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Between 800,000 and 1,000,000 annual emergency department (ED) visits are for patients with head injury; 80% of these involve minor head injuries; 35% to 61% of patients seen in the ED undergo some form of radiographic evaluation.¹⁻⁴

The use of computed tomography (CT) imaging specifically has seen exponential growth in the ED during the last 30 years. The first unit was installed at the Mayo Clinic in 1973; within only a few years, CT had virtually eliminated the use of pneumoencephalography and arteriography in head trauma.

In addition, the advent of CT scanning resulted in a reduction in the morbidity and mortality of head-injured patients when compared to historical controls studied by other methods.⁵ This study also demonstrated a reduction in the number of skull radiographs, cerebral angiograms, and unnecessary surgical exploration. Early surgical intervention in head-injured patients with extra-axial hematomas was made possible with the advent of CT and was shown to improve morbidity and mortality in this population.^{6,7}

As with all radiographic studies, an organized approach to interpretation of head CT imaging, as well as other cranial radiographic studies, is imperative. Missed radiographic findings account for 12% to 15% of all malpractice settlements.^{8,9} Some studies have demonstrated that missed CT scan interpretations are significant among those without specific training in CT interpretation.^{10,11} Fortunately, physicians with proper training have a high degree of accuracy in interpretation of radiographs when compared with that of radiologists.¹²⁻¹⁸ The authors review indications for radiographic imaging, interpreting images, and specific injuries.

— The Editor

Radiologic Evaluation of Head Trauma: Identifying the Spectrum of Injuries

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Basics Principles of Radiology

Traditional radiographs record images on film or computer, which convey information about the size, shape, and distribution of tissues within a patient. Radiographs are a two-dimensional representation of a series of x-ray beams projected through a

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three-dimensional object. The image represents a combination of black, gray, and white shades that are determined by the absorption and scattering of x-rays by each tissue through which the beam is projected. Tissues that possess little radiodensity (e.g., air or fat) allow the beam to pass easily through the body with little scatter or absorption, exposing the radiographic film and producing a black image. Very radiodense tissues (e.g., metal, calcium, or bone) obstruct the beam and produce a white image. Each radiographic plate is coated with chemicals that emit a fluorescent flash when struck by the beam, thus augmenting the actual effect of the x-ray beam. More recently, the photographic plate has been modified so that the image can be digitized and converted to a computer image. Most other tissues, especially those containing water, produce a gray image. The x-ray beam will pass through many tissues en route to the film, and the final shading will reflect the summation of all tissues through which the beam has traversed.

Plain radiographs are described in terms of the path that the beam takes from the x-ray tube to the film. For example, a plain radiograph of the skull shot from front to back is an anterior to posterior (AP) projection. If directed from one side through to the other, the radiograph is a lateral view. The oblique view is obtained by directing the beam obliquely.

In CT, images represent the same spectrum of radiographic densities as plain radiography but repeated dynamic imaging allows reconstruction of the body part in the axial plain. Newer scanners allow coronal, sagittal, and even three-dimensional reconstructions. Despite the advances in CT technology, the average cost is approximately \$125 per study.¹⁹

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The basic components of the CT scanner are the x-ray tube, detectors, and computers that allow for image reconstruction. Repeated slices are constructed as the beam rotates 360° around the patient while the table advances. Each CT image generated represents a matrix of picture elements or pixels. Each pixel is assigned an attenuation coefficient based upon its ability to absorb or scatter x-rays. This attenuation coefficient is expressed in Hounsfield units (HU), which vary from -1000 U (air) to +1000 (cortical bone). CT images can be viewed in a variety of 'windows' that accentuate tissues of a specific attenuation. In most trauma head CT protocols, 5-mm thick cuts are performed through the posterior fossa; 10-mm thick cuts are taken in the supratentorial region and will be displayed in brain, bone, and blood windows.

Newer high resolution scanners have thinner cuts, achieving submillimeter thickness. More recently, faster helical or spiral CT units that move the patient through the scanner in a continuous fashion and scan in a helical pattern around the patient have been introduced, reducing the scanning time to 20 to 30 seconds. This is particularly useful for imaging anatomy that is constantly in motion such as the chest.

Magnetic resonance imaging (MRI) uses computer technology to convert radiofrequency signals into shades of black, gray, and white. Instead of x-ray beams, an external magnetic field and radiofrequency waves are used to produce the image. The basic principle of MRI is the detection of spinning protons. When the patient is placed in the bore of the magnet, the magnetic fields of the protons align with the stronger magnetic field of the scanner. Radio waves are then intermittently and briefly applied to the tissue being examined to enhance the spin frequency by causing the protons to resonate (Larmor frequency) at a higher energy level. As the tissues return to their resting state, a radiofrequency wave is emitted and then detected by the receiving coil. The computer then converts the intensity of the detected signal to shades of black, gray, or white. The result is a three-dimensional plot of proton densities.

As noted, a signal is detected as the protons return to their resting state. This relaxation phase occurs by two major pathways: longitudinal or T1 decay, and transverse or T2 decay. Images generated from signals in the early portion of the relaxation phase (called T1-weighted sequence) produce a unique image in which fat appears as white and gray image contrast is excellent. During late relaxation (T2-weighted sequence), water appears white and fat appears gray. The T1-weighted sequence and T2-weighted sequence provide two perspectives on the same image. T1 images provide more useful architectural information; T2 images depict pathology more accurately because water (high in hydrogen protons) accumulates in many pathologic conditions (e.g., ischemia, edema, and tumor). In addition to producing images of high quality, MRI does not rely on radiation and thus, does not carry the biologic risk of x-rays.

Iodinated contrast agents used in x-ray-generated images are not useful for MR studies. Instead, paramagnetic agents such as gadolinium are used to enhance the image. Gadolinium acts by reducing T1 relaxation times and thus, improving the contrast

Table 1. High-Risk Criteria for Minor Head Injury ²¹

- Glasgow coma scale score < 15 after 2 hours
- Suspected open or depressed skull fracture
- Any sign of basilar skull fracture
- Vomiting \geq 2 episodes
- Age \geq 65 years

between tissues. It is most useful for delineating tumors and infections.

Indications for Radiographic Imaging in Head Trauma

CT scanning has virtually replaced plain skull radiographs in imaging the patient with head injury. Some physicians still will obtain plain radiographs in patients with suspected depressed skull fractures or with metallic foreign bodies. Plain radiography had previous utility in determining the presence of linear skull fractures. While 66% of patients with severe head trauma have an associated skull fracture, only 25% to 35% of patients with skull fractures have underlying cranial pathology.²⁰ The primary indications for obtaining skull plain films are to evaluate nonaccidental trauma (i.e., to look for fractures in different stages of healing), to assess ventricular shunt integrity, and as an adjunct to CT in penetrating skull trauma. It has been shown that the number of radiographs ordered for medicolegal considerations varies from 10% to 46%.^{21,22}

Although MRI has the advantage of producing images with superior anatomic detail, CT provides several important advantages in the setting of trauma. The more rapid study completion time and greater availability of CT imaging makes it a far more useful study. Additionally, CT is as reliable as MRI in demonstrating intracranial lesions requiring operative intervention. Finally, CT has none of the stringent safety requirements of MRI imposed by the strong magnetic fields surrounding the scanner. MRI has a prominent role, however, in evaluating patients with subacute and chronic injuries. In these patients, MRI offers better discrimination between lesions and normal brain tissue, whereas subacute hemorrhage may appear isodense with normal brain tissue on CT.

Patients with altered level of consciousness documented by a Glasgow coma scale (GCS) score less than 13 will require CT imaging in the acute setting. Controversy exists around the role of CT imaging in minor head trauma, defined as patients with blunt head injury, amnesia or disorientation or documented loss of consciousness, and a GCS score of 13 to 15. Several scoring systems have been suggested,²³⁻²⁵ with the larger, validated Canadian CT rule²³ outperforming other published rules in adults with head trauma. Adults with risk factors delineated by the Canadian CT rule require emergent CT scanning. (See *Table 1*.) Using these criteria for obtaining a head CT in minor trauma, the authors noted a sensitivity of 100% and a specificity of 68.7% in detecting injuries requiring neurosurgical intervention. Additionally, they found a sensitivity of 98.4% and a specificity of 49.6%

for clinically important brain injuries. Finally, the Canadian CT rule reduced the number of CT studies by almost 50%. Some additional patient populations must be considered for early use of CT. These include intoxicated patients,^{26,27} patients with bleeding disorders,²⁸ patients with shunts from prior neurosurgical procedures,²⁹ and patients who return after initial evaluation following a head injury.³⁰ Other authors have independently found age greater than 65 years to be a risk factor for significant head injury.^{31,32} However, even with a clinical model that includes these high-risk patients, it has been suggested that 100% sensitivity for intracranial injuries may not be achieved.^{33,34} Patients with no loss of consciousness, normal neurologic findings, no vomiting, no amnesia, and minimal scalp injury can be discharged with careful instructions including 24 hours of close observation.

Clinicians should have a lower threshold for imaging infants and children with head injury as clinical features can be particularly subtle.³⁵ Independent risk factors for closed head injury include headache, vomiting, an altered mental status, physical signs of a basilar skull fracture, and focal neurological deficits. Importantly, a scalp hematoma alone signifies an increased risk of intracranial injury in infants younger than 1 to 2 years and careful consideration of CT imaging.^{35,36} One additional consideration is the fact that significant pathology can arise after a presumably normal CT scan. This occurrence is particularly true of cerebral contusions, which commonly develop hours to days after injury. Even delayed epidural³⁷ and subdural³⁸ hematomas have been reported.

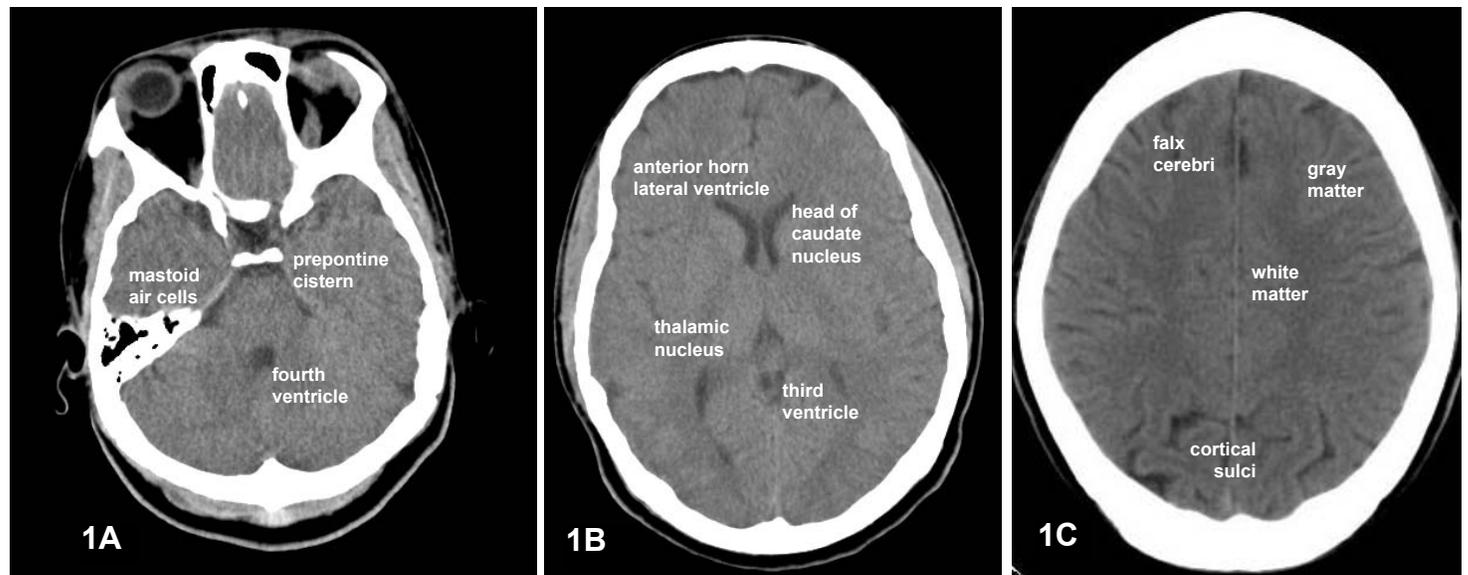
Interpretation of Radiographs in Head Trauma

As with other body systems, practitioners must have an organized approach in viewing radiographs of the cranial vault and its internal structures. Because of the importance of CT scanning in assessing the patient with head trauma, we will focus primarily on findings with this modality. The general principle is to divide head-injured patients into the following broad categories: normal intracranial findings, diffuse intracranial injury, and focal intra-axial or extra-axial findings.

Remember that the patient is placed supine on the CT table and the axial images are constructed as if one is viewing from the feet upward. As a result, the patient's left is on the right side of the image as with plain radiography. This is also true for MR images. It also should be remembered that black, gray, and white are defined by the tissue densities similar to plain radiography. However, specific tissues may be accentuated by viewing the various window settings as described previously.

The initial evaluation of the CT scan should consider the technical adequacy of the study. The axis of the x-ray beam is angled 20° downward along a line extending from the lateral canthus to the external acoustic meatus. If the patient's head is tilted as it enters the gantry, an oblique rather than a true axial cut is obtained. This can obscure an abnormality or create the appearance of an abnormality in a normal brain. The CT scout image is useful when assessing the technical quality of the study by demonstrating the orientation of the images, as well as the number of images produced and the anatomic area scanned. The

Figure 1. Cross-sectional Image of Brain at Various Levels



scout image is also valuable in assessing the skull for fractures that can be visible on this image. Images should also be evaluated for motion artifact or artifacts related to the presence of bullets or other dense foreign bodies.

Interpretation of CT imaging requires a thorough understanding of the cross-sectional anatomy of the brain. A complete review of neuroanatomy is beyond the scope of this article, however, excellent reviews on this subject are available.³⁹ With each slice, specific anatomic landmarks should be located as described below. Specific focus on symmetry, the cerebrospinal fluid (CSF) spaces, brain tissue, the skull, and soft tissues should be reviewed on brain window settings. Brain windows are used to highlight cerebral anatomy. Bone windows better delineate skull fractures and pneumocephaly. Blood windows more clearly demonstrate intracranial hemorrhage, which can be subtle, especially near the inner table of the skull. Localized soft-tissue swelling over the skull may be an indication of head trauma and may yield clues as to the location of coup and contre-coup injuries.

By convention, CT images progress cephalad from the foramen magnum to vertex of the skull. Important structures to identify on the lower images are the fourth ventricle, which lies on the midline, dorsal to the brainstem. Ventral to the brainstem are the prepontine and supracellar cisterns (*Figure 1A*). Because CSF is clear, these fluid-filled spaces appear dark gray. Air-filled spaces (e.g., the mastoid air cells and paranasal sinuses) are black on the image. Blood in either the CSF or sinuses will alter their appearance by increasing their densities. The posterior fossa structures demonstrated on lower CT images also include the cerebellar hemispheres and the dural sinuses.

Proceeding cephalad, the inferior portions of the cerebral hemispheres and the third and lateral ventricles can be seen (*Figure 1B*). The third ventricle is an important landmark for intracranial mass effect causing midline shift. The ambient cis-

terns that surround the upper pons are also visible and are important in assessing mass effect on the brainstem from injury to the temporal lobes. The third ventricle is flanked by the thalamic nuclei and each frontal horn of the lateral ventricles lies adjacent to the head of the caudate nucleus. These gray matter structures are of intermediate density as compared with the dark CSF in the adjacent ventricle.

Continuing cephalad, the cerebral cortex occupies virtually the entire image (*Figure 1C*). One should appreciate a distinct border between gray and white matter structures. In addition, the cortical sulci should be well delineated and should appear more prominent in the older brain. On the higher images, the falx cerebri becomes visible and becomes a second important midline structure. Ensure that equal volume occupies the right and left halves of the cranial vault and that no structure has crossed the midline.

Finally, there are three questions that you should consider as you view the images of a head CT scan:

- Is there blood in or around the brain?
- Is there a shift in the midline structures?
- Is there evidence of brain edema?

In the CT scan of a patient with acute injury, clotted blood is typically identified as a high density focus. Clotted blood tends to assume a characteristic shape depending upon the nature of the underlying abnormality, as will be discussed later. Next, one looks at all of the images for asymmetrical displacement of intracranial structures across the midline. Important landmarks that are useful midline indicators include the third and fourth ventricles and the falx cerebri. In addition, the ventricles may be obliterated by mass effect from edema or hematoma. Small volumes of blood in CSF can make the subarachnoid spaces appear isodense with brain, essentially obliterating the ventricles, sulci, and basal cisterns.

Table 2. Mnemonic for Reviewing Head CT Scan¹⁴

BLOOD:

- Epidural hematoma
- Subdural hematoma
- Intraparenchymal hemorrhage
- Intraventricular hemorrhage
- Subarachnoid hemorrhage

CAN (CISTERNS): EXAMINE FOR BLOOD AND EFFACEMENT

- Circummesencephalic
- Suprasellar
- Quadrigeminal
- Sylvian

BE (BRAIN):

- Symmetry
- Gray-white differentiation
- Shift
- Hyper- or hypodensity
- Pneumocephalus

VERY (VENTRICLES):

- Effacement
- Shift
- Blood

BAD (BONE): FRACTURES, SOFT-TISSUE INJURY, BLOOD IN SINUSES

Finally, one should appreciate a clear delineation between the gray and white matter structures in the brain. Significant edema reduces or eliminates these density differences to produce a more uniform, isodense appearance of brain tissue. Edema may manifest as either a localized or diffuse hypodense area of brain (usually 12 to 24 HU) with ill-defined gray/white boundaries resulting from increased brain water content. Edema also may result in the loss of sharp delineation of sulci. An area of suspected edema can be compared with the contralateral hemisphere to better appreciate the abnormality.

Perron¹⁴ has suggested that the pneumonic “Blood Can Be Very Bad” be used to ensure that the examiner has reviewed all of the important features of the CT scan (Table 2).

MRI has not gained widespread use in the acute management of the injured patient due to a number of factors including cost, availability, speed of scanning, potential for motion artifact, limitations on the use of life support equipment in the strong magnetic field and insensitivity to bone involvement. On the other hand, MRI does not utilize ionizing radiation, can better discriminate between similar tissues, is better at defining cerebral edema, and is not complicated by bone artifacts. It is also able to provide delineation of structures in three orthogonal planes (axial, sagittal and coronal); CT scanning is generally limited to the axial plane when imaging the acutely injured patient. Small parenchymal injuries and collections of blood at the vertex and skull base are better elucidated by MRI. At least one study has demonstrated

Figure 2. Linear Skull Fracture

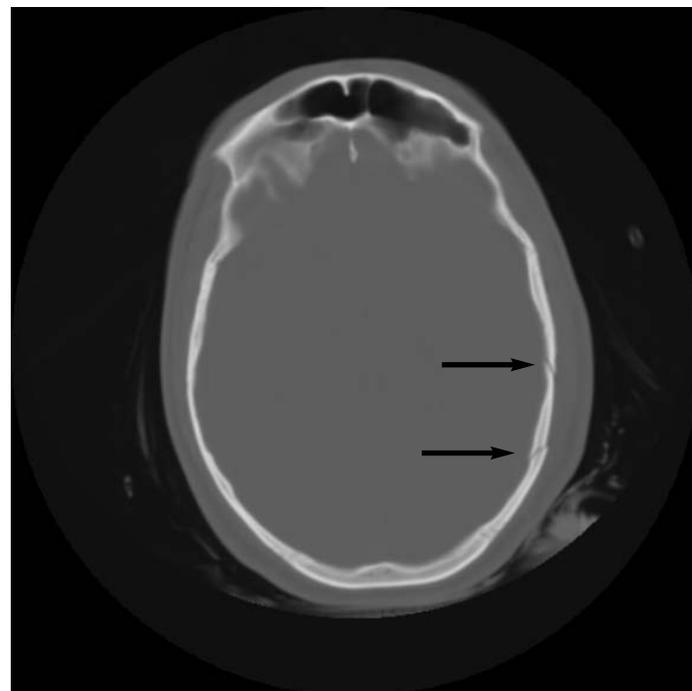


Figure 2. Black arrows indicate site of fracture.

the superiority of MRI in identifying intracranial lesions;⁴⁰ however, these radiologic findings did not affect clinical management. The basic anatomy and approach are similar to reviewing CT scans. In the setting of acute trauma, MRI may be useful in assessing the extent of parenchymal injury, the exact location of extra-axial blood collections (i.e., subdural, epidural, and subarachnoid hemorrhage), the integrity of vascular structures using MR angiography, and potentially to determine the metabolic impact of injury using MR spectroscopy.

Specific Injuries

Skull fractures can be identified using plain radiographs or CT scans. When the latter is used, bone windows best define the fracture line. Skull fractures are described as *linear*, *basilar*, or *depressed*. Diastatic fractures occur along existing suture lines. In the plain radiograph, a linear fracture appears as a clean sharply demarcated radiolucent line that is typically wider in its central portion and tapered at both ends. Linear fractures appear more sharply delineated than vascular grooves or suture lines. Fractures can further be differentiated from suture lines by the irregular corticated border seen with sutures. On a CT scan, the fracture line may be readily apparent. However, the fracture may be difficult to appreciate if it is transverse in its orientation, lying within the plane of the image. Examination of the scout film may reveal the fracture line (Figure 2). One should look for evidence of focal soft-tissue swelling in the scalp to identify areas of potential skull fractures. MRI is not useful in the assessment of skull fractures because this imaging modality requires that protons be mobile, and the protons of cortical bone are immobile.

Figure 3. CT Scans Demonstrating Depressed Skull Fracture, Basilar Skull Fracture, and Cerebral Contusion

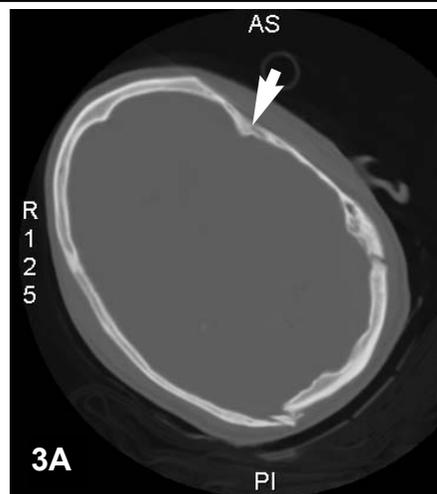


Figure 3A. Depressed Skull Fracture. Arrow denotes site of depression.



Figure 3B. Basilar Skull Fracture. Arrow demonstrates fracture through the skull base.

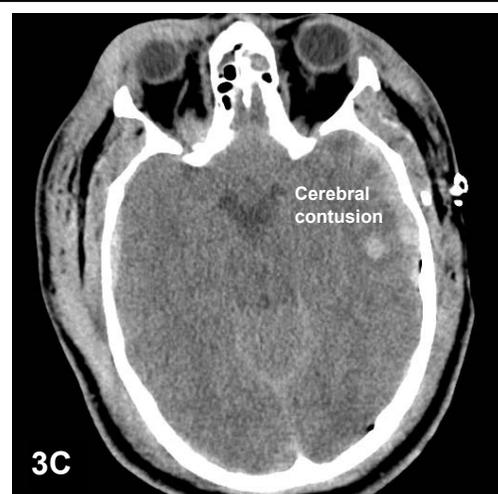


Figure 3C. Cerebral Contusion.

Thus, cortical bone appears uniformly black with MRI.

A depressed skull fracture is seen as overlapping cortical shadows on plain radiographs (*Figure 3A*). These injuries can be further elucidated by obtaining tangential views in the area of the fracture. Skull fractures are typically the result of direct trauma to the skull, most commonly in the frontal or parietal regions of the skull. A depressed skull fracture is believed to be significant when the deepest portion of the fracture extends below the inner table of the skull. These fractures are typically associated with injuries to brain parenchyma and dural tears. CT scanning offers the advantage of accurately defining the depth of the fracture and demonstrating any underlying brain injury.

Finally, basilar skull fractures are typically defined by clinical findings of raccoon eyes, Battle's sign, hemotympanum, CSF rhinorrhea, or otorrhea. A Towne view taken with plain skull radiographs occasionally may demonstrate the fracture. CT images of the posterior fossa with 1 to 2 mm cuts are the best method of demonstrating the fracture site (*Figure 3B*). Extension of the fracture line through the outer table or into an air-filled cavity (e.g., paranasal sinuses, nasal cavity, mastoid air cells) defines a compound basilar skull fracture. Pneumocephalus may accompany a compound basilar skull fracture. Basilar skull fractures through the petrous or sphenoid bone also may result in cranial nerve injuries and are best demonstrated on high-resolution CT.

Intracranial blood is classified as being *intra-axial* (within the brain substance) or *extra-axial*. The most common intra-axial traumatic lesions are cerebral contusions, hematomas, and shearing injuries. Contusions are ill-defined collections of blood along the brain surface or within the brain substance, whereas hematomas are well-circumscribed. Contusions are typically seen in the gray matter but may extend into the subcortical white matter (*Figure 3C*). There is typically a high density focus representing hemorrhage surrounded by low density edema. These are

typically defined as *coup* or *contrecoup* injuries. Coup injuries occur beneath the surface of the skull at the site of impact, whereas contrecoup injuries occur on the opposite side of the brain along the line where the force was directed. Contusions have been found in high association with depressed skull fractures. MRI also may be used to define cerebral contusion. T2-weighted images demonstrate a low intensity signal (hematoma) surrounded by a high-intensity signal (edema).

Cerebral hematomas occur in a distribution similar to cerebral contusions and are most common in the frontal and temporal regions of the brain (*Figure 4*). Hematomas may be the result of the dissection of the clot through the brain white matter or the disruption of a penetrating vessel in this region. Large clots can actually dissect through the white matter into the ventricular system that may result in obstructive or communicating hydrocephalus. Cerebral hematomas are found in association with other brain injuries in 50% of cases, and intraventricular extension occurs in 33% of cases; 20% of these lesions are bilateral.⁴¹⁻⁴² On CT, hematomas are identified by distinct collections of hyperdense blood surrounded by a hypodense area of edema in the acute injury and serum from clot degradation in the subacute injury. Typically, these are found in the frontal or anterior temporal lobe. On MRI, cerebral hematomas are similar in appearance on T2-weighted images in that the clot is hypointense and the edema or serum is hyperintense. Delayed appearance of cerebral hematomas 1 to 7 days after injury has also been reported.^{43,44}

Shear injuries typically occur at the junction of the gray and white matter of the brain as the result of rotational forces, resulting in disruption of axons and their small accompanying blood vessels. These injuries can produce diffuse cerebral edema but also may appear as multiple distinct hemorrhagic foci varying from punctate to a few centimeters in diameter. Cisternal and ventricular compression may be seen but is not common in acute injury. Typically, lesions are found in four areas: the corpus cal-

Figure 4. Cerebral Hematoma

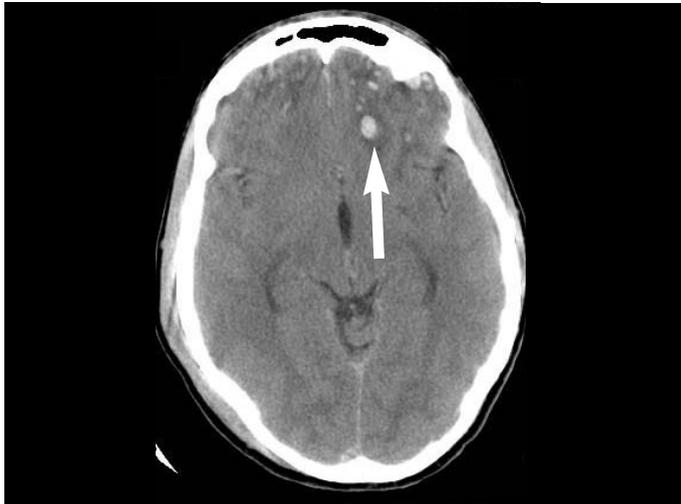


Figure 4. Cerebral Hematoma. Arrow indicates area of cerebral hematoma.

Figure 5. Subdural Hematoma

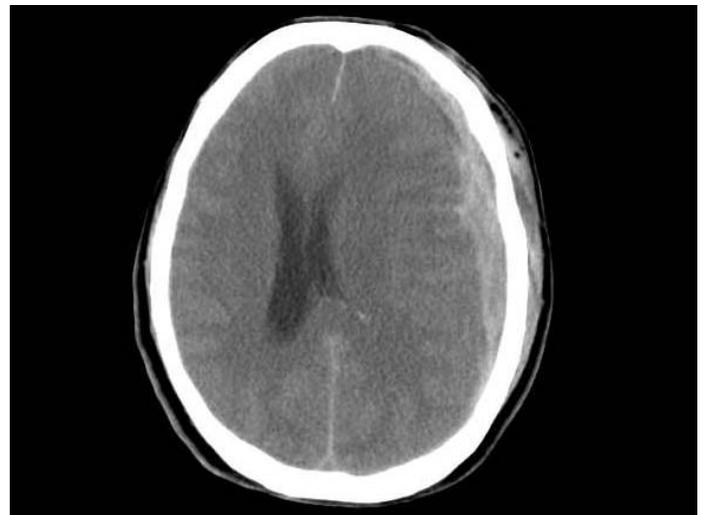


Figure 5. Subdural Hematoma. Note midline shift of lateral ventricle.

losum, the corticomedullary junction, the upper brainstem, or the basal ganglia. Hemorrhage into the corpus callosum may extend into the ventricular system where it is seen more easily.⁴⁵ It has been demonstrated that only one-fourth of shearing injuries initially present with visible hemorrhage. Thus, a negative CT study does not eliminate the possibility of shearing injury. Delayed presentations of diffuse axonal injury also have been reported.⁴⁶

MRI has been shown to better demonstrate findings of diffuse axonal injury.^{47,48} MRI should be performed when there is a disparity between the patient's clinical picture and the CT image. A high intensity signal is seen on T2-weighted images in the four regions where typical lesions occur. However, when demonstration of microhemorrhage is required, the preferred scan technique uses gradient-refocused imaging. This technique is highly sensitive to the presence of iron within hemoglobin.

Extra-axial injuries include subdural hematoma, epidural hematoma, and traumatic subarachnoid hemorrhage including intraventricular hemorrhage. In each case, the characteristic findings are defined by the relationship of the bleeding source to the brain and the meninges.

A subdural hematoma collects between the inner layer of the dura and the subarachnoid space when there is a tear in the bridging veins. The subdural space extends over both sides of the tentorium, cerebellar surfaces, convexities of the brain, and the interhemispheric fissure. Because a subdural hemorrhage lies deep to the dura, it can cross suture lines. Occasionally, a rupture of a parenchymal artery may produce these lesions. Subdural hematomas typically are associated with underlying brain injury and, therefore, carry a poor prognosis. Typical associated injuries include cerebral hematoma or contusion. Associated skull fractures are rare.

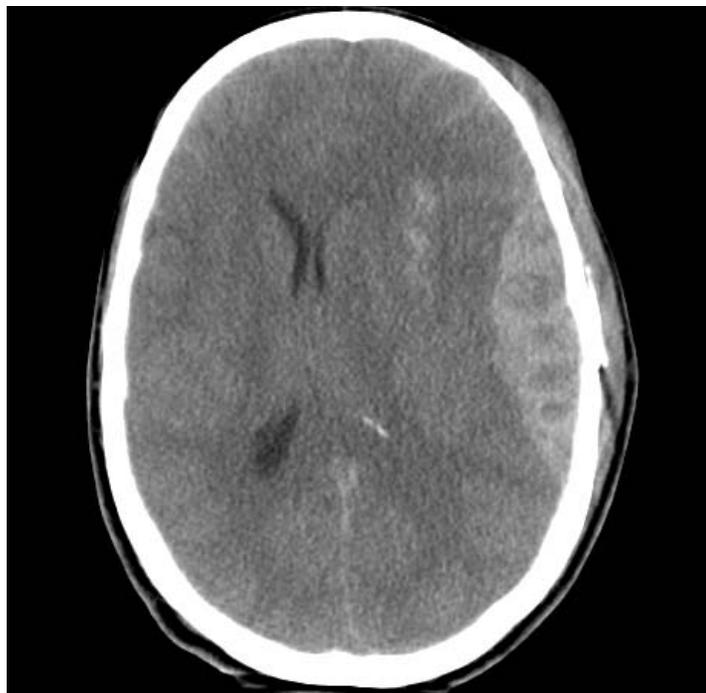
A typical subdural hematoma appears as a crescent-shaped collection of blood between the inner table of the skull and brain parenchyma (*Figure 5*). The classic shape may be modified in

patients with previous injuries or meningeal infection. Small subdural injuries may be difficult to identify (*See Pitfalls section, page 8.*) and also may coexist with an epidural hematoma. These injuries tend to extend from front to back. They also may extend around the frontal or occipital pole into the interhemispheric fissure or beneath the brain along the tentorium. These injuries are often associated with displacement of intracranial contents by mass effect.⁴⁹ Collapse of the ventricular system and midline shift commonly are associated with acute subdural hematoma. In the acute phase of bleeding associated with a subdural hematoma, MRI is very insensitive in defining this injury and has gained a prominent role in the detection and defining the extent of subacute and chronic subdural hematomas.

An epidural hematoma is typically lens-shaped with blood collecting between the inner table of the skull and the dura. Because the dura attaches to the skull at suture lines, an epidural hematoma does not cross suture lines. Classically, an epidural hematoma results from a skull fracture in 85% to 95% of cases.⁵⁰ The most common site of an epidural hematoma is in the temporoparietal region and is due to disruption of the main trunk of the middle meningeal artery (*Figure 6*). This also may give rise to epidural blood on the floor of the middle cranial fossa. Disruption of the anterior trunk of the middle meningeal artery gives rise to frontal epidural hematomas. Other injuries are venous in origin and result from the tear of a dural sinus.

Epidural hematomas are almost exclusively unilateral injuries. An epidural hematoma in the posterior fossa is typically caused by venous bleeding; occipital fractures may be seen. These lesions account for 4% to 13% of epidural hematomas.^{51,52} These injuries must be identified early; with prompt neurosurgical intervention a good prognosis can be expected. The size of the lesion depends upon the rate of bleeding, the time from injury to presentation, the severity of injury, and the formation of clot. Large epidural hematomas compress adjacent brain tissue, cause

Figure 6. Epidural Hematoma



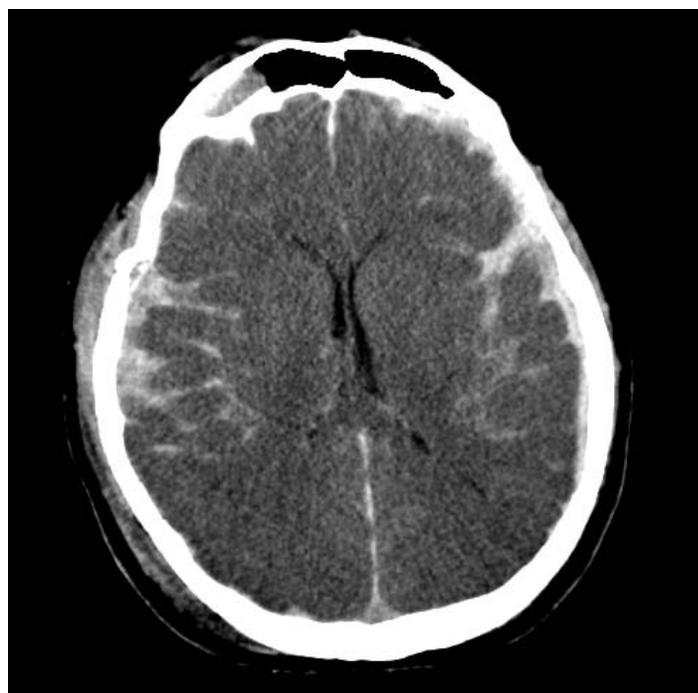
collapse of the ventricular system, and result in brain herniation. The lesion may not be uniform in appearance with an area of less-dense fluid representing both active bleeding and breakdown of clot.⁵⁰

Finally, epidural hematomas commonly are associated with cerebral contusion or subdural hematoma.⁵³ Because these lesions must be promptly evacuated surgically, there is typically no role for MRI in acute management of epidural hematomas. Finally, it should be mentioned that epidural hematomas may have a delayed presentation arising hours to days after injury. These are typically found in areas beneath known skull fractures and frequently occur after evacuation of other intracranial lesions.⁵⁴

In traumatic subarachnoid hemorrhage, disruption of the leptomeningeal vessels leads to bleeding, which tracks into the subarachnoid space. These collections course along the cerebral sulci and also may be seen along the interhemispheric fissure (*Figure 7*). Blood also can track into the ventricular system and can be visualized along the surface of the brain or layering dependently in the occipital horns of the lateral ventricle. Traumatic subarachnoid hemorrhages tend to be more focal than the spontaneous subarachnoid hemorrhage associated with a ruptured aneurysm.

Finally, disruption of the subependymal veins can result in traumatic intraventricular hemorrhage (*Figure 8*). This appears as a hyperdense localized collection within the ventricular system following trauma. Blood also may be seen in association with traumatic subarachnoid hemorrhage that extends into the ventricular system as described above.

Figure 7. Traumatic Subarachnoid Hemorrhage



Pitfalls in Radiology Interpretation

Bone averaging (*Figure 9*) occurs where a high-density structure (e.g., bone) abuts a low density structure (e.g., brain tissue). Where this occurs, the high and low density pixels are ‘averaged’ and give the appearance of an intermediate density that can mimic blood. Similarly, areas of calcification within the brain (e.g., the pineal gland, the choroid plexus, within the basal ganglia, or even a partial cut through the bony floor of the skull) may be mistaken for blood. Additionally, the falx cerebri and tentorium tend to calcify with age and may be mistaken for subdural blood.

Small collections of intra-axial (cerebral contusion) or extra-axial blood (subdural or epidural hematoma or subarachnoid hemorrhage) located near the inner table of the skull may be difficult to appreciate, especially if only brain windows are used. The high density of blood may be indistinguishable from the adjacent cortical bone, a fact particularly true for extra-axial hematomas and cerebral contusions located in the parietal vertex and inferior temporal lobe. Extra-axial hematomas or subarachnoid blood that collects along the transverse plane may be difficult to distinguish from bone when present along the floor of the posterior fossa (*Figure 10*). Collections in the vertex or along the tentorium are better detected when coronal images are obtained.

CT does not provide adequate contrast between structures with similar densities, especially when one considers the high water content of brain structures. Artifact from metal structures (e.g., bullet fragments and aneurysm clips) can degrade the CT image by a phenomenon known as ‘beam hardening,’ where high density structures (e.g., the skull) may produce a streak artifact that can obscure the images.

Figure 8. Traumatic Intraventricular Hemorrhage

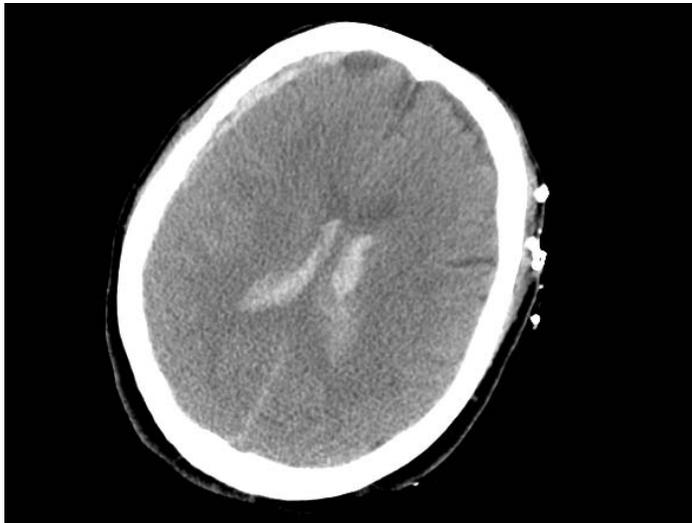


Figure 8. Traumatic Intraventricular Hemorrhage. Note that this patient also has a right subdural hematoma in the frontoparietal region.

Figure 10. Tentorial Hemorrhage

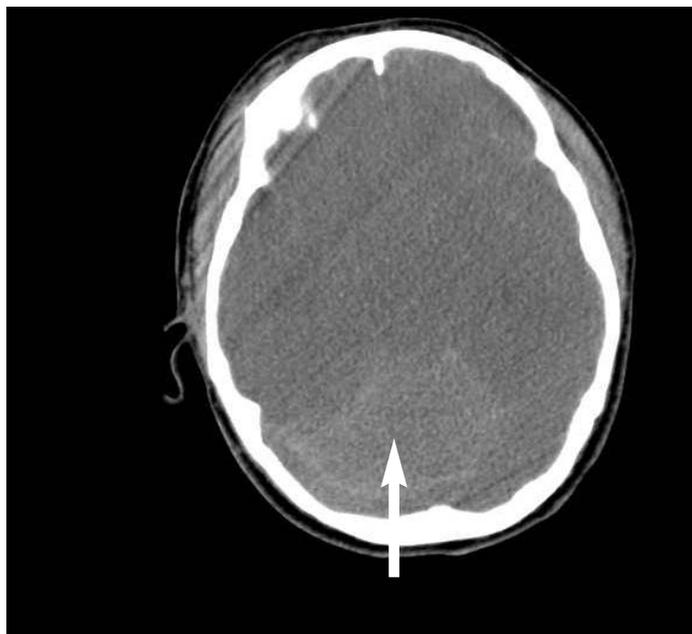


Figure 10. Tentorial Hemorrhage. Arrow depicts blood along the tentorium.

An important CT indicator of brain swelling is effacement of the subarachnoid spaces surrounding the brainstem (basal cisterns). However, blood within the basal cisterns can make them isodense with the brainstem, mimicking herniation.

Interhemispheric blood is often confused with thickening of the falx cerebri. The falx may be prominent along its posterior portion. However, subdural blood that collects along the falx can be difficult to distinguish from the more benign condition (*Fig-*

Figure 9. Bone Averaging



Figure 9. Bone Averaging. White arrow depicts bone averaging artifact from orbital roof originally interpreted as subarachnoid blood.

ure 11). When there is significant thickening along the anterior portion of the falx or when there is outlining of the adjacent sulci, interhemispheric blood must be suspected. Localized subdural hematomas may be found along the interhemispheric fissure. These are the result of tears in bridging veins and tend to occur in older patients with whiplash injury. Interhemispheric subdural hematomas tend to have a straight medial border and a convex lateral margin. The bleeding from a parasagittal subdural hematoma tends to remain contained in this region by arachnoid granulations. In addition, subarachnoid or subdural hemorrhage in the posterior falx may produce a high density ('pseudo-delta') sign that can be confused with the image of dural sinuses in a contrast-enhanced CT scan. Subarachnoid hemorrhage along the interhemispheric fissure is characterized by increased density outlining the parasagittal cortical sulci.

The sensitivity of CT may be limited when imaging subacute injuries. Subdural hematomas in the elderly patient are notorious for their subacute presentation. This relates to the breakdown of hemoglobin over time, with blood clot becoming isodense with brain and less visible on CT (usually around two weeks after the injury). In this circumstance, MRI becomes a more sensitive imaging modality for defining subacute or chronic collections of blood that will demonstrate a high-intensity signal on T1-weighted images.

Figure 11. Subarachnoid Blood Along Falx

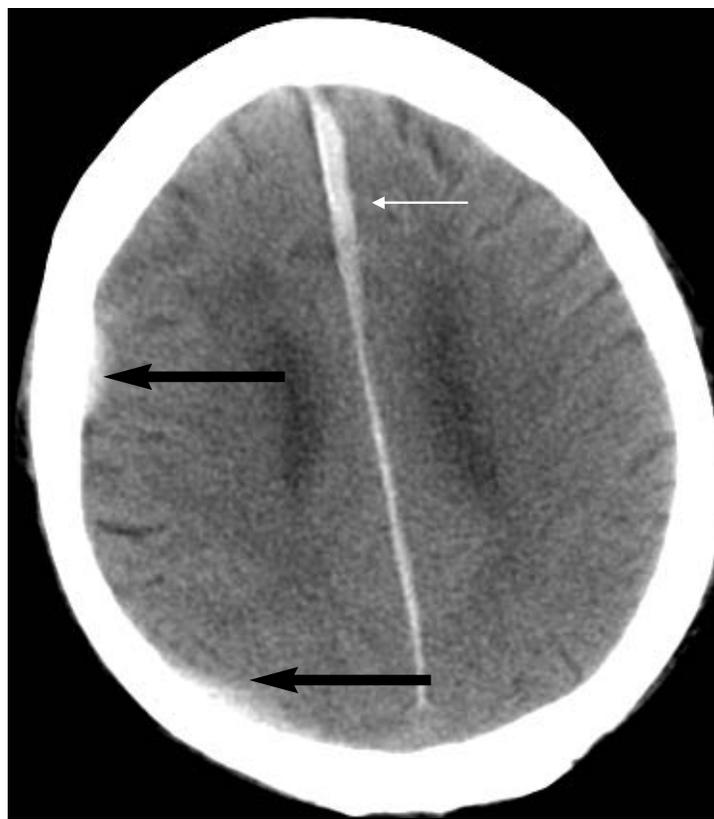


Figure 11. Subarachnoid Blood Along Falx. White arrow depicts blood along the falx. Black arrows demonstrate subdural hemorrhage along frontal and parietal convexities.

Conclusions

The clinician should be aware of the role of the various imaging modalities in the assessment of the patient with head trauma. CT imaging has revolutionized the evaluation of head injury, providing a rapid and reliable method for detecting acute traumatic hemorrhage and facilitating early surgical intervention when appropriate. Skull radiographs and MRI have limited roles in the management of early head injury. The clinician should be aware of the characteristic shape and location of intra-axial and extra-axial blood collections. In addition, when interpreting CT scans in the acute setting the clinician should be cognizant of difficulties in interpreting these radiographs caused by artifacts inherent in the imaging modality and unusual presentations of the resultant injury.

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CE/CME Objectives

Upon completing this program, the participants will be able to:

- a.) discuss conditions that should increase suspicion for traumatic injuries;
- b.) describe the various modalities used to identify different traumatic conditions;
- c.) cite methods of quickly stabilizing and managing patients; and
- d.) identify possible complications that may occur with traumatic injuries.

CE/CME Instructions

Physicians and nurses participate in this continuing medical education/continuing education program by reading the article, using the provided references for further research, and studying the questions at the end of the article. Participants should select what they believe to be the correct answers, then refer to the list of correct answers to test their knowledge. To clarify confusion surrounding any questions answered incorrectly, please consult the source material. **After completing this activity, you must complete the evaluation form provided and return it in the reply envelope provided in order to receive a certificate of completion.** When your evaluation is received, a certificate will be mailed to you.

CE/CME Questions

- Which of the following are indications for a patient to receive a head CT?
 - Glascow coma scale score of 13
 - Open skull fracture
 - Signs of a basilar skull fracture
 - All of the above
- Which one of the following groups of patients should physicians have a lower threshold for obtaining a head CT following trauma to the head?
 - Intoxicated patients
 - Patients taking antidepressant medications
 - Patients with a history of a previous concussion
 - Patients from prisons
- In children, clinicians should have a lower threshold for obtaining a head CT after head trauma. Which of the following is *not* an independent risk factor for closed head injury?
 - Crying
 - Altered mental status
 - Large scalp hematoma in a child younger than 1 year
 - Focal neurologic deficit
- The CT scout image is useful when assessing the technical quality of the study by demonstrating the orientation of the images as well as the number of images produced and the anatomic area scanned.
 - True
 - False
- MRI has been shown to be superior to CT for the detection of:
 - acute epidural hematomas.
 - acute subdural hematomas.
 - diffuse axonal injury.
 - None of the above
- Which of the following statements is *not* true regarding an epidural hematoma?
 - It is usually a unilateral injury.
 - The lesion is typically lens shaped.
 - It is associated with a skull fracture in 10-15% of cases.
 - The size of the lesion depends upon the rate of bleeding, time from injury to presentation, and severity of the injury.
- Typically there is no role for the use of MRI in the acute evaluation of an epidural hematoma.
 - True
 - False

- Which of the following statements regarding traumatic subarachnoid hemorrhage is true?
 - Disruption of the leptomenigeal vessels leads to bleeding.
 - Blood may track into the ventricular system and can be visualized along the surface of the brain or layering dependently in the occipital horns of the lateral ventricle.
 - Traumatic subarachnoid hemorrhage tends to be more focal than the spontaneous subarachnoid hemorrhage associated with a ruptured aneurysm.
 - All of the above
- An important indicator of brain swelling is blood accumulation within the lateral ventricles.
 - True
 - False
- Which of the following statements regarding interhemispheric blood is *not* true?
 - It is often confused with thickening of the falx cerebri.
 - Significant thickening along the anterior portion of the falx or outlining of the adjacent sulci should lead the clinician to suspect interhemispheric blood.
 - Typically these are a result of an arterial bleed.
 - Interhemispheric subdural hematomas tend to have a straight medial border and a convex lateral margin.

Answers:

- D
- A
- A
- A
- C
- C
- A
- D
- B
- C

In Future Issues:

The use of ultrasound in the hypotensive trauma patient

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