Current Use of CT in the Evaluation and Management of Injured Patients

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From its beginnings as a time consuming and an inefficient imaging modality with no place in the evaluation of traumatically injured patients, computed axial tomographic (CT) scanners have evolved to yield rapid, highly sensitive images, revolutionizing trauma management protocols. With utility in blunt and penetrating traumas, new applications for this modality are continually being described.

CT FUNDAMENTALS

Technology

The use of CT in blunt trauma was originally reported in the 1980s.1–3 Long acquisition times and poor resolution limited its use. Since then, newer technology has allowed CT to contribute more and more to the evaluation of injured patients. The 2 biggest advances in CT imaging have been helical scanning and the use of multidetector imaging. Helical scanning, whereby data acquisition occurs simultaneously with patient positioning has had numerous positive effects. The entire series of images can be obtained in 20 to 30 seconds. This property has not only led to reduced scan times and increased resolution but also led to greatly decreased volume of contrast material needed for the same degree of vessel opacification.

The first multidetector CT (MDCT) scanner was developed in 1998. This machine used a 4-slice detector array. Since then, 16-, 32-, and 64- slice MDCTs, and recently, 128- and 256-slice MDCTs are available.4 Combined with helical scanning, MDCT reduces the scan time further. This reduction allows imaging with a thinner collimation (1–2 mm), yielding higher resolution images more rapidly with reduction of motion artifact from patient movement and cardiac activity. The use of MDCT has allowed for more flexibility in image reformatting and applications such as CT angiography.

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Contrast

Contrast-induced nephropathy is the third leading cause of hospital-acquired renal failure in the United States. Elderly patients with chronic kidney disease, diabetes, and congestive heart failure are at increased risk. Combined with the hypovolemic state of trauma and the concurrent use of nephrotoxic drugs, elderly trauma patients are thought to be at a very high risk of contrast nephropathy. A study of more than 1000 elderly (age >55 years) trauma patients, however, did not support this fact. There was no statistical difference in the incidence of acute kidney injury (AKI) between patients receiving intravenous contrast and those not receiving it. Approximately 2% of patients in each arm developed AKI. However, the development of AKI was an independent predictor of mortality. These data are consistent with those from studies of cardiac catheterization. Data cite a 1% to 6% incidence in AKI in unselected populations. Up to 70% of patients may experience a transient increase in serum creatinine (SCr) levels; however, most of these patients will not develop AKI. High-risk groups including patients with diabetes mellitus and chronic renal insufficiency (SCr >2 mg/dL) have reported rates of AKI up to 50%.

Radiation

Patients presenting to the emergency department, trauma patients, and critically ill patients are some of the most frequently imaged patients. The cumulative effective dose for critically ill patients in one study was 30 times the annual radiation dose for the US general population. Tien and colleagues performed a prospective study using dosimeters placed on trauma patients to calculate their exposure. The investigators found the mean dose to be 22.7 mSv (average background for the general US population was 2.4 mSv). They noted that the exposure was not evenly distributed, with the majority of the exposure centering on the neck and thyroid (58.5 mSv). Almost one-fourth of the patients had a greater than 100 mSv exposure to the thyroid (mean 168 mSv for this group), the level above which rates of thyroid cancer increase significantly. The other key finding from this study was that dose estimates predicted cumulative doses to be 25% less than the actual measured doses received by the patients.

The 2 basic radiation-lowering strategies are decreasing the number of studies performed and lowering the ionizing radiation delivered in any given study. Increasing the MDCT from 4 to 16 slice and above has been shown to significantly reduce radiation exposure. In one study on the use of CT scan for diagnosing appendicitis, reducing the energy from 100 mA to 30 mA resulted in no change in the diagnostic utility. The effective reduction in radiation dose to females and males was 5.2 to 1.4 mSv and 7.1 mSv to 2.2 mSv, respectively. Other techniques, such as an adaptive statistical iterative reconstruction (ASIR) algorithm, take advantage of postprocessing software to perform improved noise reduction. Radiation dose reduction is often limited by increases in background noise. ASIR has allowed more than 60% reduction in radiation doses without significant loss in image quality. At present, the only disadvantage of ASIR is its increased processing time (about 30%); however, it is likely that this will be reduced with ongoing improvements in computer software.

IMAGING PROTOCOLS

MDCT has gained an ever-increasing role in evaluating hemodynamically normal patients sustaining traumatic injury causing intra-abdominal hemorrhage. The role of physical examination alone has been studied, and although the negative predictive value is high in patients with a reliable physical examination, a large percentage of
patients presenting to the trauma room do not have a reliable examination.\textsuperscript{17} Multiple strategies have been developed to help decide which patients will benefit most from CT examinations. Whereas some advocate the liberal use of CT for blunt trauma,\textsuperscript{18} others think that a more selective approach is safe and, at the same time, will reduce radiation risk, reduce cost, and expedite care.\textsuperscript{19}

An approach using liberal or routine abdominal CT scans finds unexpected injuries in 7.1\% to 38\% of patients.\textsuperscript{19–21} Those advocating this approach cite subsequent changes in management that occur in 11\% to 26\% of these patients. However, in all studies, most management changes affect disposition and would not likely have affected outcome. Additional procedures are reported in less than 1\% of the patients.

An algorithm for selection of patients using physiologic parameters instead of mechanistic ones has been developed for selective approach to the use of abdominal CT (Fig. 1). Through multivariate analysis, an algorithm using 9 variables from the physical examination, focused assessment with sonography for trauma (FAST), lab analysis, and chest radiographs was created with a sensitivity of 97\%. This algorithm reduces the need for CT over routine scanning by 22\% without any compromise in patient safety.\textsuperscript{22}

A similar controversy exists with respect to CT of the chest. A routine mechanism-based protocol will find more injuries than a more selective approach. To what level these injuries affect care and, more importantly, outcome is currently debated. More traumatic findings occur in the routine group, with one group showing that these lead to management changes in 7\%.\textsuperscript{18} As with the abdominal CT studies, most management decisions affected only disposition. There was an additional bronchoscopy, 6 additional chest tube insertions/manipulations, and 2 aortic repairs. It is difficult to tell from the study what effect these measures had on patient outcomes.

Most clinically relevant traumatic chest injuries can be diagnosed using a more selective approach. Age greater than 55 years; abnormal chest physical examination; altered level of consciousness; abnormal examination of thoracic spine; abnormalities in chest, pelvis, or thoracic spine radiograph, abdominal FAST; base deficit greater than 3 mmol/L, and hemoglobin levels less than 6 mmol/L have been suggested as parameters to guide selective use of chest CT.\textsuperscript{19} When chest CT was omitted in those with none of the above-mentioned criteria, 13\% of injuries were missed, with only 2\% being clinically relevant. Others have suggested patients with chest wall tenderness and those with abnormal respiratory effort in addition to an abnormal chest radiograph are candidates for chest CT.\textsuperscript{20}

**SPECIFIC INJURIES**

**Abdomen**

Originally published in 1988, the American Association for the Surgery of Trauma (AAST) has devised a set of organ injury scales (OISs). Originally graded during operative exploration, the solid organ injury scale has now been defined by radiological (specifically CT) criteria. The first iteration of this report (OIS I for Spleen, Liver, and Kidney) recently underwent validation using entries into the National Trauma Data Bank. This analysis showed successful nonoperative management of spleen, liver, and kidney injuries in 73\%, 85\%, and 89\%, respectively, regardless of the injury grade. Operative intervention did increase with increasing grade, with a notably decreased rate of operative intervention for patients with isolated solid organ injury.

**Spleen**

Approximately 60\% to 80\% of patients with blunt splenic injury are currently managed nonoperatively with a success rate approaching 95\%.\textsuperscript{21,23,24} Early inclusion criteria for
nonoperative management mandated hemodynamic stability and absence of other associated operative injuries. Failure of nonoperative management correlates with radiological grade of injury and presence of active extravasation (Fig. 2). The role of nonoperative management has been extended at some institutions to include transient responders to fluid resuscitation. Critics of this management scheme warn that this practice pattern necessitates timely response by interventional radiology and may prolong the treatment and increase transfusion requirements of patients with a surgically correctable disease.

Hemodynamically normal patients with intraparenchymal splenic pseudoaneurysm or arteriovenous fistula are candidates for arterial embolization. Routine CT surveillance of splenic injury looking for pseudoaneurysm or arteriovenous fistula is debated. In one study by Weinberg, splenic pseudoaneurysm was noted in 7%
of patients studied 24 to 48 hours after initial diagnosis. One quarter of these patients had grade I or II injuries, indicating that even patients with low-grade splenic injuries are at risk for complications of nonoperative management.

**Liver**

Similar to splenic injuries, most blunt hepatic injuries are managed nonoperatively. Most studies document successful nonoperative management rates greater than 90%. Hepatic abscess, biloma, delayed hemorrhage, and hemobilia are recognized complications of hepatic trauma.

Fang and colleagues noted, by retrospective review, that patients with intraperitoneal contrast extravasation, hemoperitoneum in 6 compartments, destruction of more than 2 segments, high AAST OIS grade, laceration more than 6 cm deep, and porta hepatis involvement showed a significantly higher likelihood of needing operative intervention. Large hemoperitoneum and contrast extravasation independently predicted the need for operative intervention. Angiography with embolization plays a greater role in hepatic trauma than other solid organ injuries. Angiography can be used primarily in hemodynamically normal patients with active extravasation on CT, as an adjunct to damage control laparotomy, or in the management of delayed complications (eg, hemobilia, delayed hemorrhage, arteriovenous fistula). However, the number of patients requiring therapeutic intervention may be fewer than originally thought. Early reports note therapeutic intervention in 70% to 100% of patients undergoing hepatic angiography. In a study by Misselbeck and colleagues, only 40% of patients undergoing hepatic angiography required embolization. Patients with active

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**Fig. 2.** CT images of a 23-year-old man involved in a high-speed motor vehicle crash. CT scan showing splenic laceration with active contrast extravasation (*blush*).
extravasation on CT scan and those exhibiting ongoing hemorrhage after an investigation for damage control had higher rates of embolization.

Although the concept of nonoperative management of blunt solid organ injury has been universally accepted, operative exploration remains the standard of care for penetrating solid organ injuries. Traditionally, CT has played a limited role in the management of penetrating injuries. Several groups have questioned this management dictum and shown that carefully selected patients with penetrating solid organ injuries can be managed nonoperatively (Fig. 3). Selection of these patients is largely determined by physical examination, vital signs, and findings on CT scan. Using an algorithm that included laparotomy for hemodynamic instability or suspicion of hollow viscera injury and observation for solid organ injury, this method was determined safe. Thirty-nine penetrating trauma patients with 42 injured solid organs were managed nonoperatively.38 Of these, 2 required operative intervention without adverse consequence for delayed recognition of hollow viscus injuries. Of note, this group relied on delayed laparoscopic exploration for left-sided thoracoabdominal wounds to perform diaphragmatic evaluation and repair, if indicated. Another study from the military reported similar success, adding that physical examination and ultrasonography alone were too unreliable and that CT should be a part of the diagnostic workup if a nonoperative algorithm was going to be used.39

Fig. 3. Selected images from a CT scan of a patient sustaining a gunshot wound to the right upper quadrant. This patient was hemodynamically normal on presentation. Images note a liver laceration without evidence of active extravasation. This patient was managed nonoperatively.
The CT scan seems to be less useful in the evaluation of abdominal stab wounds than in the evaluation of select gunshot wounds. Recent data from the Western Trauma Association Multicenter Trials Group note that in patients sustaining anterior abdominal stab wounds (without evidence of shock or diffuse peritonitis), an evaluation scheme that includes local wound exploration and serial clinical assessments is superior to routine abdominopelvic CT scanning.

**Pancreas**

Compared with liver and splenic injuries, isolated blunt injuries to the pancreas are rare. The estimated injury rate ranges from 0.2% to 1.3% in patients sustaining blunt trauma. The focus of pancreatic injuries revolves around the suspicion for pancreatic duct injury. CT findings include frank disruption of the main pancreatic duct, peripancreatic fluid, pancreatic enlargement, or alteration of the pancreatic contour (Fig. 4). If there is a suspicion, follow-up imaging (CT, MR cholangiopancreatography, endoscopic retrograde cholangiopancreatography [ERCP]) may be necessary. For minor distal pancreatic injuries, CT guided percutaneous drainage offers favorable outcomes. ERCP carries a high morbidity and stricture rate and should be used selectively.

**Kidney**

Renal injuries may involve simple parenchymal injuries, injuries to the collecting system, or significant renovascular injuries to either the arterial or the venous system. Significant parenchymal injury seen on initial CT should be accompanied by an 8- to 10-minute delayed film to evaluate for contrast extravasation indicating damage to the collecting system. Most collecting system injuries can be managed with a combination of endoscopic and percutaneous drainage techniques.

Vascular injuries may involve branches or segmental arteries, evidenced by a wedge infarct on CT or main vessel avulsion with absent cortical enhancement or peripheral enhancement only. Distinguishing between an intimal tear and a vascular avulsion is done by noting the presence of a perirenal hematoma seen with avulsion.

Renal injuries show higher rates of successful nonoperative management than either splenic or hepatic injury. Follow-up CT scan after 24 to 48 hours rarely leads

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**Fig. 4.** CT image showing traumatic pancreatic transaction and surrounding peripancreatic edema (arrow).
to changes in management. These investigators concluded that renovascular injuries do not warrant routine serial imaging; however, urinary extravasation may require additional imaging for optimal management.

The dictum of mandatory exploration for penetrating renal injury has long been challenged because the success rate for nonoperative management of these patients approaches 50%. About 40% of gunshot injuries to the kidney in carefully selected patients (hemodynamically normal, absence of hilar injury) can be managed without operative exploration.

**Bowel and Mesentry**

Bowel and associated mesenteric injuries are noted in approximately 5% of patients sustaining blunt abdominal trauma. Whereas it is universally accepted that CT excels in the diagnosis of solid organ injury, some controversy exists surrounding its role in hollow viscus injury. The advent of helical and MDCT scanning may change this situation. CT findings consistent with bowel injury include extraluminal air, extraluminal oral contrast (if administered), and moderate (>6 consecutive CT cuts) volumes of free intraperitoneal fluid in the absence of solid organ injury or pelvic fracture. Using these criteria, the sensitivity of diagnosing surgically significant bowel trauma has been reported to be as high as 94% and the accuracy and positive predictive value have been reported to be 86% and 90%, respectively.

CT is slightly less favorable in diagnosing clinically significant mesenteric injuries. Clinically significant mesenteric findings are active extravasation and bowel wall thickening associated with mesenteric hematoma. Mesenteric hematoma alone is not typically regarded as a surgically significant finding. Using similar criteria, the sensitivity of MDCT for detection of mesenteric injury is 96%; however, its use in determining clinically significant findings was only 75%.

**Chest**

**Thoracic aorta**

Classically described as a result of significant deceleration, traumatic aortic injury accounts for as many as 20% of fatalities in blunt chest trauma. Estimates suggest that 85% of patients will die immediately. Of the survivors, historical estimates suggest that if left untreated, up to one-third will die within 6 hours of injury and most of

![Fig. 5. (A, B) Axial sections representing mesenteric injury in a patient sustaining blunt injury from a motor vehicle crash. Both figures note bleeding in the mesentery. (A) Image shows a prominent blush in the mesentery of the left colon.](image)
the remaining will die within 4 months.\textsuperscript{51} With the increasing sensitivity of CT scans, these numbers have been challenged. Plain radiograph of the chest has a sensitivity greater than 90\% in detecting mediastinal hemorrhage and is used as a screening test to determine the need for further evaluation. Classic chest radiograph findings of mediastinal hemorrhage are well documented (Fig. 7). The most useful of these findings are obliteration of the aortic knob and mediastinal widening (sensitivity 53\%–100\% and 81\%–100\%, specificity 21\%–55\% and 10\%–60\%; respectively). Although the exact definition of mediastinal widening has been debated, data support the use of a subjective assessment as an adequate screening measure.\textsuperscript{52,53} CT has virtually replaced traditional aortography and transesophageal echocardiography as the gold standard for diagnosis, which was evidenced in a comparison study between 2 similar AAST multicenter prospective studies separated by a decade (1997 and 2007) examining blunt aortic injury.\textsuperscript{54} The 2007 study noted a near complete elimination of conventional angiography and TEE, with nearly all patients undergoing CT angiography.

**Chest wall**
The presence and number of rib fractures on plain radiograph has been used both as a marker for other thoracic injuries as well as an independent predictor of mortality. Additional data suggest that the presence of more than 3 fractured ribs on a radiograph should prompt transfer to a trauma center.\textsuperscript{55} These data, however, are not likely applicable to rib fractures diagnosed by CT alone. Thoracic CT is more sensitive than chest radiograph for the detection of fractured ribs and, at the same time, provides detailed information as to the anatomic displacement and number of ribs fractured. Data suggest that although CT has greater sensitivity and anatomic definition, injuries noted on chest radiographs may be a better marker for pulmonary complications.\textsuperscript{56} Although outcomes and clinical utility of rib fixation are still being studied, 3-dimensional reconstruction of the thoracic cage may assist in operative planning (Fig. 8).

**Diaphragm**
Blunt diaphragmatic rupture is a rare injury with an incidence reported between 0.8\% and 8\% in the literature. CT diagnosis has historically been difficult, mainly because of the horizontal orientation of the diaphragm. Helical scanning and the use of MDCTs

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**Fig. 6.** Axial CT image showing traumatic aortic injury (arrow) with mediastinal hematoma (circle).
have assisted in the radiographic diagnosis. Using 3- to 5-mm axial sections with 3-dimensional volume-rendered images and multiplanar reconstructions has increased the sensitivity and specificity to 71% and 100%, respectively. Four radiographic signs of diaphragmatic rupture have been described,\textsuperscript{57,58} including (1) discontinuity of the hemidiaphragm with a gap in the muscle, (2) herniation of intra-abdominal viscera, (3) rim sign, represented by edges of rupture wrapped around viscera, and (4) dependent viscera sign,\textsuperscript{59} which is the loss of posterior support by the diaphragm allowing the involved viscera to lie directly on the posterior ribs.

**INCIDENTAL FINDINGS**

*Masses and Follow-up*

With submillimeter resolution and increasing numbers of scans performed, the rate of incidental radiographic findings has increased dramatically. Rates of incidental findings...
findings have been estimated between 10% and 50%.\textsuperscript{60–62} Whereas some have argued that these findings place undue stress on an already overburdened medical system, studies have shown that a significant portion of these incidental findings represent potentially life-threatening diagnoses. In one series of incidental thyroid masses, out of more than 200 thyroid masses discovered, 118 were biopsied, revealing a 22% malignancy rate. In a series of incidentally discovered adrenal masses, the rate of malignancy for masses greater than 3 cm was nearly 30%.

More recent studies have classified these findings according to the urgency in which they need to be addressed. Among the most common lesions needing attention during admission include pulmonary nodules (7%), adrenal lesions (4%), mediastinal lymphadenopathy (6%), hepatic lesions (4%), and thyroid nodules (3%). Other findings that are less likely to require timely workup include renal/hepatic cysts, inguinal/ventral hernias, and diverticular disease.\textsuperscript{63}

Ensuring proper follow-up of these incidental findings has become extremely important, although often difficult in the trauma population. Retrospective chart studies have found that only 49% of patients with clinically significant incidental findings had documented follow-up for these diagnoses.\textsuperscript{64} There was no comment on the outcome of these patients and therefore the risks of inadequate follow-up.

\textbf{Pulmonary Embolus}

The incidence of asymptomatic pulmonary embolus (PE) in moderately to severely injured patients is approximately 25%. In 90 asymptomatic trauma patients studied by Schultz and colleagues, 22 had demonstrable clot burden on helical CT of the chest (performed between trauma days 3–7).\textsuperscript{65} The emboli in 2 of these patients were present on the presenting trauma CT. Those with PE were older, more severely injured patients. There was no difference in the rate of prophylactic anticoagulation.

The management of patients with small asymptomatic pulmonary emboli is debated. The American College of Chest Physicians (ACCP) guidelines recommend short-term anticoagulation for nonmassive PE.\textsuperscript{66} Others, however, think that observation alone is sufficient in asymptomatic patients with minor clot burden. In the aforementioned study, those with minor clot burden (Miller Score 0.25–2.0) were managed expectantly, not placed on systemic anticoagulation, and had no adverse outcomes. Patients with major clot burden (Miller score >4.25) were systemically anticoagulated according to the ACCP guidelines.

\textbf{Occult Pneumothorax and Hemothorax}

Occult pneumothorax (OPTX) is defined as pneumothorax (PTX) diagnosed by CT scan not originally suspected by clinical examination or supine plain film radiograph (\textbf{Fig. 9}). According to trauma registries, the incidence is around 5%. The actual incidence, however, varies depending on the frequency with which CTs are obtained and how the plain films are interpreted. Rates of OPTX in trauma patients undergoing CT scans of the chest approach 15%. Studies using radiologist interpretation show far lower incidences than studies with trauma surgeon interpretation (as high as 76%). Subtle radiographic signs, such as the deep sulcus sign, are quoted as the main reasons for missing PTX on initial plain films.

Management of OPTX is controversial, and differences are likely related to physician perceptions and historical dogma rather than to data. Rates of tube thoracostomy between overt and occult PTX vary greatly. One study cites more than 60% chest tube insertion rate for overt PTX as compared with a 30% insertion rate for OPTX, irrespective of patient hemodynamics or respiratory symptoms.\textsuperscript{67} Despite data to the contrary, this is thought to be caused by the perception that occult PTXs represent...
lesser lung collapses than overt PTXs. This perception has been questioned, and in one study using CT to compare overt and occult PTXs, no statistical difference in size of collapse was noted.\textsuperscript{68}

Occult hemothoraces are similarly defined, with rates estimated between 20\% and 30\%.\textsuperscript{69,70} As in OPTX, the true incidence of occult hemothorax is difficult to estimate. Although there is much less information on the natural history and appropriate management, one study noted that patients successfully managed expectantly had smaller hemothoraces (<2 cm) and lower injury severity scores.\textsuperscript{71}

**SUMMARY**

There is no question that CT scanners have changed the way injured patients are evaluated and managed. As resolution is further increased and acquisition times are decreased, more applications will likely be described. It is important, however, to remember no imaging modality can replace sound surgical judgment. Increasing resolution will likely yield even more findings. More research is necessary to understand the clinical significance of these findings. Throughout their lifetime, patients are undergoing increasing numbers of radiological evaluations. As physicians, it is imperative to remember the longitudinal effects of ionizing radiation and subject the patients to only those studies that will have a significant effect on their outcome.

**REFERENCES**


