Although an increased incidence of perception error may be due to other specific risk factors including radiologist fatigue, interruptions, distractions, reading too rapidly, satisfaction of search, or various forms of cognitive bias as this chapter will discuss, most perceptual errors lack a clear identifiable cause. However, studies on radiologist perceptual errors from around the world, involving radiologists at all levels of training and experience and across all modalities, conclude that perceptual errors are not a result of carelessness or negligence; rather, perceptual errors are deemed a consequence of the physiological processes of human perception and an inherent feature of the complex system in which radiologists operate [11, 13, 14, 26, 37, 42, 43].

While perceptual errors account for approximately 60–80% of interpretive errors, the remaining 20–40% of internal errors may be classified as cognitive errors [5, 11, 36–38]. Cognitive errors have been defined as “judgment errors” [5], “faulty reasoning” [22], or “logic fallacies” [44], in which an abnormality is identified, but its clinical significance is misinterpreted, resulting in an inaccurate diagnosis [11]. Cognitive errors may be a result of lack of knowledge, faulty reasoning, or a multitude of cognitive biases. Additionally, these biases may be secondary to undue influence of previous erroneous reports (known as an alliterative error) or misleading clinical information that misdirects the radiological gaze. However, interpretive errors are more likely due to a combination of multiple factors, both intrinsic and extrinsic to the radiologist interpreting the imaging examination.

Of the numerous cognitive biases that may influence a radiologist’s interpretive process, four primary types have been repeatedly identified as potential causes of diagnostic error: anchoring, framing, availability, and alliterative [11, 31, 44–46]. Anchoring bias occurs when the radiologist fails to alter his or her initial interpretation despite being provided with contrary information [11, 31, 44]. Framing bias occurs when the radiologist is unduly influenced by the wording or framing of the clinical problem, which leads to restricted diagnostic possibilities [31, 44]. Availability bias is defined as the propensity to consider a diagnosis that comes to mind more readily to be the correct diagnosis [11, 31, 44]. This is more likely to occur after the radiologist has committed an interpretive error, which predisposes him or her to mistakenly attribute the previously “missed” diagnoses to a similar finding in a subsequent patient [44]. An alliterative error occurs when the results from the interpretation of a previous imaging examination biases the radiologist toward the same diagnosis when interpreting the current examination, which results in a diagnostic error [11, 31, 44]. Another cognitive bias described by Bruno et al. [11] is the “zebra retreat,” which occurs when the radiologist resists proposing a rare diagnosis (despite supportive findings) due to the rarity of the diagnosis.

Additional cognitive errors include complacency, faulty reasoning, lack of knowledge on the part of the viewer, and underreading [30, 42, 47]. Underreading is the equivalent to a perceptual miss, where the finding is identifiable but was overlooked by the first radiologist [30, 42]. Complacency occurs when a finding is identified but is attributed to the wrong cause and not deemed pathological, while faulty reasoning occurs when a finding is seen and interpreted as abnormal but is subsequently attributed to an incorrect etiology [30, 42]. Satisfaction of search is another common radiological interpretive error and one that produces nearly as much frustration in the radiologist as perceptual errors. Satisfaction of search is the premature discontinuation of a diagnostic search pattern after a primary, usually more obvious abnormality is detected [34, 48–51]. Once a single prominent abnormality is identified, the “search for meaning” is satisfied, and the interpreter ceases to search for additional, usually more subtle abnormalities.

In addition to internal factors, there are numerous external factors that also play a substantial role in radiological error. These external, or system-based, factors include poor or limited radiological technique, lack of access to potentially relevant prior imaging, inadequate or misdirected clinical history, increasing volume and complexity of cases, staff shortages, constant interruptions, and reader fatigue, to list just a few of the more significant external sources potentially contributing to interpretive error [5, 18, 30, 32, 42, 44, 52]. The lack of prior imaging examinations, or the failure to review relevant examinations, also contributes to interpretive error [32, 42]. Both scenarios suggest that interconnected networks of electronic medical records including radiological examinations, and increased ease of access to such prior exams, would help reduce interpretive error.

The ever-increasing volume and complexity of radiological examinations, in addition to staff shortages, have led to mounting pressure on radiologists to read more in a shorter period, which in turn results in longer work hours and mounting reader fatigue, all of which contribute to diagnostic error [44, 53–57]. Not surprisingly, increasing one’s speed at image interpretation is also a source of error. Sokolovskaya et al. [58] demonstrated that when radiologists interpreted examinations at twice the speed of their baseline, the number of significant errors increased from 10% to 26.6%. Constant interruptions and multitasking may also result in increased interpretive error. Balint et al. [59] studied the number of telephone calls on-call radiology residents received at night, and compared the increased interruptions to the rate of interpretive error (defined as a resident-attending discordant report). The study found that in the hour preceding the interpretive error, a single additional phone call above the baseline increased the likelihood of a major discrepancy by 12% [59].

One of the most important sources of radiological error occurs at the start of the imaging cycle with the examination requisition and clinical history. Pinto et al. [40] noted that the study of radiological errors has traditionally been limited to errors in the radiologist's report, which are frequently taken out of the larger diagnostic context, thereby omitting the integral role of the referring physicians. In the majority of studies on radiological errors, researchers have found that a relevant clinical history can improve diagnostic accuracy during both the perception and interpretation phases [46, 60–63]. Loy and Irwig's [60] examination of 16 studies analyzing the accuracy of reports with and without clinical history found that providing relevant clinical history improved the sensitivity of findings without decreasing specificity. Similarly, Leslie et al. [63] found that when referring clinicians provided a clinical history, radiologists changed 19% of their CT reports, more than half of which reflected major changes. Providing accurate clinical information also ensures that the appropriate radiological examination is performed, and ultimately assists the diagnostic workup [44, 46, 64].

While 40–54% of medical malpractice lawsuits against radiologists are due to diagnostic errors [65], the majority of the remaining legal complaints are due to failure to communicate the findings in a timely manner, and the failure to suggest the next appropriate procedure or examination (imaging or otherwise) [47]. Failure to communicate clinically significant findings rapidly is the fourth most frequent medical malpractice claim made against radiologists [66]. Therefore, it is in the patients' and the radiologists' best interests to communicate – and document – urgent findings quickly, and to explicitly recommend appropriate additional imaging or clinical/laboratory follow-up as necessary.

## 1.2 Errors in Emergency and Trauma Radiology

The potential for diagnostic error, whether due to perceptual errors, cognitive biases, or technical errors, is further magnified in emergency departments and trauma centers. The fast-paced setting and high-stress environment of emergency and trauma departments create a potential "perfect storm" for diagnostic errors: medically unstable and/or uncooperative patients, insufficient histories, multiple concurrent tasks, involvement of a large multidisciplinary trauma team, severity and complexity of trauma injuries, quick life-saving decisions, and often junior physicians with less experience working after hours when the trauma volume is typically highest [67–70]. Radiological errors may also be caused by radiologist fatigue and ocular strain from longer work hours, multiple interruptions, lack of prior imaging for comparison, the pressure to read examinations quickly, and the variable conspicuity of acute abnormalities in difficult-to-image poly-trauma patients. Patients who present to emergency and trauma departments are typically those with more acute injuries, and therefore carry an increased risk of morbidity and mortality at baseline. As such, the diagnostic errors committed in this acute setting carry a greater risk of severe complications and worse patient outcomes, including death.

Multiple studies evaluating missed injuries and delayed diagnoses in the emergency setting have been published, with a reported incidence of 1.3–39% [67, 71–77]. Among patients with missed injuries, 15–22.3% had clinically significant findings [77]. Gruen et al. [67] found that among trauma patients who died from recognizable errors, 16% died from delayed operative or angiographic control of an acute abdominal or pelvic hemorrhage, and 9% died from delayed intervention for on-going intrathoracic hemorrhage. In autopsy studies involving poly-trauma patients, researchers found that the primary cause of death was due to severe hemorrhage from traumatic bronchopulmonary vessel injury [78]. Of all the missed injuries in emergency and trauma centers, Teixeira et al. [72] report that diagnostic errors are responsible for approximately 10–15% of preventable deaths in trauma center audits. As selective non-operative management has become increasingly feasible after abdominopelvic trauma, diagnosis of injuries requiring surgery or interventional radiology has become more imperative. As such, injuries missed on multi-detector computed tomography (MDCT) have the potential to result in more dire consequences.

Multiple studies have proven MDCT to be superior to both clinical evaluation and diagnostic peritoneal lavage for the diagnosis of clinically significant abdominal injuries in poly-trauma patients [71, 79–82]. Due to multiple factors including decreased consciousness, unreliable histories, and distracting injuries, clinical examination of trauma patients is frequently unreliable [69, 83]. A physical examination of a trauma patient with abdominal injuries is only about 60% reliable [69, 84, 85]. As missed abdominal injuries are a well-documented cause of increased morbidity and mortality in trauma patients [71, 81, 82], early detection of these injuries by CT is crucial to improving patient outcomes. MDCT is also critical to the assessment of head trauma, which is particularly difficult to assess clinically in many poly-trauma patients due to decrease levels of consciousness, distracting injuries, and drug and/or alcohol intoxication. Studies have shown that 25% of unconscious patients with a serious head injury have misleading or equivocal clinical findings on examination [69]. In patients with poly-trauma, blunt cerebral-vascular injuries with associated vertebral and/or carotid injuries in particular are frequently missed if they are only investigated with ultrasound, which has been shown to have a sensitivity of 38.5%, compared to a 100% sensitivity with CT angiography [86].

Over the past two decades, significant developments in CT technology, including faster image acquisition, higher spatial resolution, multi-planar and 3D reformats, and decreased radiation, have resulted in the increased use of MDCT in the emergency setting. The integration of MDCT in emergency departments has improved both the speed and accuracy of diagnostic procedures and has led to early detection of clinically significant injuries [77, 87–89], thereby decreasing mortality in trauma patients [90]. With peritoneal lavage becoming increasingly obsolete [79, 91], the diagnosis of poly-trauma injuries, including acute arterial hemorrhage, now relies almost exclusively on the swift and accurate interpretation of findings from properly performed CT examinations acquired in a timely fashion [83]. In poly-trauma patients in particular, the pan-scan CT (head, chest, abdomen, pelvis, and full spine) is now considered the reference standard for the early assessment of acute potentially life-threatening injuries.

As a key member of the multidisciplinary trauma team, the radiologist not only plays a critical role in diagnosing acute life-threatening injuries but also helps direct the clinical decision-making process for surgical or conservative management. Therefore, errors in image acquisition and image interpretation may lead to suboptimal treatment and potential patient harm. Radiological errors in the emergency setting follow predictable patterns, and recognition of these patterns is crucial to avoiding error and improving patient outcomes.

## 1.3 Perception and Recognition Errors in Emergency Radiology

Although diagnostic radiology errors are often associated with perception, studies have shown that only 10% of interpretive errors are due to human perception or other nonvisual cues [67, 72, 92], while approximately 60% of radiologic errors are caused by poor technique or image quality [93, 94]. One of the most frequent causes of diagnostic error in trauma patients is the failure to identify fractures on radiographs, which accounts for 41–80% of interpretive errors in the emergency department [17, 74, 95, 96]. Moreover, missed or delayed diagnosis of skeletal injuries, particularly fractures of the appendicular skeleton, accounts for the majority of malpractice claims against radiologists [74]. The most commonly missed fractures involve the periarticular regions, shoulder girdle, and feet [97]. Approximately 10% of missed fractures involve the spine, with the cranio-cervical junction (40–50%) and the cervicothoracic junction being the most common sites of missed injury [97]. While spinal fractures can have significant orthopedic and neurological implications, they may also direct the radiologist to other associated injuries. For example, although transverse process fractures are only associated with vertebral body fractures in 1% of cases, 50% of patients with transverse process fractures have intra-abdominal injuries [98, 99].

Due to the higher sensitivity and specificity of CT compared to traditional radiography [100], delayed or missed diagnoses of abdominal and pelvic injuries are less frequent than orthopedic injuries; however, interpretive errors in abdominopelvic injuries carry a greater risk of severe complications due to the potentially life-threatening nature of solid and hollow organ injury and active hemorrhage. Among solid organs, injuries of the liver and spleen each account for approximately 10–15% of missed or delayed diagnoses [97]. Although diaphragmatic injuries are relatively uncommon and represent only 5% of delayed diagnoses [101], they remain difficult to detect [102]. Radiological suspicion, attention to secondary signs, and use of multiplanar reconstructed CT images are crucial for the correct identification of diaphragmatic injuries. In addition, vascular injuries account for approximately 5% of delayed diagnoses [97]. In pediatric trauma patients, injuries to the ureteropelvic junction are overlooked in approximately 50% of affected patients on the initial image interpretation [103], which may be due to perceptual error as well as technical error if delayed CT images are not performed. More than 80% of female trauma patients with a previously unknown first-trimester pregnancy are not found to be pregnant during the initial evaluation prior to undergoing CT examination, thereby exposing the embryo to potentially harmful radiation [104].

Other commonly missed injuries in trauma patients involve bowel and mesenteric injuries, which account for approximately 15–20% of diagnostic errors [105]. From a clinical perspective, acute bowel injury often implies surgical exploration, and missed or delayed diagnoses may significantly increase patient morbidity and mortality from sepsis and hemorrhage [106]. However, bowel and mesenteric injuries pose a unique challenge to radiologists, as 9.1–19.4% of patients with surgically proven bowel and mesenteric injuries do not have any identifiable findings on the preoperative MDCT [107, 108]. More recent surgical literature has shown an increased mortality in patients with a diagnostic delay in bowel injury in as little as 5 h [106]; therefore, Patlas et al. [109] suggest that it may be prudent to perform a follow-up CT in 6–8 h for patients with clinically suspected bowel injury or new clinical symptoms concerning for bowel injury.

In addition to recognition errors, interpretive errors may also occur when the radiologist appropriately identifies an abnormality, but mistakenly attributes it to an incorrect etiology. This type of error has been classified as faulty reasoning or a misclassification of a true-positive finding [30, 42]. Provenzale and Kranz [41] use the example of venous infarction and dural venous sinus thrombosis (DST) to illustrate this category of interpretive error. While the radiologist may accurately detect the presence of infarction, she or he may fail to appreciate a thrombosed cortical vein or dural sinus, and mistakenly interpret the finding as an arterial infarct. Similarly, when patients with DST receive IV contrast-enhanced CT and MRI, the abnormal dural enhancement due to collateral vessels may be mistaken for alternative pathologies such as neurosarcoidosis or dural metastases [41, 110].

Errors also occur when the radiologist mistakenly interprets a normal finding as abnormal, which has been described as overcalling or false-positive findings [41, 42, 70]. These findings may be attributed to poor technique, such as artifact, or anatomical variants mistaken for pathology. This type of diagnostic error is more likely to occur among radiology residents or less experienced radiologists who both lack experience and who tend to be overly cautious [41]. For example, on CT images, respiratory motion artifact may produce an indistinct gray margin around the liver, spleen, kidney, abdominal wall, or ribs [70]. This linear or halo-like appearance may be mistaken for a subcapsular hematoma or even rib fractures [70]. Similarly, cardiac motion artifact in the mediastinum may obscure the aortic root and produce crescentic gray bands within the ascending aorta, which may be mistaken for acute aortic injury. In addition to motion artifact, anatomical variants such as a splenic cleft may also be mistaken for a low-grade splenic laceration [70]. Although this category of error may not result in immediate harm, unlike a missed acute positive finding, it may result in unnecessary hospital admission for observation [70] and unnecessary follow-up examinations, which may indirectly lead to patient harm.

In contrast to overcalling, under-calling is another type of diagnostic error that has the potential to contribute to patient morbidity and mortality. Under-calling occurs when the radiologist identified an abnormality but dismissed it as normal or secondary to artifact. While over-calling may occur more frequently among cautious junior radiologists, under-calling may be more common among experienced radiologists who are accustomed to seeing artifacts and are therefore seemingly more confident in their interpretations. Provenzale and Kranz [41] suggest under-calling may occur subconsciously, without deliberation about the nature of the findings; however, Scaglione et al. [69] suggest these types of errors may occur as a result of external pressure to reduce the number of false-positive interpretations in order to minimize unnecessary follow-up. It may be reasonable to assume these errors may also be a result of lack of knowledge, whereby an abnormality is identified, but because its etiology cannot be confidently deduced, it is erroneously dismissed as insignificant, thus resulting in a missed or delayed diagnosis.

In the faced-paced and high-pressure evaluation of poly-trauma patients, many of whom present with potentially life-threatening injuries, radiologists are particularly vulnerable to satisfaction of search errors. In satisfaction of search errors, as previously described, once a major abnormality is identified, the radiologist may rapidly shorten her or his search time, thereby overlooking additional abnormalities [30]. As Berbaum et al. [51] noted, satisfaction of search errors are the result of a deliberate truncation of a search rather than a faulty search pattern. Poly-trauma patients, by definition, present with multiple injuries, many of which may be life-threatening. It is therefore the radiologist's responsibility to quickly and accurately identify the most urgent findings that require immediate surgical or other clinical interventions, carefully characterize the findings, and directly communicate critical findings to the appropriate clinical team members. When injuries such as active vascular extravasation, acute aortic injury, pneumoperitoneum, or massive pneumothorax are identified, the radiologist may focus on these findings, and inadvertently abbreviate the remainder of the search, thereby overlooking more subtle, but potentially just as clinically significant abnormalities.

Due to the acuity of patients in the emergency department and the speed with which clinical decisions must be made, strong communication between the radiologist and the treating physician is critical. In many instances, a final written report is not sufficient, as the time delay between the radiologist completing the report and the ER physician or surgeon reading the report is unpredictable. This delay in communication is one of the most frequent causes of medical malpractice claims made against radiologists [66]. In cases of acute, life-threatening findings that require immediate intervention, direct verbal communication between the radiologist and clinician may avoid delays in treatment and prevent any confusion about the severity of injury. Documentation of all verbal reports should include the date, time, name of the clinician(s) with whom the radiologist discussed the findings, and a detailed account of what was discussed [111].

Another important communication error occurs when the radiologist does not expressly communicate her or his recommendations for additional or follow-up imaging or other examinations. As discussed previously, the ACR practice guidelines state that "follow-up or additional diagnostic studies to confirm the impression should be suggested when appropriate" [112]. Frequently in poly-trauma patients, these recommendations are made at the time of scanning at the CT console. For example, delayed phases may be added if there is suspicion for ureteral injury, or a CT cystogram may be recommended in the case of potential bladder injury. However, in patients with equivocal findings who require follow-up, it is important that the radiologist recommend both the type of follow-up examination and the timeline in which it should be performed. This is particularly crucial for suspected bowel and mesenteric injury, which may not have any imaging findings on the initial MDCT scan, or the findings may be quite subtle [107, 108]. However, if bowel injury is suspected, it is imperative the radiologist recommended follow-up in as little as 6–8 h [109] to avoid potential sepsis and hemorrhage [106].

Emergency physicians and associated health-care practitioners must also communicate clearly with the radiologist and provide an adequate clinical history to avoid potential missed and delayed diagnoses. Without adequate history of the mechanism of trauma and presenting injuries, the radiologist cannot protocol the appropriate cross-sectional examination with the necessary sequences, which predisposes the radiologist to both perceptual and technical diagnostic errors. Scaglione et al. [69] stated that approximately 40% of the patients with delayed diagnoses are due to clinical survey oversight. More specifically, an incomplete history has been shown to result in a 10% likelihood of delayed diagnosis [73]. Additional studies have found that 15% of delayed diagnoses are due to the failure of the clinician to order appropriate imaging of the region of injury identified during clinical examination [73]. Obtaining an adequate history from a trauma patient is notoriously difficult, as noted [97]. However, appropriate imaging and interpretation can only be accomplished if there is clear communication between the treating physician/health-care practitioner and the radiologist regarding the clinical suspicion of injury.

## 1.4 Technical Errors in Emergency Radiology

Although there has been a great deal of research conducted on diagnostic errors associated with individual perception and cognitive biases, it is important to remember that a far greater percentage (upward of 60%) of radiological errors are caused by poor technique or image quality [93, 94]. As MDCT has become the reference standard for evaluating poly-trauma patients, adherence to proper technique and protocol is critical to avoid inadequate and potentially non-diagnostic examinations. When imaging a poly-trauma patient with MDCT, it is important that the radiologist and CT technologist work in close collaboration with the trauma team to avoid potential errors and optimize scanning technique. To start, the patient should be undressed to ensure no clothing-related artifacts obscure the image, have at least an 18 g IV to ensure adequate contrast administration, have their arms raised above their head (if possible in the context of injury) to avoid bony artifact in the chest and abdomen, have their arms down if the area of interest is in the head or neck, and either be cooperative or sedated to minimize motion artifact [113].

Once the patient is properly prepared for the CT scan, the appropriate protocol must be selected based on the clinical history and mechanism of injury. While in some patients this may include a full-body scan (head, chest, abdomen, pelvis, and spine) with arterial and portal venous phases, other patients may require more tailored approaches with additional phases of imaging. This includes patients with acute hemorrhage who may require multiphasic imaging to accurately characterize the source of hemorrhage. At the minimum, a CT angiogram of the chest, abdomen, and pelvis is recommended to detect the source of acute arterial hemorrhage [114–117], although non-contrast and/or delayed CT acquisitions may be useful to better characterize the source of bleeding. However, not all sources of hemorrhage are arterial; therefore, it is imperative to attempt to identify whether the source of extravasation is due to either an arterial or venous injury, which will help direct interventional and surgical management as necessary [69, 118].

After the biphasic (arterial and portal venous) examination has been performed, the radiologist may detect potential renal, ureteral, or bladder injuries requiring additional phase images. If the emergency radiologist is not at the scanner at the time of CT image acquisition to direct further imaging, multiple injuries only detectable on delayed phases may potentially be missed. For example, if there is suspicion for renal or ureteral injury, a delayed excretory phase is recommended at an 8–12-min delay. If there is suspicion for bladder injury, an MDCT cystogram should be performed to assess the extent of injury and to characterize if it is intra- or extraperitoneal or both, which will dictate surgical management [119]. Delayed CT images also help to further characterize solid visceral organ injuries that involve the vasculature and which may also require surgical or urgent interventional management [120–123].

Appropriate MDCT technique is also crucial in the evaluation of cerebral trauma. As blunt cerebral-vascular injuries are frequently underdiagnosed in poly-trauma patients [86], full evaluation with a CT angiogram of the carotid and vertebral arteries as well as of the circle of Willis may help avoid missed or delayed diagnoses of vascular injury and potentially prevent neurological complications. With advances in MDCT techniques, a full-body CT angiogram from the circle of Willis to the pelvis is possible and has been advocated in patients with severe poly-trauma [124–126]. In order to maximize image quality and prevent missed or delayed diagnoses, appropriate MDCT protocols must be used. This includes important follow-up examinations for patients with equivocal findings on the initial MDCT, such as those with potential bowel or mesenteric injury, as well as in patients with new or worsening symptoms.

Once all of necessary phases of an MDCT examination have been obtained, multi-planar reformatted images must also be evaluated. Coronal and sagittal reconstructions are particularly helpful for localizing the source of any acute hemorrhage [17], characterizing spinal fractures, assessing bowel and mesenteric injury [127], and identifying diaphragmatic injuries which are notoriously difficult to detect only on axial images [102] and are therefore easily missed.

## 1.5 Solutions and Prevention of Radiological Errors

When considering potential solutions to preventing diagnostic error in radiology, it is important to consider both person-centered and system-based solutions. However, care must be taken when defining a person-centered approach, as the aim is not to focus on an individual who has committed an error and thereby subject him or her to blame, shame, or disciplinary action [18]. Such targeted shame-based approaches have been proven counterproductive and ill-suited to the health-care domain [128]. Instead, the focus should be on the larger forces that have created the conditions for the error to occur. This is not to say that solutions such as improved education cannot be directed at particular individuals, specifically radiologists-in-training and junior attendings; rather, continuing education and adherence to standards of care should be directed toward all members of the radiology department.

Education on radiological errors, including cognitive biases and the propensity to commit satisfaction of search errors, may help raise awareness of the common "error traps" [18] and thereby decrease the incidence of these errors. For example, if awareness is raised about alliterative bias, whereby reading the previous report may unduly influence the interpretation of the current examination, radiologists may choose to avoid consulting the prior report until they have completed their own evaluation of the current examination. To decrease satisfaction of search errors, education on complete search strategies and common mechanism-based multiple injury patters may prove beneficial [127]. For example, knowledge of trauma injury "packages" (such as right-sided injuries or left-sided injuries) may help focus the radiologist's attention on organ systems and adjacent structures most likely to be involved in particular mechanisms of injury, thereby decreasing the potential for missed or delayed diagnoses. Additionally, the use of checklists or dictation templates (especially for residents and junior attendings) may reduce diagnostic error by promoting a more systematic and complete search process [127].

Intradepartmental and multidisciplinary meetings focusing on clinical and radiological diagnostic errors may also prove beneficial from an educational standpoint. However, for such meetings to be productive and to have a positive learning outcome, the culture of the meeting must not be one of blame. Fitzgerald [18] noted in 2001 that the culture at that time was to embarrass and shame the radiologist who committed the error. This approach has the potential to undermine the educational value and instead foster a culture of fear and animosity. Radiological error/quality assurance meetings (or morbidity and mortality rounds) may be more beneficial if they are conducted according to the principles outlined by Chandy et al. [129]: a confidential reporting system, anonymous presentation, written reports by peers at the meeting, and consensus adjudication on the presence or absence of error. Encouraging radiologists to share their diagnostic misses and mistakes with others in a supportive learning environment may not only help others avoid similar errors but may also lead to greater self-awareness of one's own search errors and cognitive biases, thereby decreasing diagnostic errors overall.

At the system level, it is important that all equipment is functioning optimally in order to maximize the quality of image production. Standardized MDCT protocols are also important, particularly in the evaluation of poly-trauma patients. Depending on the mechanism of injury and the clinical suspicion, whole-body MDCT protocols including angiographic examinations from the circle of Willis to the pelvis may prove beneficial in detecting otherwise occult injuries [124–126]. The radiologist should also be encouraged to be present, when possible, at the CT scanner at the time of image acquisition in order to assess the need for delayed imaging or a CT cystogram.

As fatigue and ocular strain have also been proven to contribute to diagnostic errors [56], optimizing ergonomics, encouraging breaks, and promoting physical activity whenever possible may prove beneficial in reducing error rates [130]. Optimal lighting and individualized ergonomic settings of PACS stations may reduce physical stressors and improve the reading experience, which may potentially decrease diagnostic error [44]. Decreasing the number of interruptions may also prove beneficial, as disrupting radiologists' focus during image interpretation has been shown to result in interpretive errors [59]. For example, Rosenkrantz et al. [131] found that the introduction of reading room coordinators to assist radiologists with phone calls and other administrative tasks significantly decreased interruptions and improved radiologists' workflow efficiency. Implementing similar programs throughout radiology departments may also help to reduce diagnostic errors.

Recent advancements in artificial intelligence (AI) and machine learning (ML) algorithm also promise to streamline the data mining and organizational tasks that often detract from radiological interpretation of examinations [132–135]. For example, Thrall et al. [133] argued that, more than improve diagnostic accuracy, AI can be applied to numerous practical issues that radiologists encounter on a daily basis: optimizing work lists to prioritize cases, pre-analyzing cases in high-volume settings to help eliminate observer fatigue, extracting information from images not readily apparent to the human eye, and improving the quality of reconstructed images [133]. The application of AI may also assist with the timeliness of image interpretation and communication of urgent findings. If algorithms can be used to prescreen examinations rapidly and detect urgent findings such as pulmonary emboli, pneumothorax, pneumoperitoneum, or other potentially life-threatening conditions, the program could alert the radiologist to prioritize the case for immediate interpretation [133]. For example, Prevedello et al. [136] developed a machine learning algorithm to identify critical findings on non-contrast-enhanced CT examinations of the brain. The program was found to be highly accurate in detecting intracranial hemorrhage, mass effect, and hydrocephalus, with an area under the receiver operating characteristic curve of 0.91 [136].

By prioritizing examinations for urgent review, AI may potentially reduce interpretive error by decreasing delays in diagnosis and improving communication. Prescreening algorithms may also help to identify critical findings and prevent errors of omission and satisfaction of search errors [135], which would also help to avert delayed and missed diagnoses. In their study on identifying strokes, Griffis et al. [137] developed an algorithm using naïve Bayes classification to automatically identify strokes on T1-weighted MRI images, which correctly predicted lesion locations for 30/30 untrained cases. Additionally, Thornhill et al. [138] have used advanced morphometric analysis to help distinguish free-floating intraluminal thrombus from atherosclerotic plaque in patients presenting with TIA or stroke. By more accurately characterizing a symptom-related intravascular lesion as thrombus or plaque, the application of this algorithm may help to optimize patient management and improve patient outcomes [138].

While some may argue that AI will eventually replace human radiologists [139] (and other specialists including dermatologists, neurologists, radiation oncologists, and many more), others see AI as a valuable tool that will ultimately increase radiologists value, efficiency, accuracy, and personal satisfaction [132–135]. As Recht et al. [132] argued, using AI algorithms to perform the quantification tasks and data mining of electronic medical records will help radiologists refocus their energies on more value-added functions that computers cannot provide. With the help of AI, radiologists can increase their professional interactions, become more visible to patients, and ultimately play a more active, visible role in integrated clinical teams to improve patient care [132].

## 1.6 Conclusion

Radiological diagnosis in an emergency and trauma setting demands quick decision-making under conditions of significant uncertainty in which the availability of clinical information, prior examinations, or the use of proper techniques is often highly variable [18]. Therefore, all such decisions have inherent error rates [19]. While diagnostic errors are responsible for only approximately 10–15% of preventable deaths in trauma center audits [72], as selective non-operative management has become increasingly feasible after abdominopelvic trauma, the accurate diagnosis of injuries requiring surgical or interventional management has become more imperative. As such, injuries missed on MDCT have the potential to result in more dire consequences. Radiologists are key members of the multidisciplinary trauma team, and play a critical role in not only diagnosing acute, potentially life-threatening injuries, but also in directing the clinical decision-making process toward appropriate surgical, interventional, or conservative management.

Radiological errors in the emergency setting follow predictable patterns. By analyzing these patterns, individual and system-wide measures may be enacted to help prevent similar errors from being made in the future. For example, diagnostic errors may be reduced by on-going education on the individual sources of error, including satisfaction of search error and cognitive biases, as well as through the use of standardized reporting or checklists. Additionally, implementing supportive intra- and interdisciplinary morbidity and mortality rounds may allow radiologists to learn from each other's mistakes, while becoming more cognizant of their own search patterns and biases. Finally, at the system level, ensuring appropriate MDCT and other imaging protocols are followed, attempting to limit interruptions, and promoting radiologists' physical and mental well-being through optimization of ergonomics and minimization of fatigue, may all help to reduce interpretive error.

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# Mistakes in Imaging Interpretation of Traumatic and Non-traumatic Brain Emergencies

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The Merriam-Webster Dictionary defines an error as an act that through ignorance, deficiency, or accident departs from or fails to achieve what should be done. Errors in medicine can arise from different causes including technical failure, perceptual problem, cognitive biases, system errors, etc., and mitigation of these errors requires a thorough understanding of the root causes in each scenario since it may be multifactorial. Errors in radiology are unique within the practice of medicine, since the missed imaging finding or misinterpretation of an imaging examination stays for posterity and can be accessed easily much later in time, unlike errors in clinical examinations that often are not accessible for investigation at a later time. They are also unique due to the inherent differences in the acquisition and interpretation of imaging examinations, and are more prone toward perceptual and cognitive biases.

For the sake of simplicity, errors in radiology can be broadly divided into perceptual and interpretive errors, but it is important to understand that these categories are not mutually exclusive. There are different system and cognitive factors which can lead to diagnostic error. In the field of emergency radiology, errors often occur due to repeating themes, which are particularly specific to this subspecialty. These include the need for a quick turnaround time (implying less time to spend on each image in cross-sectional examinations, which typically have hundreds of images, if not thousands for some MR examinations), inadequate clinical history (which can lead to misdirection of the focused search for abnormalities), relative inexperience of the radiologist in

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