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Errors in imaging of traumatic injuries

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Abstract

The advent of multi-detector computed tomography (MDCT) has drastically improved the outcomes of patients with multiple traumatic injuries. However, there are still diagnostic challenges to be considered. A missed or the delay of a diagnosis in trauma patients can sometimes be related to perception or other non-visual cues, while other errors are due to poor technique or poor image quality. In order to avoid any serious complications, it is important for the practicing radiologist to be cognizant of some of the most common types of errors. The objective of this article is to review the various types of errors in the evaluation of patients with multiple trauma injuries or polytrauma with MDCT.

Key words: Traumatic injuries—Abdominal trauma—Polytrauma—Errors—MDCT

Errors in radiology have been a highly debated topic as early as the 1920s because of their serious medical and legal implications [1]. This topic is especially important in patients with polytrauma, which is defined as traumatic injuries affecting multiple organs concurrently and being life threatening, even though the mortality of polytrauma patients has significantly dropped from 40% to 10% from 1907 to 2008 [2]. Only 10% of these errors are due to human perception or other non-visual cues [3–5]. With the implementation of multi-detector computed tomography (MDCT), errors can also be caused by poor image quality and technique [6].

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A trauma team, which consists of emergency physicians, surgeons, radiologists, and the ancillary staff, works very efficiently if they are given sufficient patient information [7, 8]. If patients are unconscious, uncooperative, hemodynamically unstable, or do not have an adequate clinical history, then they become particularly challenging [9, 10]. An incomplete history results in 10% likelihood in the delay of diagnosis [11] and insufficient physical exam in a patient with abdominal injuries is only 60% reliable [12, 13]. Twenty-five percent of unconscious patients with serious head injuries have equivocal or misleading clinical findings. Therefore, a patient with polytrauma is a catalyst for multiple errors as well as serious complications for various reasons: inadequate history, quick life-saving decisions, multiple concurrent tasks, and multidisciplinary approach. Moreover, the vast majority of physicians working at a level 1 trauma center comprise junior medical staff, often still poorly experienced in the management of polytrauma patients [4, 7]. Therefore, errors can occur because of the severity and complexity of the injuries or due to the patient's pre-existing medical conditions [9].

Because of all these factors, a radiologist must review a patient's studies thoroughly.

A complete history, including the type and the mechanism of injury, is instrumental in directing the physician to perform a more thorough physical exam [14, 15]. By knowing this, radiologists can avoid future mistakes, which are common among a specific patient population. For example, blunt trauma in the elderly has more severe injuries than in children [16]. Approximately 40% of the cases of a delayed diagnosis are due to a clinical survey oversight: 15% occur during the primary survey, 25% occur during secondary survey, and 50% occur during tertiary survey or re-evaluation. Errors in

the execution or reporting of diagnostic exams can also contribute to these oversights in the secondary and tertiary surveys. The rate of misdiagnosis (incorrect or even not performed diagnosis) ranges widely from 2% to 40% based on how the frequency of error was determined (trauma registries, retrospective chart review, and retrospective review of all admissions) and a clear numerical estimation is difficult just because of the considerable heterogeneity of the methods of retrospective assessment between the different centers [17]. At the end of a large retrospective study, Geyer et al. concluded that only a few missed injuries in initial WBCT reading are clinically relevant; however, as the vast majority of these injuries are detectable, the radiologist has to be alert for commonly missed findings to avoid a delayed diagnosis [18]. Therefore, the errors in emergency radiology are multivariable [19, 20]. Since MDCT's implementation in the evaluation of the patients with polytrauma, the cause for different and recurrent types of errors in addition to their rationale has been discussed extensively [21–24].

Typically, errors with MDCT are commonly associated with perception or non-visual cues, but about 60% of the missed cases are caused by poor technique or poor image quality [2, 25] which is known as technical and methodological errors.

Technical and methodological errors

Since inception of faster multi-detector CT scanners with higher resolution, various members of the medical staff are able to perform ''whole-body'' Computed Tomography (WBCT) scans on both the stable and unstable patient. With the appropriate technique, adequate contrast enhancement, and sufficient clinical information, MDCT has become the gold standard for the evaluation of patients with polytrauma. At many institutions, a WBCT protocol [26–28] is routinely performed in patients with polytrauma. This is especially important in the assessment of patients with spinal and pelvic fractures, which are frequently missed on plain-film radiography. MDCT is also essential in the identification of traumatic injuries to head, chest, or abdomen. Above all, this is critical in locating the source of bleeding with a vascular injury, which are more acutely important and of greater clinical relevance than fractures of the extremities or solid organ injuries [29]. Blunt cerebral-vascular injuries are frequently under-diagnosed in patients with polytrauma [30]. Therefore, these patients should also undergo a contrast-enhanced MDCT involving the carotid and vertebral vessels in the arterial phase. MDCT technology results in reduction of the temporal resolution, which has several advantages in the detection and characterization of vascular injuries [31]. The primary cause of death in patients with polytrauma is primarily due to severe hemorrhage from traumatic broncho-pulmonary vessel injury [32]. Therefore, MDCT protocols in the polytrauma patient should also include CTA of the chest [33].

MDCT has a high sensitivity for the detection of active bleeding in the trauma patient [34]. The sensitivity of active hemorrhage with MDCT in patients with visceral injury or pelvic fractures is 13%–18% [35, 36]. This carries a significant morbidity and mortality in polytrauma patients because it suggests a vascular or solid organ injury [37]. The detection and localization of active extravasation improves patient care, thus it avoids a delay or a missed diagnosis. The topic of vascular injuries in polytrauma patients with solid organ (liver, spleen, kidney), gastrointestinal/mesenteric, and pelvic sources of bleeding have been discussed extensively and many classifications of injuries were established based on CT findings [29, 31, 38–43].

From the authors' perspective, it is not sufficient to just identify the region of extravasation, but it is even more important to differentiate whether it is arterial or venous hemorrhage. This is important because patients with hemorrhage are not always hemodynamically unstable. Therefore, the use of the appropriate MDCT protocol is important to find the source of the bleed for the interventional radiologist before the patient succumbs to hypovolemic shock [43].

Current MDCT protocols are highly sensitive for active hemorrhage and should be tailored as necessary. A non-contrast study should always be performed in order to assess for parenchymal lesions in the presence of hemoperitoneum or the ''sentinel clot'' sign (this is important in identifying the source of bleeding when other findings of vessel injury are not present, or identifying intramural hematoma of the aorta, which cannot be seen on contrast-enhanced study). Then, a biphasic—arterial and venous—study after the injection of approximately 100–130 mL of iodinated contrast (370–40 mgI/mL) at high flow rate of 3–5 mL/s [44] allows the identification of any eventual active bleeding also defining its characteristics (low or high flow, arterial or venous origin). Bolus tracking is preferred in any case over manual technique for timing of the arterial phase. A slice thickness in the range of 0.5–3 mm is recommended for evaluating vasculature in the arterial phase, but 3–5-mm slice thickness is sufficient for identifying solid organ injury with venous phase. In order to immediately evaluate the progress of the bleeding sites, additional scans can be performed soon after the acquisition of the venous phase, so differentiating life-threatening massive arterial bleedings from insidious low-flow venous bleedings. If there is suspicion of injury to the kidneys or ureters, delayed excretory phase is recommended as nephrographic phase at 500–700 s delay. This phase is important not only in the dynamics of vascular extravasations (changing in morphology) but also to assess for trauma to ureters, which is managed either conservatively or with a percutaneous drainage catheter with or without

ureteral stenting [41] (Fig. 1). For bladder injury, active distension of the bladder followed by MDCT Cystogram with diluted contrast material is required to exclude a bladder leak [45–47]. It is important to avoid false-negative cases to recognize that passive distension of the bladder, using excreted contrast material only, during a routine MDCT study cannot be relied on to diagnose bladder rupture, even with clamping of a urethral catheter [45, 48, 49], even if the bladder is distended. Between 300 and 350 mL of 5% diluted contrast media is

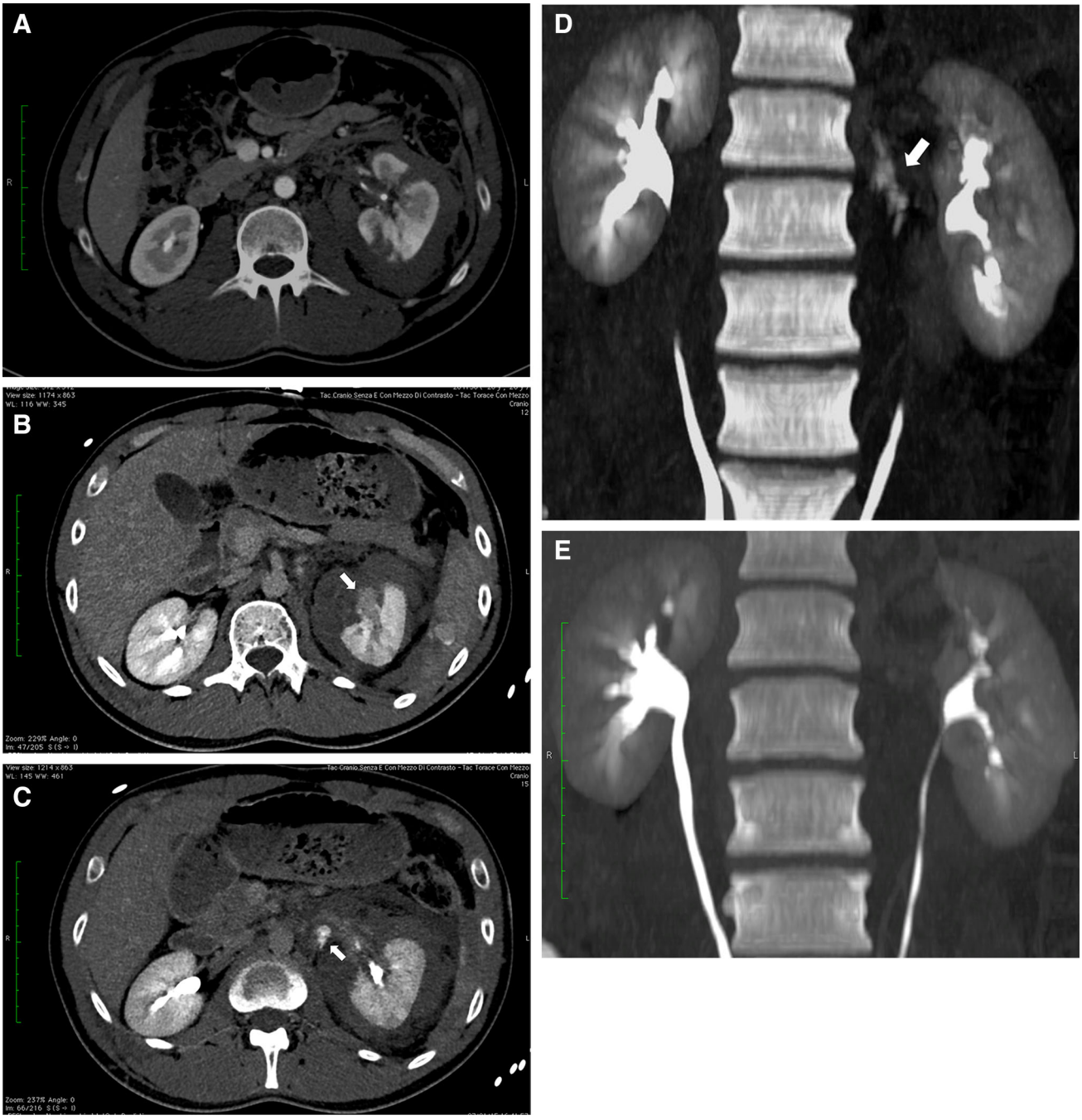

Fig. 1. 28-year-old male patient admitted to the Emergency Department after a motor vehicle accident. **A** Contrast-enhanced axial scan shows deep renal lacerations with a surrounding peri-renal hematoma. **B** Contrast-enhanced axial scan shows a high-density fluid within the urinary pelvis (*arrow*). Fluid within the pelvis should not be mistaken for a venous bleeding. **C** In the delayed acquisition, axial CT scan shows urine extravasation from the left pyelo-ureteral junction (*arrow*). **D** Coronal MIP image shows continuity of the left collecting system which suggests a non-operative management. Urinary leak from the pyelo-ureteral junction is also seen (*arrow*). **E** After six hours of follow-up, coronal MIP reformation demonstrates integrity of the collecting system without any urinary leak.

instilled into the bladder followed by axial CT imaging of the pelvis [49]. The distension of the bladder with diluted contrast material before performing CT of the abdomen and pelvis CT has shown satisfactory results [46].

At our institution, MDCT cystography is performed after the initial CT of the abdomen and pelvis [50]. This technique consists of pre- and post-cystography CT scans, to insure extra-luminal contrast material from the procedure is actually from the bladder. If the bladder is filled before the CT scan, a urinary leak can be confused with an active bleeding. Therefore, contrast medium, which leaks due to lower urologic injuries, can interfere with the CTA for pelvic arterial extravasation, thus resulting in a delay of localization and plans for embolization [51]. Another way to avoid a delayed diagnosis is with the use of the post-processing tool multiplanar reformations (MPR). This is helpful in identifying spine fractures, pelvic fractures, diaphragmatic injuries, hematoma, and regions of active hemorrhage. MPR can also better delineate a ureteral or bladder injury. The most common location for a bladder injury involves the dome of the bladder [51]. MDCT scanners have improved imaging quality using faster acquisitions and thinner slice thickness. Isotropic datasets of large regions are acquired with reformations to provide a roadmap of the vascular and bony structures [52].

Axial, sagittal, and coronal planes are important to identify the vessel of origin of active hemorrhage as well as to understand the extent and severity of injury by identifying the area of active hemorrhage [53]. MPR can also be used to accurately classify vessel injury such as pseudo-aneurysm and arterio-venous fistulae. In all cases, coronal and sagittal MPRs should be calculated using the complete reconstruction matrix for only one body region such as thorax and abdomen and head and neck. This is crucial, as only this strategy allows for optimal high-resolution good-quality MPR reconstructions knowing that the pixel matrix is fixed and limited and so stretched over just one body region and not the entire torso.

Differentiating an active arterial bleeding from other entities such as pseudo-aneurysms and arterio-venous fistulae remains difficult in some cases, with 25% of the latter two conditions misdiagnosed or even non-diagnosed [43]. The use of standardized MDCT protocols may increase diagnostic sensitivity, with significant therapeutic and prognostic implications: when an active bleeding or a contained vascular injury is detected, in fact, the trauma surgeon can then decide whether a conservative therapy, endovascular intervention, or emergency surgery is the best course of action.

Spectrum of diagnostic errors

One of the most commonly type of error in diagnostic radiology is the failure of recognition. For instance, one of the most common causes of error in polytrauma patients is failure to detect fractures, which may account for 41%–80% of diagnostic errors in the Emergency Department [53–56]. Missed fractures are most commonly located in the peri-articular regions, shoulder girdle, and feet. Spine injuries comprise only 10% of all initially missed diagnoses. These are common at the cranio-cervical junction and cervico-thoracic junction. Transverse process fractures are associated with vertebral body fractures in approximately 10% of the cases and are associated with intra-abdominal injuries in up to 50% of the cases [57, 58].

In comparison, the fractures of the extremities missed liver and spleen injuries contribute to 10%–15% of missed findings. Injuries to the small and large bowel also contribute to diagnostic errors (approximately 15%–20% of delayed diagnoses). Diaphragmatic injuries are uncommon and also represent only 5% of all delayed diagnoses. Vascular injuries constitute only 5% of delayed diagnoses [17]. Among children with polytrauma, uretero-pelvic junction injuries were missed in approximately 50% of cases on initial evaluation [59]. Finally, more than 80% of women with a unknown pregnancy are undiagnosed on initial evaluation and clinical guidelines and radiological protocols are not established for emergent imaging in pregnant women [60].

Perceptual errors, in general, can be related to multiple cognitive and physiological factors, including level of observer alertness or fatigue, duration of the observation task, any distractions, conspicuity of the abnormality as well as many others [61].

Another type of error is incorrectly classifying a normal finding as abnormal; this phenomenon is often common among radiology residents or inexperience radiologists who are being overly cautious [62]. As a result, this will cause an unnecessary hospital admission. For example, patient movement or respiratory motion can sometimes simulate fracture or cause a double contour within a solid organ which can mimic a subcapsular hematoma. Streak artifact from bones (arms commonly) can simulate a parenchymal laceration in the solid organs (spleen and liver typically). Anatomic variants, actually of no clinical relevance, may mislead the observer, as in the case of splenic clefts, often misdiagnosed with low-grade parenchymal laceration (Fig. 2) [7, 63].

Conversely, intentional under-calling is a tendency to interpret abnormality finding as negative [64]. This can occur because of pressure from others to reduce the number of false-positive interpretations, thus thereby minimizing any unnecessary follow-up. Some have described this type of error as faulty reasoning [65].

Another category of error is not due to failure to detect or characterize an abnormal finding but assign it an incorrect etiology or underestimate–overestimate the severity of the related pathologic condition (e.g., a radiologist may address to operative management when

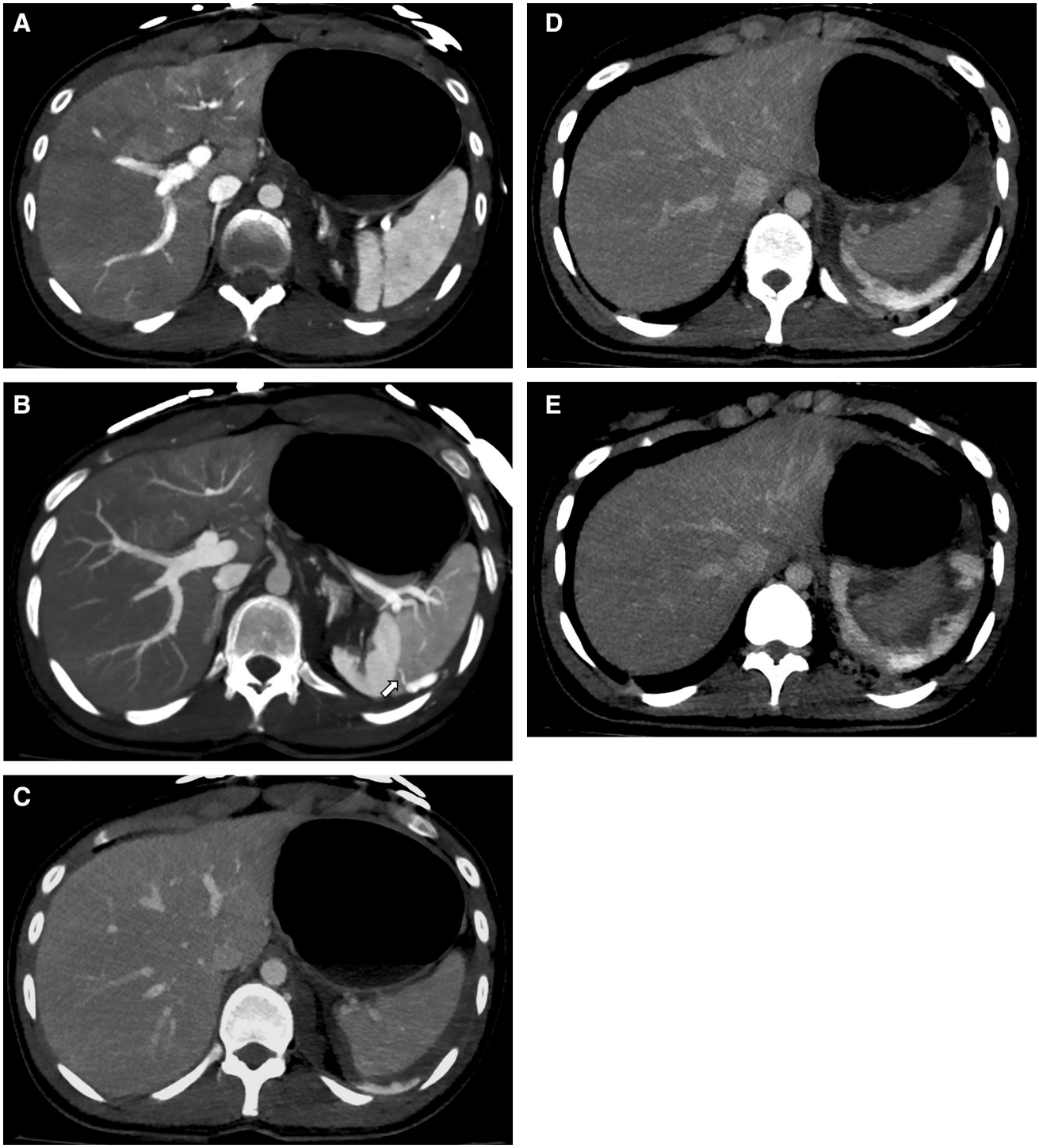

Fig. 2. 36-year-old female post a high-energy deceleration injury in comatose status. **A** Contrast-enhanced axial CT scan shows a deep splenic cleft. This finding may be confused with a splenic laceration especially when there are traces of blood in between (**B** *arrow*). **C**–**E** Three non-contiguous enhanced CT scans show large amount of active bleeding in the left subphrenic space which was erroneously related to a splenic injury. Location and disposition of active bleeding would have addressed the suspicion on a diaphragmatic arterial injury. The patient was taken to the operating room. The spleen was intact at laparotomy. However, a diaphragmatic arterial injury was found. This injury is managed ideally with angiographic embolization.

not necessary) (Fig. 3). Provenzale et al. classified these last two types of error as a error of misinterpretation [62].

Another form of observer error that can result in important findings being overlooked is due to the ''satisfaction of search'' (SOS) error. This is defined as once a

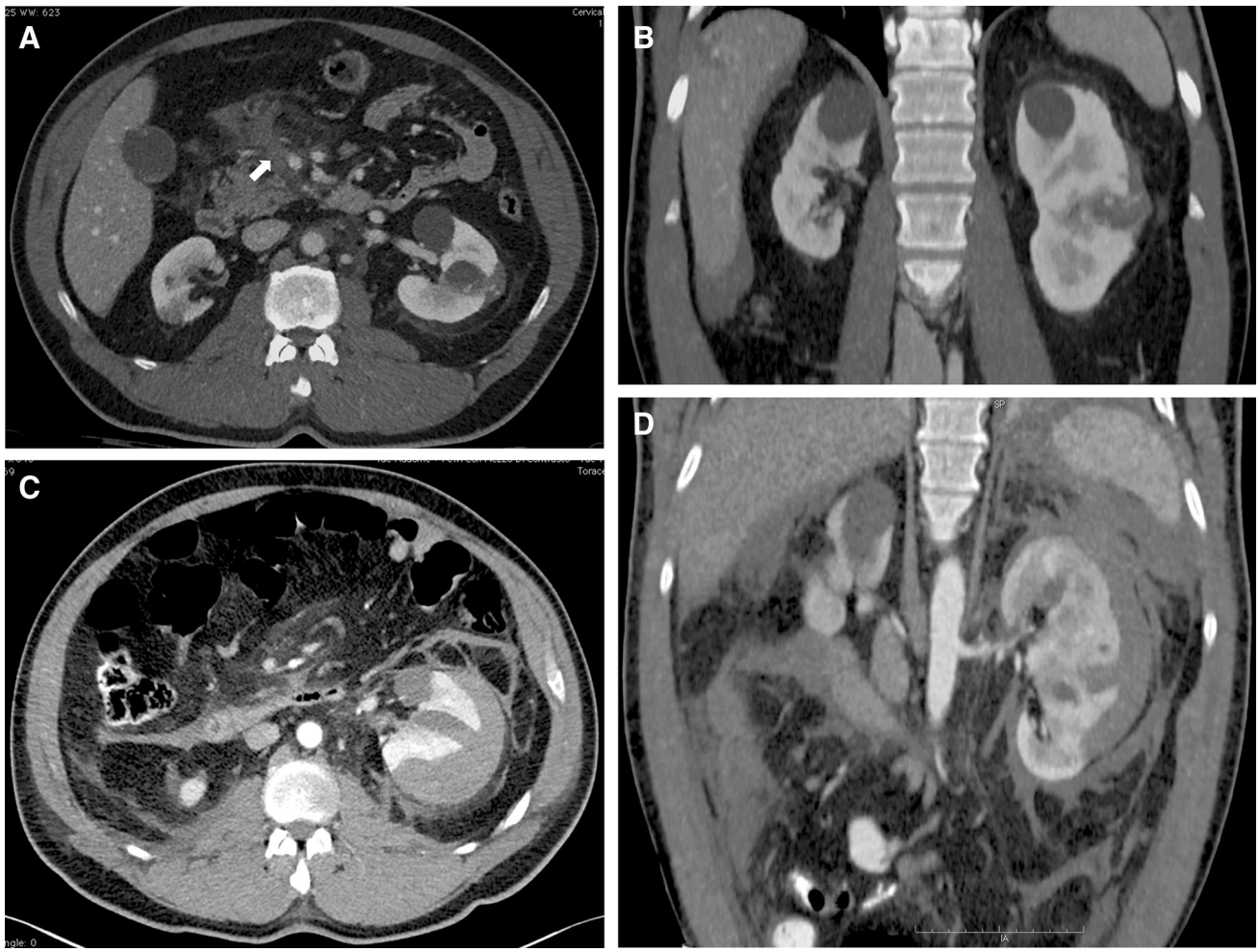

Fig. 3. 60-year-old male patient run over by a car. **A** Axial contrast-enhanced scan reveals ruptured left renal cyst with signs of active bleeding. A wide meta-traumatic mesenteric infiltration from trauma is also appreciable, with small, not refurnished blood collections, suggestive for mesenteric haematomas (*arrow*). Coronal reformation image (**b**) better depicts the ruptured left renal cyst, also highlighting the presence of a subtle subcapsular haematoma. CT control performed 48 h later (**C**, **D**) shows evident increase of the subcapsular blood collection and diffuse imbibitions and inhomogenity of the retroperitoneal spaces from haemoretroperitoneum, with ruptured cyst more evident. No active bleeding was demonstrated at CT. Finally, the patient was successfully managed non-operatively.

major abnormal finding has been detected, the radiologist's search time is quickly abbreviated from the rest of the study [66], thus further abnormalities are left virtually undetected. This is a deliberate truncation of a search rather than a faulty search pattern [67].

Another main reason why radiologists are sued is the failure to suggest the next appropriate study. Radiologists must recommend the most appropriate study according to the American College of Radiology appropriateness criteria. The American College of Radiology "Practice Guideline for Communication of Diagnostic Imaging Findings" states that "follow-up or additional diagnostic studies to clarify or confirm the impression should be suggested when appropriate" [68]. This is the case, for example, of a polytrauma patient who has equivocal findings.

However, errors in communication are most frequent cause of medical malpractice against radiologists [69, 70]. In addition to issuing a final written report, the radiologist should communicate important findings directly to the emergency physician or surgeon [71]. In emergency radiology, a quick diagnosis and treatment is essential to improve the management and outcome of trauma patients. Therefore, if the communication between the radiology and referring physician does not occur and is not documented, the radiologist can be held accountable when there are adverse or unexpected clinical outcomes. Therefore, documentation should always include the date, time, name of the person who was spoken to, and what was discussed [72].

Conclusion

Polytrauma is an acute multi-organ disease, which requires immediate clinical assessment and evaluation. With the advent of MDCT, patient outcomes have significantly improved, but diagnostic errors still persist and can result in serious mismanagement with grave consequences for patients. In addition, radiologists can be held accountable for any misfortunate turn of events.

Therefore, a strong relationship with the trauma team is important before and after the MDCT, in order to obtain an adequate history and important findings on physical exam.

Diagnostic error rate can be reduced using shared guidelines and established pre-programmed WBCT protocols, applying an institutional-based logistic and personal concept, organizing institutional morbidity and mortality conferences on difficult clinical cases and unexpected death, external and internal quality assurance system and external registries, and allowing for research and development in the fields of emergency radiology and patient care. Finally, young emergency radiologists, as well as possessing a strong knowledge, should have a working experience of least of 1 year at major trauma centers as assistants to expert colleagues.

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