An Evidence-Based Approach To Imaging Of Acute Neurological Conditions

It’s Monday afternoon, the ED is full, and neuroimaging seems to be the “theme” for the day. You realize how your clinical skills are merged with technology and how dependent your clinical decision-making is on radiology.

A 75-year-old male presents with two hours of right-sided hemiplegia. The on-call neurologist recommends TPA if the head CT does not show hemorrhage. The radiologist tells you there is no blood but there are early ischemic changes….

A 55-year-old male presents after a syncopal episode. He has a normal neurological exam and no evidence of head trauma. His wife asks if a head CT should be done to rule out stroke….

A 19-year-old female presents with four days of severe headache. She describes a thunderclap onset, with some improvement over the past several days. You initially suspect subarachnoid hemorrhage; however, her non-contrast head CT is normal. After prochlorpromazine and fluids, she is eager to leave….

A 20-year-old male presents with a new onset tonic clonic seizure witnessed by his roommate. He has no past medical history and takes no medications or drugs. He is back to his baseline and his neurological exam is completely normal. The CT scanner is backed up for at least two hours and you wonder if it would be OK to send him home for an outpatient workup…

A 52-year-old male is involved in a motor vehicle collision. He does not recall the moment of impact and appears to have had a brief loss of consciousness. He is now neuroradiologically intact with no other complaints and a normal exam. You wonder whether CT is necessary…

A lot of patients, a lot of decisions; not enough CT scanners!

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CME Objectives
Upon completion of this article, you should be able to:
1. Describe indications for neuroimaging for a variety of clinical presentations.
2. Describe a systematic approach to the interpretation of non-contrast head CT.
3. Select the most appropriate imaging modality for a variety of acute neurological complaints.
4. Compare and contrast CT and MR in terms of sensitivity and specificity for the evaluation of neurological pathology.
5. Identify areas of overuse or misuse of imaging techniques in the assessment of neurological complaints.
6. Select a diagnostic algorithm that improves patient care by facilitating rapid and accurate diagnosis while minimizing radiation exposure and cost.

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Prior to beginning this activity, please see “Physician CME Information” on the back page.

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Emergency physicians are frequently confronted with patients with neurological complaints requiring emergent imaging for diagnosis and treatment. The diversity and variations of imaging modalities may appear confusing, resulting in physician uncertainty about the most appropriate modality to evaluate the presenting complaint. An evidence-based approach, with the modality and technique selected based on patient characteristics and differential diagnosis, is essential. In this review, the evidence supporting the use of computed tomography (CT) and magnetic resonance imaging (MRI) for the diagnosis and treatment of emergency brain disorders will be reviewed. Adjunctive imaging techniques will also be considered, including conventional angiography, plain films, and ultrasound. Clinical decision rules intended to target imaging utilization to high-risk patients will also be discussed.

Abbreviations Used In This Article

CASL: Continuous Arterial Spin Labeling (an MRI technique for magnetic labeling of blood)
CCHR: Canadian CT Head Rule
CT: Computed Tomography
CTA: Computed Tomographic Arteriography (Angiography)
CTPS: CT Perfusion Studies
DAI: Diffuse Axonal Injury
DWI: Diffusion Weighted Imaging (an MRI sequence)
GCS: Glasgow Coma Score
GEPS: Gradient Echo Pulse Sequencing
ICP: Intracranial Pressure
IV: Intravenous
LP: Lumbar Puncture
LR: Likelihood Ratio
MCA: Middle Cerebral Artery
MR: Magnetic Resonance
MRA: Magnetic Resonance Arteriography (Angiography)
MRI: Magnetic Resonance Imaging
NIH: National Institutes of Health
NINDS: National Institute Of Neurological Disorders And Stroke
PWI: Perfusion Weighted Imaging (an MRI sequence)
SAH: Subarachnoid Hemorrhage
TEE: Transesophageal Echocardiography
TIA: Transient Ischemic Attack
TPA: Tissue Plasminogen Activator
TTE: Transthoracic Echocardiography

Critical Appraisal Of The Literature

A large number of studies have examined indications for neuroimaging as well as the test characteristics (including sensitivity, specificity, and positive and negative likelihood ratios) of the available imaging modalities. This article focuses on large, multicenter, prospective trials whenever possible; unfortunately, however, strong evidence is lacking for many of the clinical questions addressed.

Principles Of Evidence-Based Medicine

Imaging studies for neurological emergencies share a common problem in that the gold-standard for diagnosis is often another imaging study, and there is no clear, independent means of settling discrepancies. It is unclear what strategy should be used when two imaging studies yield divergent results. For example, if CT is compared to MR for evaluation of acute intracranial hemorrhage, which test should serve as the gold standard? Given a negative CT in the context of a positive MR, is the CT a false negative or the MR a false positive? Alternative gold standards may include clinical follow-up for mortality, readmission, neurosurgical intervention, or neurological outcome. When evaluating a study’s relevance to clinical practice, the strength of the gold standard must be considered.

Another important concept when interpreting the results of a study is “point estimate” versus “95% confidence interval.” Take the example of a study with a point estimate sensitivity of 99% and a confidence interval of 66-100%. The 95% confidence interval indicates that the sensitivity of the test has a 95% chance of lying between the extreme values of 66% and 100%. While the likelihood of the test having either of these extreme values is low, it cannot be ruled out on the basis of the data. Small studies will often have broad 95% confidence intervals for their results, while larger studies usually have narrower confidence intervals. For a test to be reliable for ruling out a disease process, it must have both high sensitivity and a narrow confidence interval. To rule in pathology, the specificity must be high and the confidence interval narrow. The lower boundary of the confidence interval can be considered a “worst case scenario” for the test characteristic.

Another means of reporting a test’s ability to “rule in” or “rule out” pathology is the likelihood ratio (LR). The likelihood ratio positive (LR+) is the factor by which the likelihood of disease increases when the test result is positive. The likelihood ratio negative (LR-) is the factor by which the likelihood of disease decreases when the test result is negative. The pretest probability multiplied by the LR (positive or negative) yields the post-test probability.

Positive and negative predictive values are not emphasized in this review because they are heavily influenced by disease prevalence and must be used cautiously in clinical practice.

Neuroimaging Modalities

Indications for neuroimaging are diverse and include traumatic and non-traumatic conditions. The major brain neuroimaging modalities are CT and MRI, with adjunctive roles for conventional angiography and ultrasound. Plain films of the calvarium have an
CT

CT has been in general clinical use in the emergency department (ED) in the United States since the early 1980s. The modality was simultaneously and independently described by the British physicist Godfrey N. Hounsfield and the American Allan M. Cormack in 1973, and the two were co-recipients of the Nobel Prize for Medicine in 1979. Advances in computers and the introduction of multi-slice helical technology have dramatically enhanced the resolution, sensitivity, and specificity of CT since its introduction. CT relies on the differential attenuation of x-ray by body tissues of differing density. The image acquisition occurs by rapid movement of the patient through a circular gantry opening equipped with multiple x-ray sources and detectors. A three-dimensional volume of image data is acquired; this volume can be displayed as axial, sagittal, or coronal slices or as a three-dimensional image. When performed without intravenous (IV) contrast, CT is considered to be excellent for detection of bony abnormalities, acute hemorrhage, cerebral edema, hydrocephalus, or mass effect. It is less sensitive for acute ischemic stroke but becomes more sensitive with the passage of time, as will be discussed later. Adding IV contrast improves the sensitivity of CT for neoplastic, infectious, and vascular abnormalities. IV contrast can be used to generate CT arteriograms, CT venograms, and CT perfusion maps. These will be described in more detail later in this paper. CT does raise some safety concerns with regard to long-term biological effects of the ionizing radiation and carcinogenesis. The radiation exposure to the fetus in a shielded patient undergoing head CT is minimal. Most commercially available CT scanners have a weight capacity of approximately 450 pounds, although some manufacturers now offer units with capacities up to 650 pounds, and a portable head CT scanner with a manufacturer-reported unlimited weight capacity is also now available.

MRI

MRI has been in wide clinical use in the U.S. since the late 1980s. The modality was co-invented by the American Paul C. Lauterbur and the British physicist Sir Peter Mansfield, who shared the 2003 Nobel Prize in Medicine for their work. MRI allows imaging of the brain by creating variations in the gradient of a magnetic field and analyzing the radio waves emitted in response to objects within the field. Advantages of MRI include its noninvasive nature and its apparent safety in pregnancy. It also has no known permanent harmful biological effects. Traditionally, contraindications have included the presence of ferromagnetic material within the body, including electronic devices (such as pacemakers) or metallic debris (such as shrapnel), especially when they are located in sensitive structures (such as the eye or brain). However, there are now over 230 published prospective cases of patients with pacemakers having safely undergone low-field MRI, making MRI a possible imaging option in these patients. Magnetic effects on tattoos, including first-degree burns and burning sensation, have been reported, although these appear rare and more likely to interfere with completion of MRI than to cause significant harm.

Interpretation Of Non-Contrast Head CT

Several systematic methods for interpretation of non-contrast head CT have been described. The mnemonic “Blood Can Be Very Bad” has been shown to assist in the sustained improvement of interpretation by emergency medicine residents. The mnemonic reminds the interpreter to look for blood (“blood”), abnormalities of cisterns and ventricles (“can,” “very”), abnormalities of the brain parenchyma (“be”) and fractures of bone (“bad”). Another mnemonic uses the familiar ABC paradigm to drive the assessment of the head CT. The mnemonic is reviewed in Table 1, with images illustrating each finding in the figures that follow. The full mnemonic is freely available from the nonprofit organization EMPACS (http://www.empacs.org/library/headCT/news100106.htm). Additional images for concepts discussed in this article as well as larger copies of the images presented here can also be found on this website.

Principles Of Interpretation Of Non-Contrast Head CT

Non-contrast head CT is the most commonly ordered neuroimaging test in the ED, utilized in up to 12% of all adult ED visits. On CT, the density of a tissue

Table 1. A Mnemonic For Systematic Interpretation Of Non-Contrast Head CT: ABBBC

- Air-filled spaces
  - Sinuses
  - Mastoid air-cells
- Infections
- Fractures
- Bones
- Blood
  - Subarachnoid
  - Epidural
  - Subdural
  - Intraparenchymal
- Brain
  - Infarction
  - Edema
  - Masses
  - Midline shift
- CSF spaces
  - Sulci
  - Ventricles
  - Cisterns
- ICP
- Atrophy
- Hydrocephalus
- Edema
is represented using the Hounsfield scale, with water having a value of zero, tissues denser than water having positive values, and tissues less dense than water having negative values (Figure 1). By convention, low density tissues are assigned darker (black) colors and high density structures are assigned brighter (white) colors. Because the human eye can perceive only a limited number of gray shades, the full range of density values is typically not displayed for a given image. Instead, the tissues of interest are highlighted by devoting the visible gray shades to a narrow portion of the full density range, a process called “windowing” (Figures 1 and 2). The same image data can be displayed in different window settings to allow evaluation of injury to different tissues. In general, head CT images are viewed on “brain” or “bone” windows to allow the most emergent pathology to be assessed (Figure 2).

The brain, air, CSF spaces, and surrounding bone are normally symmetrical structures (Figures 3, 4, 5). A head CT should be inspected for normal symmetry, as deviation often indicates pathology (Figure 3). However, if the patient’s head is not centered symmetrically in the CT gantry, the resulting images can create a false sense of asymmetry.

The compression or displacement of normal brain structures by adjacent masses is called “mass effect.” When this effect becomes extreme, shift of brain structures across the midline of the skull can occur, a finding referred to as “midline shift.” Midline shift can indicate significant pathology, including threatened subfalcine herniation (Figure 6). This finding should be carefully sought after, as it may be more important than the underlying etiology of the shift in determining management. A brain CT should also be examined for artifacts which may limit interpretation, including motion and “streak artifact” from high density structures such as metal (Figure 7 on page 6). Although artifact may degrade the overall quality of the study, useful diagnostic information can often still be gleaned from an imperfect scan.

The Mnemonic: ABBBC

A systematic approach to the interpretation of the head CT is necessary to avoid missing important abnormalities. An approach will be reviewed here with a discussion of the normal appearance of the brain.

A is For Air

The normal brain contains air-filled spaces: the maxillary, frontal, ethmoid, and sphenoid sinuses and the mastoid air-cells (Figure 4). On both “bone” and “brain” window settings, a normal air-filled space appears black. Opacification of an air-space may occur due to fluids (such as pus, mucous, or blood) or due to tumor invasion of the space. In the setting of trauma, opacification of an air-space may indicate...
bleeding into that space, raising suspicion of a fracture of the surrounding bone (Figure 8 on page 6). In the absence of trauma, opacification may indicate sinus infection, although this is a nonspecific finding.

**B Is For Bone**

Bone abnormalities (including acute fractures) are best identified using “bone” windows. Defects in the cortex of bone indicate fracture, but these must be distinguished from normal suture lines (Figure 9 on page 6). Comparing the contralateral side to the side in question may help to distinguish fractures from normal sutures. Secondary signs of fracture, such as opacification of adjacent air-spaces, may assist in recognition of fractures (Figures 8 and 9 on page 6). Pneumocephalus (air within the calvarium) may also be present and may provide an additional clue to open fractures (Figure 10 on page 6).

**B Is For Blood**

A brain CT should be carefully inspected for the presence of subarachnoid, epidural, subdural, and intraparenchymal blood. On non-contrast head CT, acute hemorrhage appears hyperdense (brighter / whiter) compared with brain tissue. Multiple hemorrhage types may co-exist on CT.

Blood in the subarachnoid space can diffuse into the sulci, fissures, cisterns, and ventricles (Figure 11 on page 7). Common locations for subarachnoid hemorrhage include the basilar cisterns surrounding the brainstem. Diffuse subarachnoid hemorrhage can be symmetrical, so symmetry alone is not enough to rule out this process. Familiarity with the normal black appearance of normal CSF spaces (Figure 5) can help to avoid confusion.

Blood in the epidural space classically assumes a biconvex disc shape (Figure 12 on page 7). Epidural hematomas most often do not cross suture lines because the dura mater is tightly adherent to the calvarium at these locations and restricts extension of the hematoma. An expanding epidural hematoma

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**Figure 4. Air-filled Spaces**

These are the normal locations and appearances of air-filled spaces when viewed on “brain windows.” Air-filled spaces are normally black on both “brain” and “bone windows.”

- A. Maxillary sinuses
- B. Mastoid air cells
- C. Ethmoid sinuses
- D. Sphenoid sinus
- E. Frontal sinus

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may exert mass effect, leading to midline shift and herniation. Epidural hematomas are classically found in a temporal location and are due to bleeding from injury to the middle meningeal artery. Active bleeding from this vessel may result in the “swirl sign,” a heterogeneous appearance of the epidural hematoma.

Subdural hematomas (Figure 6 on page 5) typically assume a concave or crescent shape and can cross suture lines, as they lie between dura and brain and are not restricted by attachment sites between dura and calvarium. Like epidural hematomas, subdural hematomas may result in mass effect and midline shift. Subdural hematomas are typically caused by injury to dural veins. They frequently have a heterogenous appearance, indicating blood of varying ages.

Intraparenchymal hemorrhage (Figure 13 on page 7) may also result in mass effect and midline shift. Hemorrhage should be distinguished from...
calcification, which may also be present as an incidental finding (Figures 13 and 14). Although the specific type of hemorrhage is important to recognize, the end results of mass effect may be more important determinants of acute management.

**B Is For Brain**

Inspection of the brain parenchyma should include assessment for masses, infarction, edema, and midline shift.

Masses may be visible due to calcifications (Figure 14), surrounding vasogenic edema (Figure 15 on page 8), or solely due to their mass effect on surrounding structures. Vasogenic edema refers to edema occurring in the presence of abnormally leaky blood vessels (such as those seen in the setting of neoplasm), perhaps in response to vascular endothelial growth factor. Edema reduces the density of tissues toward that of water (zero on the Hounsfield scale), resulting in a “hypodense” (darker/blacker) appearance on CT.

Ischemic infarction (Figure 17 on page 8) results in a number of abnormalities (Table 2), including loss of gray-white matter differentiation, vasogenic and cytogenic edema, and the frank hypodensity of infarction, depending on time elapsed from onset.

**Table 2. Prevalence Of Early Ischemic CT Changes Within Three Hours, Possibly Contraindicating TPA Use, From NINDS**

<table>
<thead>
<tr>
<th>Change</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any change</td>
<td>31%</td>
</tr>
<tr>
<td>Loss of GWMD*</td>
<td>27%</td>
</tr>
<tr>
<td>Hypodensity</td>
<td>9%</td>
</tr>
<tr>
<td>Compression of CSF spaces</td>
<td>14%</td>
</tr>
<tr>
<td>Loss of GWMD &gt; 1/3 MCA</td>
<td>13%</td>
</tr>
<tr>
<td>Hypodensity &gt; 1/3 MCA</td>
<td>2%</td>
</tr>
<tr>
<td>Compression of CSF spaces &gt; 1/3 MCA</td>
<td>9%</td>
</tr>
</tbody>
</table>

*GWMD = gray-white matter differentiation

**Figure 11. Subarachnoid Hemorrhage**

Subarachnoid hemorrhage appears white on non-contrast CT. In this case of diffuse subarachnoid hemorrhage, note the presence of subarachnoid blood filling the sulci, as well as extending into the cisterns, Sylvian fissures, and even lateral ventricles.

- A. Blood in basilar cistern
- B. Blood in Sylvian fissure
- C. Blood in posterior horns of lateral ventricles
- D. Blood in sulci

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**Figure 12. CT Of An Epidural Hematoma**

Classic features of epidural hematoma (arrowheads) are visible:
- Lens-like or biconvex disc shape
- Temporal location, with associated depressed temporal bone fracture (A)
- Does not cross suture lines (B - expected location of suture)
- Mass effect with midline shift (C)
- “Swirl sign” – heterogeneous appearance suggesting active bleeding (D)
- Elevated ICP, with small ventricles (E) and no visible sulci (F)

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**Figure 13. CT Of An Intraparenchymal Hemorrhage**

Acute intraparenchymal hemorrhage appears white on CT. Hemorrhage in the patient’s left frontal region is creating mass effect with midline shift. The left lateral ventricle has been effaced.

A calcified mass in the right occipital region must be differentiated from acute hemorrhage. Calcifications are extremely bright white on brain windows – as white and dense as bone. On bone windows, they remain visible, while hemorrhage does not.

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Normal gray-white matter differentiation (Figure 16) is the result of the normal density difference between gray matter and white matter in the brain. White matter, representing myelinated structures, has a higher fat content than gray matter; therefore, it normally appears less dense and darker gray on CT. As ischemia or infarction develops, ATP-dependent ion pumps fail, and fluid shifts result in the development of interstitial edema in the affected region. Affected tissue becomes hypodense on CT, compared with normal tissues. The earliest manifestation of this change on CT is loss of the normal differentiation between gray and white matter, progressing ultimately to the appearance of infarct (Figure 17).

Localized brain edema may be evident as hypodensity of brain parenchyma (Figures 15 and 17). In addition, local edema may result in local mass effect, including the effacement of ventricles (Figure 15).

Figure 14. Calcifications

Calcification of the choroid plexi (A) is a frequent incidental finding which may resemble punctate intraparenchymal hemorrhage. Clues are a bright white density (equal to that of bone), location in the posterior horns of the lateral ventricle, and frequent bilaterality. This patient also has a calcified meningioma (B). Meningiomas are common benign neoplasms which may become quite large. A well-circumscribed rounded appearance and calcification are common. © 2007 Joshua Broder.

Figure 15. Masses

This image shows a mass with surrounding vasogenic edema (arrowheads). Neoplasms are frequently associated with vasogenic edema, named for the putative cause, which is abnormal vessels that allow extravasation of edema fluid. This form of edema appears hypodense, like an ischemic infarct, but is not restricted to a vascular territory. An abscess might appear similar. © 2007 Joshua Broder.

Figure 16. Gray And White Matter

This shows normal gray-white matter differentiation. Myelinated regions (white matter) have a greater fat content than unmyelinated regions (gray matter). As a consequence, white matter is lower density and appears darker on CT. When ischemia renders this interface less discrete, the CT appearance is called loss of gray-white differentiation. © 2007 Joshua Broder.

Figure 17. Progression Of Ischemic Hypodensity Over Days

A left MCA distribution stroke, day two (A) and day four (B) after symptom onset. Early ischemic changes may be visible within three hours of symptom onset. The rate of progression of CT findings may depend on the degree of ischemia or infarction and thus may vary between patients. © 2007 Joshua Broder.
effacement of the posterior horn of the lateral ventricle), and effacement of sulci as adjacent gyri expand in size (Figure 17).

As described previously, midline shift should be carefully assessed during inspection of the brain on “brain” windows (Figures 6, 12, and 13).

C Is For CSF Spaces
Normal cerebrospinal fluid (CSF) spaces (Figure 5 on page 5) show symmetrical lateral ventricles that are neither enlarged nor effaced, patent sulci, and patent basilar cisterns. Deviations from this norm are best appreciated by understanding the normal pattern. In cerebral atrophy (Figure 18), all CSF spaces are enlarged. In obstructive hydrocephalus (Figure 19), the enlarging ventricles compress other CSF spaces, causing effacement of the sulci and basilar cisterns. In diffuse cerebral edema (Figure 20), the swelling brain parenchyma compresses and effaces all CSF spaces, including sulci, ventricles, and cisterns. Figure 21 compares various combinations of CSF spaces and their diagnostic correlates.

Costs Of Neuroimaging
Costs of CT and MR tests are listed in Table 3 on page 10. These Medicare reimbursement figures may dramatically underestimate the cost billed to the patient. An industry survey of imaging costs in New Jersey found a wide variation in consumer costs, ranging from $1000 to $4750 for brain MRI/MRA.\textsuperscript{15} The American Hospital Directory reports the national average charge to be $996 for head CT and $2283 for MRI.\textsuperscript{16} Additional radiologist physician fees may apply. Some authors have concluded that, in the setting of traumatic brain injury, the extreme cost of a missed injury justifies the use of CT in all patients, rather than a more selective imaging policy based on clinical criteria.\textsuperscript{17} However, with an annual cost of emergency head CTs in the U.S. estimated to exceed $130 million, others have estimated the savings from selective use of CT to be high and the risk of missed injury to be low using validated clinical decision rules such as the Canadian CT Head Rule.\textsuperscript{18}

Figure 18. Cerebral Atrophy

In cerebral atrophy, all CSF spaces become prominent. The basilar cisterns (A, arrow) are open, and the lateral ventricles are enlarged (B). Sulci (C) are equally prominent, helping to distinguish this condition from hydrocephalus. © 2007 Joshua Broder.

Figure 19. Hydrocephalus

In hydrocephalus, the basilar cisterns (A, arrow) are effaced, as are the sulci (C). The lateral and third ventricle are enlarged (B). © 2007 Joshua Broder.

Figure 20. Cerebral Edema

In cerebral edema, the basilar cistern (A, arrow) becomes effaced. The lateral ventricles become compressed and slit-like (B), or even completely effaced. Sulci (C) become effaced. © 2007 Joshua Broder.
Radiation

The radiation dose from a head CT is approximately 60 mGray.\textsuperscript{19,20} Attributable mortality risk varies, depending on age of exposure. A single head CT in a neonate would be expected to contribute less than a 1 in 2000 attributable risk of fatal cancer; the risk in adults declines even further, to less than 1 in 10,000.\textsuperscript{20} However, head CT may have other risks — one study of patients undergoing external beam radiation therapy for scalp hemangiomas, with a radiation exposure similar to that from CT, found an association with lower high school graduation rates.\textsuperscript{21} This study, while large (over 2000 subjects followed over time) was retrospective and therefore can demonstrate only an association, not causation. In general, the radiation exposure from head CT likely poses a very low level of risk for deleterious biological effects, but care should be taken to perform testing only when indicated, as radiation effects are cumulative and not fully understood.

Emergency Department Evaluation

Before neuroimaging can be considered, basic principles of emergency medicine must be applied, including management of the patient’s airway and hemodynamic stabilization as indicated. An unstable patient is not appropriate for imaging tests that will take the patient out of the ED for extended periods of time (such as MRI). The history and physical examination can guide imaging decisions. A thorough neurological examination, including assessment of orientation, strength, sensation, deep tendon reflexes, cerebellar function, and language, may help localize the neurologic lesion and assist in choosing the imaging modality. Motor and sensory deficits that are unilateral may be more suggestive of an anterior fossa brain abnormality, imaged by CT or MRI, whereas a bilateral motor and sensory level may suggest a spinal lesion. Symptoms of vertigo, ataxia, and dysmetria may suggest posterior fossa cerebellar abnormalities, best imaged by MRI. Acute onset of these symptoms could suggest posterior circulation stroke, for which imaging options would include MRI/MRA and CTA of the head and neck. Symptoms of cranial nerve dysfunction, including dysarthria, dysphagia, and abnormalities of extraocular muscles suggest brainstem pathology which is better imaged with MRI than with CT. A motor deficit with ptosis and miosis may suggest carotid artery aneurysm or dissection, imaged by CTA, MRA, or carotid ultrasound. Table 4 correlates chief complaints, differential diagnosis, and suggested initial imaging test. A complete review of neuroanatomic localization is beyond the scope of this article.

Stroke

Stroke is the leading cause of disability in the U.S.\textsuperscript{22} and may be ischemic (85\%) or hemorrhagic (15\%) in nature. When presented with signs and symptoms suggestive of stroke, the emergency physician (EP) must take steps to differentiate ischemic stroke from intraparenchymal hemorrhage while entertaining the possibility of “stroke mimics” (e.g., hypoglycemia or Todd’s paralysis). To aid in this task, a number of neuroimaging studies exist. Some techniques may yield additional information, including localization of the vascular territory affected, the extent of injury, clues to the underlying precipitant cause(s), and identification of tissue that might be ischemic but still viable. This information is critical when contemplating the use of thrombolytic or neuroprotective therapies.

Table 3. Costs Of CT And MR Imaging, Based On 2007 Medicare Reimbursement National Averages

<table>
<thead>
<tr>
<th>Diagnostic Procedure</th>
<th>Hospital Outpatient</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT head or brain without contrast</td>
<td>$230.54</td>
</tr>
<tr>
<td>CT angiography head, without contrast followed by contrast, further sections, and post-processing</td>
<td>$382.19</td>
</tr>
<tr>
<td>MR angiography, head with contrast</td>
<td>$386.64</td>
</tr>
<tr>
<td>MR angiography, neck with contrast</td>
<td>$386.64</td>
</tr>
<tr>
<td>MRI brain w/contrast</td>
<td>$386.64</td>
</tr>
<tr>
<td>MR angiography, neck without contrast material(s), followed by contrast material(s) and further sequences</td>
<td>$522.54</td>
</tr>
</tbody>
</table>

Figure 21. A Comparison Of CSF Spaces

An overview of CSF spaces:
- Normal brain
  - All CSF spaces are present, neither effaced nor enlarged
- Atrophy
  - All CSF spaces are enlarged
- Hydrocephalus
  - The ventricles expand
  - The sulci and cisterns are compressed
- Edema
  - All CSF spaces are compressed
© 2007 Joshua Broder.
Unfortunately, many imaging modalities are not currently available at all institutions during all hours of the day. Furthermore, many options remain untested or inconclusive with regard to their utility in guiding intervention and disposition.

**Computed Tomography (CT) For Stroke**

CT is the most widely available immediate imaging technique for patients presenting to the ED with signs and symptoms of stroke. Non-contrast head CT is rapid, taking less than five seconds for image acquisition using some 64 slice scanners. It is sensitive for detecting intracranial hemorrhage, and immediate imaging is more cost effective than either delayed or selective imaging strategies. Limitations do exist, however. For example, the surrounding bone can obscure evidence of ischemic stroke, an artifact effect known as “beam hardening.” This problem can be minimized by requesting fine thickness cuts (~ 1 mm); however, the risk of false negatives for stroke detection still exists, particularly when a vertebral-basilic distribution is present since beam hardening is worsened by the thick bone surrounding the posterior fossa.

In response to cell damage and associated edema, ischemic brain typically appears as a lower density signal on non-contrast head CT. A variety of early ischemic changes have been described (Figures 17, 22, 23). These include hypoattenuation of the middle cerebral artery (MCA) territory, obscuration or shadowing of the lentiform nucleus, loss of the insular ribbon or obscuration of the Sylvian fissure, effacement of the cortical sulcus, focal parenchymal hypoattenuation, or loss of gray-white matter differentiation in the basal ganglia. The much publicized “hyperdense MCA sign” (Figure 24 on page 12) (hyperattenuation of the MCA) may also be present; although, it is only visible in 30-40% of patients with stroke affecting the MCA territory, and its relevance to clinical outcome is equivocal. The presence of one or more of these signs during the early stages (within six hours of stroke onset) of brain ischemia is important since it correlates with worse functional outcomes, but it must be emphasized that a truly normal non-contrast head CT is still consistent with the diagnosis of acute ischemic stroke in a patient presenting with suggestive signs and symptoms. This is because, although the sensitivity increases beyond 24 hours, the sensitivity for ischemia-induced changes in the early stages is relatively low at 66%.

For the emergency physician, several points about early ischemic changes should be emphasized. First, in contrast to the assertion in some emergency medicine texts that ischemic stroke becomes visible on non-contrast head CT only after six hours, the NINDS trial upon which TPA therapy is largely based demonstrates that 31% of patients had early findings of ischemia within three hours of symptom onset (Table 2 on page 7). Although early ischemic changes were not an exclusion criterion for TPA in the original NINDS trial, subsequent research has shown a heightened risk of hemorrhagic conversion of ischemic stroke, poor neurological outcomes, and death in patients with these changes. As a consequence, the FDA, the American Heart Association, and the American Academy of Neurology recommend against the use of TPA in patients with major early ischemic changes. Specifically, early ischemic changes occupying an area one-third the size of the MCA territory or one-third of a cerebral hemisphere, cerebral edema, and midline shift are considered

<table>
<thead>
<tr>
<th>Neurological Complaint</th>
<th>Differential Diagnosis</th>
<th>Initial Imaging Modality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td>Mass, traumatic or spontaneous hemorrhage, meningitis, brain abscess, sinusitis, hydrocephalus</td>
<td>Non-contrast CT</td>
</tr>
<tr>
<td>Altered mental status or coma</td>
<td>Mass, traumatic or spontaneous hemorrhage, meningitis, brain abscess, hydrocephalus</td>
<td>Non-contrast CT</td>
</tr>
<tr>
<td>Fever</td>
<td>Meningitis (assessment of ICP), brain abscess</td>
<td>Non-contrast CT</td>
</tr>
<tr>
<td>Focal neurological deficit – motor, sensory, or language deficit</td>
<td>Mass, ischemic infarct, traumatic or spontaneous hemorrhage, meningitis, brain abscess, sinusitis, hydrocephalus</td>
<td>Non-contrast CT – possibly followed by MRI/MRA or CTA, depending on context</td>
</tr>
<tr>
<td>Focal neurological complaint – ataxia, cranial nerve abnormalities</td>
<td>Posterior fossa or brainstem abnormalities, vascular dissections</td>
<td>MRI/MRA of brain and neck; CT/CTA of brain and neck if MR not rapidly available</td>
</tr>
<tr>
<td>Seizure</td>
<td>Mass, traumatic or spontaneous hemorrhage, meningitis, brain abscess, sinusitis, hydrocephalus</td>
<td>Non-contrast CT, possibly followed by MR</td>
</tr>
<tr>
<td>Syncope</td>
<td>Trauma</td>
<td>Little indication for imaging for cause of syncope, only for resulting trauma</td>
</tr>
<tr>
<td>Trauma</td>
<td>Hemorrhage, mass-effect, cerebral edema</td>
<td>Non-contrast CT</td>
</tr>
<tr>
<td>Traumatic loss of consciousness (LOC)</td>
<td>Hemorrhage, diffuse axonal injury, mass-effect, cerebral edema</td>
<td>Little indication when transient LOC is isolated complaint</td>
</tr>
<tr>
<td>Planned lumbar puncture</td>
<td>Increased intracranial pressure</td>
<td>Non-contrast head CT – limited indications</td>
</tr>
</tbody>
</table>
relative contraindications to TPA due to increased risk of hemorrhage. The more extensive the ischemic changes on CT, the higher the risk of bleeding — as demonstrated in the multinational ECASS II trial. When discussing the head CT findings with a radiologist prior to administration of TPA, it is important to ask specifically about the presence and extent of these changes, in addition to asking about hemorrhage.

Standard contrast-enhanced head CT is rarely used since it provides little additional information compared with non-contrast head CT. With the advent of multi-detector CT scanners and spiral CT

**Figure 22. Early Ischemic Changes**

Early ischemic changes may be visible within three hours of onset of ischemic stroke. They include sulcal effacement, loss of gray-white matter differentiation, and the “insular ribbon sign.” Sulci are simply CSF-containing spaces between gyri. Sulcal effacement occurs when the adjacent gyri swell, displacing CSF from the sulci. Loss of gray-white matter differentiation occurs as ion pumps fail, leading to equilibration of diffusion gradients and shift of fluid. The normal ability of CT to differentiate gray from white matter relies on differences in their density, due to differences in their fluid and lipid content. White matter contains more fat, is less dense, and therefore appears darker on CT. Gray matter contains less lipid, is denser, and therefore appears whiter on CT. Local edema in the region of a developing infarct renders the region darker on CT, due to the presence of increasing amounts of fluid. This masks the normal differentiation between white and gray matter. The “insular ribbon” sign is another manifestation of this loss of gray-white matter differentiation. The insula is a region of gray matter lining the lateral sulcus, in which ischemic strokes of the MCA distribution may demonstrate early abnormalities. In this patient, both sulcal effacement (A) and loss of gray-white matter differentiation (B) have occurred. The frank hypodensity of ischemic stroke is also becoming visible. The abnormalities on the patient’s left side are particularly evident when compared with similar normal regions on the patient’s right side (normal sulci [C] and normal gray-white matter differentiation [D]). © 2007 Joshua Broder.

**Figure 23. Early Ischemic Changes**

Normal gray-white matter differentiation is subtle. Gray matter has lower lipid content than myelinated white matter and therefore appears brighter on CT. This leads to the unexpected fact that, on CT, gray matter looks white and white matter looks gray. Normal gray matter areas include the cerebral cortex (A), lentiform nucleus (B), caudate (C), and thalamus (D). White matter tracks separate these structures (E). © 2007 Joshua Broder.

**Figure 24. CT Angiography**

The hyperdense MCA (middle cerebral artery) sign is a CT finding of thrombosis of the MCA. It can be seen in the immediate hyperacute stages of thrombotic/ischemic stroke and may guide therapy (such as intra-arterial TPA administration). On CT, the hyperdense MCA appears as a white line or point representing the thrombosed vessel. Care must be taken not to confuse this with the white appearance of fresh extravascular blood in hemorrhagic stroke. In this patient, who presented within 30 minutes of onset of right hemiplegia, the normal MCA is not visible (A) while the left MCA is thrombosed and demonstrates the hyperdense MCA sign (B). © 2007 Joshua Broder.
technology, however, CT angiography (CTA) can be performed to obtain images of the extra- and intracranial vasculature from the aortic arch to the cranial vertex (Figure 25). Images are acquired by administering a rapid bolus of IV contrast immediately after standard non-contrast head CT. The raw images can be acquired in as little as 60 seconds, and three-dimensional computer reconstructions can be performed in fifteen minutes. The results can profoundly alter the course of management since large artery occlusions correlate with NIH Stroke Scale scores and may indicate a need for endovascular intervention. Generally, agreement between CTA and catheter angiography — still the gold standard for diagnosis of vessel stenosis — approaches 95%. For severe carotid artery stenosis, sensitivity for CTA approaches 100%, while the sensitivity for diminished flow in the Circle of Willis is 89%. Although traditional angiography may have subtle, additional benefits related to characterization of the plaque lesion (and the relatively non-invasive and rapid nature of CTA) render it an attractive option to the EP (assuming that the risks of exposure to contrast and additional radiation are acceptable to the patient).

CTA uses enhancement of the cerebral vasculature as a surrogate for estimating perfusion of the parenchyma. CT perfusion studies (CTPS) can be performed simultaneously using the same bolus of contrast and have a sensitivity and specificity for detecting ischemia of 95% and 100%, respectively. By measuring the rise and fall in concentration of injected contrast over time, CTPS are capable of even more direct estimates of cerebral perfusion than CTA, including measurements of cerebral blood volume (CBV) and cerebral blood flow (CBF) (Figure 26). By quantifying these variables, the goal is to allow clinicians to identify areas of the brain that, although ischemic, are potentially still viable – the so-called “ischemic penumbra.” This has implications for the clinician attempting to weigh the benefits of administering intravenous or intra-arterial thrombolitics versus the risk of intracranial hemorrhage. Routine use of CTPS could potentially allow a more precise prediction of outcome and could even herald a paradigm shift in one of the indications for thrombolytic administration: rather than excluding the use of thrombolitics in patients presenting after an arbitrary time interval (e.g., three hours), thrombolytic therapy could be initiated or excluded based on actual visualization or absence of a penumbral area likely to benefit from such intervention.

Routine use of CTPS in the hospital setting (much less in the ED) is not without challenges. First, the usual difficulties of imaging the posterior fossa with CT techniques persist. Second, only limited volumes of brain can be imaged at one time with each bolus of contrast so ischemia located outside the scanning level of interest can be missed, although this is partially alleviated by the use of multi-slice scanners or using repeated contrast boluses. Third, despite the theoretical appeal, only small studies in limited populations exist that confirm the ability of CTPS to detect infarct, predict infarct location and size, and predict final outcomes. Confirmation of these studies is needed before their use in routine clinical practice can be recommended.
Magnetic Resonance Imaging (MRI) For Acute Stroke

Standard MRI imaging for stroke includes scout images, T1- and T2-weighted images, and MRA. Increasingly available new generation scanners incorporate additional high sensitivity methods such as diffusion-weighted imaging (DWI), gradient echo pulse sequencing (GEPS), and perfusion-weighted imaging (PWI).

Obtaining DWI has been possible since 1985. In brief, the technique involves detecting and processing a signal in response to the movement of water molecules caused by two pulses of radio frequency. Ischemic changes can be detected in as little as 3-30 minutes after insult. In a small study of 22 patients who presented within six hours of symptom onset, DWI was found to be 100% sensitive and 100% specific. In a subsequent study, DWI was found to have a far superior sensitivity compared to CT (91% vs. 61%). When MRA is done simultaneous with DWI as part of a fast protocol to detect vascular stenosis, their combined usage within 24 hours of hospitalization substantially improved the early diagnostic accuracy of ischemic stroke subtypes.

The utility of DWI to detect ischemia may also be present when the clinician encounters a patient with remote onset defects. In patients presenting with a median delay of 17 days after symptom onset, clinicians added additional clinical information one-third of the time (including clarification of the vascular territory affected) by performing DWI in addition to conventional T2. Of this third, the information was designated as “highly likely” to affect management strategy in 38%.

MRI is superior to CT at detecting acute ischemic change and visualizing the posterior fossa. However, MRI has failed to supplant CT as the imaging modality of choice for stroke in the ED due to cost considerations, availability of the requisite personnel, time, and a long-standing belief that MRI is not reliable for detecting intracerebral hemorrhage. At least the last two factors are being surmounted. New scanners are increasingly faster — with acquisition times in the range of three to five minutes, compared to 15-20 minutes previously. With respect to hemorrhage, DWI has been proven to be sufficient to exclude intracerebral hemorrhage. Additionally, in studies comparing GEPS with CT, the former was at least as useful for detecting acute intracranial hemorrhage and actually better at elucidating chronic hemorrhagic changes, with sensitivity approaching 100% when interpreted by trained personnel.

The issues of cost and personnel are more complex, however. MRI hardware costs and costs associated with imaging are roughly double that of CT. Whether these costs will fall in the future or if they can be justified in the form of better outcomes, shorter hospital stays, or other measurable endpoints is unknown. Personnel issues are related not to sheer manpower, but also to qualitative training demands. MRI requires specially trained technicians spending more time per study as compared to CT. Additionally, expert-level radiologists with extensive training in MRI interpretation must be employed since interpretation is still not reproducible (though advocates of DWI point out that there is virtually no intra- or inter-observer variability with this modality).

Similar to the ability of CTPS to identify the ischemic penumbra, the combination of DWI and PWI makes it possible to make inferences about ischemia before injury has occurred. PWI is performed with standard MRI and MRA using gadolinium and requires a total imaging time of less than 15 minutes. PWI can be performed on patients with contraindications to gadolinium (a rare event, as gadolinium has been found to be safe in most instances, though recent fatal nephrogenic systemic fibrosis has been noted in patients with advanced renal disease) by magnetically labeling the blood as the blood enters the brain, a technique known as continuous arterial spin labeling (CASL).

The benefits of using DWI and PWI (so-called diffusion/perfusion mismatch) have started to accrue. Large perfusion defects and patients with occluded arteries are at heightened risk for enlarging lesions, leading some to suggest that these findings should prompt early revascularization, either pharmaco-logically with thrombolytic agents or with mechanical devices. Volume abnormalities on DWI and PWI during acute stroke correlate with acute NIH stroke scales and with chronic neurological scores, and lesion size may be predictive with respect to early neurological deterioration. Still another benefit of advanced techniques like DWI and PWI is, as is the case for CTPS, the potential to identify areas of ischemia which have not yet progressed to infarction, potentially permitting extension of the traditional three-hour window for thrombolytic administration and/or a paradigm shift to ruling in/out stroke based on perfusion/diffusion mismatch. However, PWI and DWI have yet to prove practical and reliable in defining the ischemic penumbra and infarct core, and head-to-head trials comparing diffusion/perfusion studies performed with MRI versus CTPS are limited.

Figure 27 shows images from a single patient in various modalities, including CT, CTA, MRI, and MRA.

Ultrasoundography For Ischemic Stroke

Ultrasound techniques include Doppler (used to assess flow rate and the presence of stenosis), brightness-mode (permitting anatomical and structural details of the tissue to be illuminated), and duplex (a combination of the two). Carotid duplex ultrasound has traditionally been deployed on an elective basis (i.e., non-emergent) to investigate whether the origin of an acute ischemic event in a given patient could be due to carotid artery stenosis. Studies show conflicting results, with some showing poorer performance of ultrasound (65% sensitivity, 95% specificity) compared with MRA (sensitivity 82-100%, specificity 95-100%).
and the gold standard of digital subtraction angiography (as the gold standard, by definition 100% sensitive and specific). Transcranial ultrasound can be used to visualize the vessels in and near the Circle of Willis. Here, it is possible to identify stenosis with reasonable success, though less well for the vertebral-basilar system. In the internal carotid artery (ICA), distribution of the respective sensitivity and specificity for this task is 85% and 95%, but falls to 75% and 85% in the vertebral-basilar. Additional benefits of transcranial ultrasound reportedly include the ability to identify collateral pathways, visualize harmful emboli in real time, and judge the success of therapy in the post-thrombolysis state. In addition, ultrasound is being used therapeutically in trials to augment the thrombolytic effect of medications. Whether an acute indication for ultrasound exists has received some attention, particularly with the aim of selecting patients for thrombolytics or endovascular treatment. The inexpensive and non-invasive nature of ultrasound is obviously attractive, but the integrity of the results is highly operator-dependent. In addition, it is impossible to differentiate reliably between complete versus high-grade stenosis, and contralateral stenosis can result in reassuring flow velocities (false negatives for stenosis) ipsilaterally.

Conventional Catheter Angiography For Stroke
Still considered the gold standard for diagnosing arterial stenosis, conventional catheter angiography has been substantially improved with the advent of digital subtraction techniques which enable visualization of even small, cortical branches of intracranial arteries. Endovascular techniques permit administration of intra-arterial thrombolytics and some users have the ability to perform clot retrieval and angioplasty with or without stenting. However, despite its utility when noninvasive techniques are equivocal or conflicting, it is still used only sparingly in the acute stroke setting due to its invasive nature and the approximate 1% risk of iatrogenic stroke associated with the procedure.

Stroke Neuroimaging Summary
The goals of neuroimaging in the ED patient presenting with signs and symptoms consistent with stroke include the exclusion of intraparenchymal hemorrhage, space-occupying lesions, and other stroke “mimics.” Ideally, the imaging technique would also

Figure 27. Multi-modality Assessment Of Stroke

This patient presented with dizziness, nausea, and vomiting. The brain CT (A) was interpreted as normal but symptoms were concerning for posterior circulation stroke. CTA (B) suggested right vertebral artery dissection (arrow). MRI (C) confirmed posterior inferior cerebellar artery (PICA) territory ischemic stroke (arrows), and MRA (D) showed vertebral dissection (arrow). © 2007 Joshua Broder.
highlight areas of ischemia, possible underlying etiologies of ischemia (i.e., vessel occlusion), and potentially identify those areas that, although ischemic, are still potentially salvageable. Currently, there is no single imaging modality that can accomplish all of these goals quickly and at a low cost, and there is no combination of studies that is widely available in all centers.

When confronted with a patient for whom stroke is the suspected diagnosis, the patient must be imaged as quickly as possible with the most readily available neuroimaging modality to rule out hemorrhage and other stroke “mimics.” Typically, this is with non-contrast CT. In the absence of contraindication to the use of contrast agents, it seems prudent to perform simultaneous CTA to rule out large vessel occlusion. If available and if it will not delay other indicated therapy, CTPS may be useful for prognosis and to guide therapeutic decisions (i.e., the use of thrombolitics). In specialized centers with the required expertise and resources, MR stroke protocols including MRI, MRA, DWI, and PWI may be feasible from the ED without the need for prior CT imaging.

**Suspected Subarachnoid Hemorrhage (SAH)**

Traditional practice in the evaluation for suspected SAH has been LP following negative CT, a practice still advocated by major emergency medicine textbooks. The reported sensitivity of CT (third generation or higher) for SAH is in the range of 90% in the first 24 hours, declining after 24 or more hours. A recent study of fifth generation CT found no SAHs in patients undergoing LP after negative CT. However, this retrospective review examined only 177 ED patients undergoing both CT and LP. Records and follow-up were not reviewed for patients who underwent CT but not lumbar puncture, so it is possible that cases of SAH with negative head CT occurred but were not detected. In addition, the interval between headache onset and CT/LP was not recorded, so this study provides no information on any time dependency of CT sensitivity for SAH. Given an incidence of SAH of only 3.4% of ED acute severe non-traumatic headache patients compared with previously reported numbers in the range of 12%, the true sensitivity of fifth generation CT may be as low as 61%, . A prospective study of patients presenting with the worst headache of their life reported a sensitivity of 97.5%; again, the small number of patients (107) yielded a confidence interval as low as 91%. Sensitivity of CT is thought to decline with the passage of time due to clearance of blood, and it is reported to be as low as 50% at seven days. EPs are only moderately accurate at predicting SAH based on clinical history, so a conservative approach including LP after negative head CT is probably still warranted based on CT sensitivity. Even the authors of studies of CT sensitivity are reluctant to state that LP is not needed after negative CT. Future advances in CT may eliminate this need.

**CT Angiography For Aneurysmal SAH**

When non-contrast head CT is negative in a patient suspected of SAH, is additional neuroimaging warranted to assess for aneurysmal disease (i.e., is there a role for CT angiography)?

The precise role is, as yet, undefined. A small study found aneurysms in 5.1% (6/116) of patients with a negative CT and positive LP and in 2.5% (3/116) following a normal CT/LP. Given the incidence of berry aneurysms in the general population, believed to be approximately 1-5%,  it is possible that the aneurysms detected in these patients were incidental, not the acute cause of the patients’ symptoms. Wide use of CTA might result in detection of large numbers of asymptomatic aneurysms, resulting in unneeded procedures, including formal angiography and endovascular coiling of aneurysms, with associated morbidity and mortality. Perhaps the best role of CTA would be in patients in whom LP is not feasible — those with coagulopathy, for example. CTA might also be useful in patients with a particularly high pretest probability of disease but negative non-contrast CT and LP. 

**Imaging Of Vascular Dissections**

Vascular dissections of the carotid and vertebral arteries are a relatively rare cause of acute headache and neurological symptoms; they account for only about 2% of all ischemic strokes but as many as 20% of strokes in young adults. Non-contrast head CT is expected to be negative in the setting of these lesions, unless ischemic stroke has resulted. In addition, dissection of the vertebral arteries would be expected to result in ischemia in the region of the basilar artery (which forms from the confluence of the vertebral arteries), and the territories supplied by the basilar artery lie within the posterior fossa, an area poorly seen on non-contrast CT. Multiple imaging techniques are available for this diagnosis. CTA, MRA, and conventional angiography all have greater than 95% sensitivity and specificity. Imaging of the head and neck should be ordered when these diagnoses are suspected, to ensure that the lesion is within the imaged field (Figure 25 on page 13).

**Imaging In Acute Hydrocephalus And Shunt Failure**

Non-contrast head CT is the initial study of choice for diagnosis of acute obstructive hydrocephalus. As the ventricles enlarge due to obstruction of the normal outflow of CSF, other CSF spaces become progressively effaced due to the fact that the total volume of all skull contents is fixed (Figures 19 and 21 on page 9 and 10). Large ventricles with small or completely effaced sulci and cisterns are consistent with hydrocephalus. In contrast, all CSF spaces are enlarged in atrophy, while all spaces are effaced in cerebral edema. Occasionally a mixed picture can occur, with both obstructing hydrocephalus and
diffuse cerebral edema. A number of radiographic criteria for hydrocephalus have been described (Table 5).

How common is shunt obstruction among children presenting with suspected obstruction undergoing CT?
Among children presenting with suspected shunt malfunction, up to 25% may have malfunction requiring surgical intervention.

How sensitive and specific is the CT in a patient with an existing ventricular shunt suspected of shunt failure?
The sensitivity of non-contrast head CT is reported to be 83%, with a specificity of 76%. Traditionally, a shunt series (a series of plain x-rays without contrast following the course of the shunt from head to destination, usually the peritoneum) is also performed. Shunt series have low sensitivity (20%) but high specificity (98%). Studies do not suggest high utility of this test in patients with normal non-contrast head CT, but the shunt series may occasionally be positive in these patients (Figure 28). In one series, 3 of 233 patients undergoing imaging had normal head CTs but abnormal shunt series and documented shunt obstruction.93,94

Neuroimaging In Patients With Seizures
Neuroimaging of patients with new onset seizure who have returned to a normal neurological baseline is a Level B recommendation in the 2004 ACEP Clinical Policy on seizures (Table 6).95 Level B recommendations generally reflect evidence with moderate certainty based on class II studies (e.g., nonrandomized trials, retrospective or observational studies, case-control studies) directly addressing a clinical question or broad consensus among experts based on class III studies (e.g., case reports and case series).

What is the basis of the ACEP recommendation?
Studies on patients with new-onset seizure show a high rate of abnormal neuroimaging results, as high as 41%, often unsuspected on the basis of history or examination.96-98 It is not clear that there is a causal relationship between some of the CT abnormalities found in these studies and acute seizure or that any change in management resulted from CT imaging. A systematic review found that among all adult ED patients with new onset seizure, 17.7% had an abnormal head CT – 26.6% of those undergoing head CT. Among patients with AIDS and new-onset seizure, the risk appears higher still (30%), with frequent CT diagnoses including cerebral toxoplasmosis, progressive multifocal leukoencephalopathy, and CNS lymphoma.99 Risk factors for life-threatening lesions include new focal deficits, persistent altered mental status, fever, trauma, persistent headache, cancer history, anticoagulation, AIDS or immunocompromise, or age greater than 40. Whether seizure is new onset or recurrent, emergent CT scanning is recommended for patients with any of these findings.100 Non-contrast CT is the initial neuroimaging method as the majority of life-threatening lesions (hemorrhage, edema, mass effect, hydrocephalus) would be expected to be found with this modality. Enhanced

Table 5. Radiographic Findings Of Acute Hydrocephalus

<table>
<thead>
<tr>
<th>Criteria</th>
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<tbody>
<tr>
<td>Dilated lateral ventricles</td>
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<tr>
<td>Effaced sulci</td>
</tr>
<tr>
<td>Both temporal horns &gt; 2 mm</td>
</tr>
<tr>
<td>Sylvian and interhemispheric fissures effaced</td>
</tr>
<tr>
<td>Ratio largest width of frontal horns: internal diameter from inner table to inner table &gt; 0.5</td>
</tr>
<tr>
<td>Ratio of largest width of frontal horns to maximum biparietal diameter &gt; 30%</td>
</tr>
<tr>
<td>Periventricular low density due to transependymal absorption</td>
</tr>
<tr>
<td>Ballooning of frontal horns of lateral ventricles and third ventricle, also known as “Mickey Mouse” ventricles — aqueductal obstruction</td>
</tr>
</tbody>
</table>

Figure 28. Shunt Failure

A VP shunt series is a series of plain x-ray images documenting the course of a shunt from brain to abdomen. Rarely, a shunt series may reveal an abnormality not revealed by brain CT. Much more frequently, the shunt series will be abnormal only if the head CT shows hydrocephalus.

In this patient, a discontinuity is faintly visible between the shunt catheter in the chest and abdomen (double arrow). © 2007 Joshua Broder.
CT or MRI may be indicated if unenhanced CT is normal and suspicion remains of a structural lesion.

**Febrile Seizures And Typical Recurrent Seizures**

Neither emergent nor urgent neuroimaging is recommended for patients with typical simple febrile seizure (Table 7) or recurrent seizures with typical features compared with the patient’s prior seizure history.100

**Do complex febrile seizures require emergent neuroimaging?**

A recent study found that although 16% of children presenting with new onset complex febrile seizure had abnormal CT or MR findings, none required emergent intervention (0%, 95% CI 0-4%).101

**Do partial seizures suggest a focal structural brain abnormality and thus mandate imaging?**

A study from South Africa in a region with a high incidence of tuberculosis and neurocysticercosis calls this tenet into question. This prospective cohort study of 118 children with new onset partial seizure found abnormal CT scans in only eight (7%) patients, all of whom were suspected prospectively of having the CT diagnosis. The investigators concluded that routine scanning would require 11 scans and 5 courses of antihelminthic therapy to prevent one case of childhood seizure disorder, versus no scans and 11 courses of drug therapy if all seizure patients were empirically treated.102 Of course, this study is from a population quite different from the U.S. population, and its results must be viewed in this context.

**Table 6. Indications For Neuroimaging In Adult Patients With New Onset Seizure**

- Recommended for all patients, even with return to baseline neurological status
- New focal deficits
- Persistent altered mental status
- Fever
- Trauma
- Persistent headache
- Cancer history
- Anticoagulation
- AIDS or immunocompromise
- Age older than 40 years

**Table 7. Simple Febrile Seizure (Neuroimaging Not Generally Indicated)**

- Three months to five years of age
- Generalized
- Duration < 15 min
- Does not recur within 24 hours

Complex febrile seizure (neuroimaging may be indicated, though recent studies suggest low risk of emergent intervention)

- Less than three months or greater than five years of age
- Focal, with or without secondary generalization
- Duration > 15 min
- Recur within 24 hours

**Neuroimaging In Syncope**

Head CT is commonly obtained as part of the evaluation of a patient with syncope, despite little evidence supporting its use. Syncope is a brief, non-traumatic loss of consciousness with loss of postural tone. Most syncope is due to global cerebral hypoperfusion, but the brain is generally the “victim” of syncope, not the cause. Syncope is rarely due to stroke, as loss of consciousness requires loss of blood flow to both cerebral hemispheres or to the medullary reticular activating system in the brainstem. Studies of the diagnostic yield of head CT performed for syncope show little pathology clearly related to the syncope episode.103 In one retrospective study, 34% of patients presenting to a community ED underwent head CT, with only one patient (0.7%) having the etiology identified by imaging (posterior circulation infarct).104 A second retrospective study found that 283/649 (44%) patients admitted with syncope at two community teaching hospitals from 1994 to 1998 underwent head CT, with five (2%) revealing an apparent causal diagnosis; 10 patients underwent MRI without a diagnosis of a cause of syncope. Utilization of head CT fell from 61% of syncope patients to 33% from 1994 to 1998, but diagnostic yield remained extremely low, under 1% for both groups.105 A prospective observational study found a 39% rate of head CT in ED syncope patients at Harvard’s Beth Israel Deaconess Medical Center, with only 5% having head CT abnormalities. That research group proposed that a decision rule for head CT in syncope might reduce utilization by 25-50%, although such a rule has not been prospectively validated (Table 8).106 Head CT may be warranted when the history and examination do not fully exclude other diagnoses such as seizure or stroke, or when trauma results from a syncope episode.

**Neuroimaging Of Traumatic Brain Injury**

For evaluation of traumatic brain injury (TBI), non-contrast CT remains the primary imaging modality. Brain injuries can include traumatic subarachnoid hemorrhage, subdural hematoma, epidural hematoma, intraparenchymal hemorrhage, diffuse axonal injury, and traumatic cerebral edema. Concurrent injuries may include bony injuries such as skull fracture. More rarely, head and neck trauma may result in vascular dissection of the intracranial or extracranial arteries (carotid or vertebral), with

**Table 8. Proposed Decision Rule For CT Head In Syncope, Not Yet Validated**

Head CT indicated only for patients with:

- Signs or symptoms of neurologic disease, including headache
- Trauma above the clavicles
- Coumadin use
- Age > 60 years
potential catastrophic neurological outcomes such as ischemic stroke.

**Epidemiology Of Traumatic Brain Injury**
The incidence of an acute intracranial injury seen on CT following a “mild” TBI (GCS score 13-15) is approximately 6-9%, but not all detected injuries result in a clinically meaningful change in management.\(^{108,109}\) Eight percent of patients in the derivation phase of the Canadian CT Head Rule had potentially important CT head findings, yet only 1% underwent a neurosurgical intervention.\(^{109}\) The NEXUS-II study enrolled 13,728 patients at 21 medical centers in the United States, including all ED patients undergoing head CT after blunt head trauma, regardless of GCS or neurological examination. There was clinically significant traumatic blunt head injury (prospectively defined, Table 9) in 6.7-8.7%.\(^{110,111}\) For purposes of the NEXUS-II study, a clinically significant traumatic brain injury was defined based on prior research as an injury that may require neurosurgical intervention (such as craniotomy, invasive ICP monitoring, or mechanical ventilation) or an injury with potential for rapid deterioration or long-term neurological dysfunction.\(^{112}\) Based on the NEXUS-II study, the average emergency physician evaluating patients with a range of GCS and neurological examination findings might expect to find a potentially important head CT abnormality in between 1 in 20 and 1 in 10 patients in whom head CT was ordered after blunt trauma.\(^{110,111}\) Stiehl and collaborators in Canada showed a 6% incidence of head injuries in ED patients undergoing CT following blunt head injury, although they also demonstrated great heterogeneity in the ordering practices of ED physicians, with 6.5-80% of patients with head trauma undergoing CT depending on the treating physician.\(^{113}\) A variety of decision rules have been investigated to target neuroimaging to patients with a high risk of intracranial injury.

**Skull Films For Blunt Head Trauma**
The ACEP clinical policy on altered mental status and mild blunt head trauma states that “plain films of the skull have essentially no utility in [the emergent evaluation of patients with altered mental status].”\(^{114}\) Surprisingly, they are still widely used in international emergency practice. In the United Kingdom, skull radiographs are obtained in approximately 20% of blunt head injury patients, a decrease from nearly 50% in the past.\(^{115}\) Some investigators have argued that this diagnostic test may play a limited role when CT is not available.\(^{116,117}\)

**Clinical Decision Rules For Blunt Head Trauma**
Clinical decision rules have been derived by several groups in the United States and Canada, with moderate success. These rules differ in their definitions of clinically significant injuries, the neurological inclusion criteria (GCS, loss of consciousness, and neurological examination), and the time from injury to imaging. Table 10 compares the three rules, while Tables 11-15 list the specific inclusion and exclusion criteria and specified outcomes of interest. In general, the New Orleans Criteria seeks to identify any acute intracranial injury, while NEXUS-II and the Canadian CT Head Rule seek to identify injuries most likely to require neurosurgical intervention or to result in serious neurological deficits. It is a matter of debate as to which definition is most appropriate. For example, is it important to know of the existence of a traumatic brain injury that does not require neurosurgical intervention in order to follow cognitive function long-term? Moreover, some clinical interventions may not have truly been “needed,” but rather may have been driven by the judgment of individual physicians once they became aware of imaging findings.

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**Table 9. NEXUS II: Intracranial Injuries Considered Significant**

- Mass effect or sulcal effacement
- Signs of herniation
- Basal cistern compression or midline shift
- Substantial epidural or subdural hematomas (greater than 1.0 cm in width or causing mass effect)
- Substantial cerebral contusion (more than 1.0 cm in diameter or more than one site)
- Extensive subarachnoid hemorrhage
- Hemorrhage in the posterior fossa
- Intraventricular hemorrhage
- Bilateral hemorrhage of any type
- Depressed or diastatic skull fracture
- Pneumocephalus
- Diffuse cerebral edema
- Diffuse axonal injury

---

**Table 10. A Comparison Of Three Clinical Decision Rules For Blunt Head Injury**

<table>
<thead>
<tr>
<th></th>
<th>GCS/Neurological Examination</th>
<th>Time To Imaging</th>
<th>Outcome Of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXUS-II</td>
<td>Any GCS/any examination/with or without LOC†</td>
<td>Within 24 hours of injury</td>
<td>Clinically important traumatic injuries</td>
</tr>
<tr>
<td>New Orleans Criteria</td>
<td>LOC, GCS 15, normal neurological examination €</td>
<td>Within 24 hours of injury</td>
<td>Any intracranial injury</td>
</tr>
<tr>
<td>Canadian CT Head Rule</td>
<td>GCS 13-15 with LOC</td>
<td>For patients with GCS &lt; 15, two hour post-injury observation required to observe for improvement in GCS</td>
<td>Injuries requiring neurosurgical intervention</td>
</tr>
</tbody>
</table>

†LOC = loss of consciousness
€ Normal neuro examination = normal strength, sensation, and cranial nerves
New Orleans Criteria

The New Orleans Criteria (Table 13) investigators sought a rule with 100% sensitivity, citing prior surveys of emergency physicians indicating that a clinical decision rule with anything less than perfect sensitivity would be unacceptable. Their rule achieved the sensitivity goal (100%, 95% CI 95-100%) but with a low specificity (25%, 95% CI 22-28%).

This rule has been challenged for its lack of specificity, which might lead to increased utilization of CT for patients with no other indication for neuroimaging beyond headache, vomiting, or minor head and neck trauma (such as facial abrasions).

Canadian CT Head Rule (CCHR)

The Canadian CT Head Rule (Table 14) found 100% sensitivity and 52% specificity for patients with blunt trauma and a GCS 15. This rule has been criticized for relative complexity, as well as for endpoints which might be considered unacceptable in some medical practice settings, including the United States, where fears of litigation might make it undesirable to miss any CT abnormality. Nonetheless, in multiple validation studies and subanalyses, the rule appears to perform well in identifying patients who present with normal mental status but require emergent neurosurgical intervention, including in U.S. populations.

NEXUS II Rule

The NEXUS II investigators identified a decision rule with high sensitivity (98.3%, 95% CI 97.2-99.0%) but low specificity (13.7%, 95% CI 13.1-14.3%) for significant intracranial injury. This rule (Table 15) has limited clinical utility because it would mandate brain CT in the majority of patients following blunt trauma and thus might actually increase CT utilization when compared with current physician practice. Its clinical outcome benefit is uncertain — no study to date has demonstrated whether application of the NEXUS II rule would identify important injuries that would otherwise have been missed. Another difficulty with

Table 11. “Positive” CT Findings, New Orleans Criteria

<table>
<thead>
<tr>
<th>Any acute traumatic intracranial lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Subdural hematoma</td>
</tr>
<tr>
<td>• Epidural hematoma</td>
</tr>
<tr>
<td>• Parenchymal hematoma</td>
</tr>
<tr>
<td>• Subarachnoid hemorrhage</td>
</tr>
<tr>
<td>• Cerebral contusion</td>
</tr>
<tr>
<td>• Depressed skull fracture</td>
</tr>
</tbody>
</table>

Table 12. Outcomes, Canadian Head CT Rule

Primary Outcomes: Neurosurgical Intervention
- Death within seven days secondary to head injury
- Any of the following procedures within seven days:
  - Craniotomy
  - Elevation of skull fracture
  - Intracranial pressure monitoring
  - Intubation for head injury (demonstrated on CT)

Secondary Outcomes: Clinically Important Brain Injury On CT
- Any acute brain finding revealed on CT that would normally require admission to hospital and neurosurgical follow-up
- Not clinically important:
  - Patient was neurologically intact and had one of the following
    - Solitary contusion of less than 5 mm in diameter
    - Localized subarachnoid blood less than 1 mm thick
    - Smear subdural hematoma less than 4 mm thick
    - Closed depressed skull fracture not through the inner table

Table 13. New Orleans Criteria

Head CT is required for blunt trauma patients with loss of consciousness: GCS 15, a normal neurological examination*, and any of the following:
- Headache
- Vomiting
- Age over 60 years
- Drug or alcohol intoxication
- Deficits in short-term memory
- Physical evidence of trauma above the clavicles
- Seizure

*Normal cranial nerves and normal strength and sensation in the arms and legs, as determined by a physician on the patient’s arrival at the emergency department

Table 14. Canadian CT Head Rule*

For patients with GCS 13 to 15 after witnessed traumatic loss of consciousness, CT is only required for patients with any one of the following findings:

High Risk For Neurosurgical Intervention
1. Glasgow Coma Scale score lower than 15 at two hours after injury
2. Suspected open or depressed skull fracture
3. Any sign of basal skull fracture†
4. Two or more episodes of vomiting
5. 65 years or older

Medium Risk For Brain Injury Detection By Computed Tomographic Imaging
1. Amnesia before impact of 30 or more minutes
2. Dangerous mechanism‡

*Exclusion criteria: no history of trauma, GCS < 13, age < 16 years, warfarin use or coagulopathy, obvious open skull fracture.†Signs of basal skull fracture include hemotympanum, raccoon eyes, cerebrospinal fluid, otorrhea or rhinorrhea, and Battle’s sign.‡Dangerous mechanism is a pedestrian struck by a motor vehicle, an occupant ejected from a motor vehicle, or a fall from an elevation of ≥ three feet or five stairs.

Table 15. Variables Associated With Significant Head Injury in NEXUS II

1. Evidence of significant skull fracture
2. Scalp hematoma
3. Neurologic deficit
4. Altered level of alertness
5. Abnormal behavior
6. Coagulopathy (includes aspirin use)
7. Persistent vomiting
8. Age greater than 65 years
this proposed rule is the potential variability in application of terms such as “scalp hematoma” or “abnormal behavior” by different observers. In addition, coagulopathy – found to be a high risk factor – included aspirin use, potentially increasing the need for head imaging among patients who do not otherwise appear at risk of brain injury. One important finding of NEXUS II is a lack of association between several clinical variables which have traditionally been considered as potential markers of significant clinical injury, including loss of consciousness, seizure, severe headache, and vomiting.

External Validity Of Decision Rules For Blunt Head Trauma
The Canadian CT Head Rule and the New Orleans Criteria have been prospectively tested in other populations with less success; in Australia, the rules fail to exclude injury while reducing utilization.125 In Britain, the CCHR would increase CT utilization and associated costs.126,127 In German populations, the rules appear to reduce utilization.128 A prospective Dutch study validated the high sensitivity of both rules but found that the New Orleans Criteria would decrease utilization by only 3% and the CCHR by only 37.3%.119 These reductions in utilization are smaller than the estimates from the original New Orleans Criteria publication (20%)108 and CCHR (50-70%).109 These findings reflect the existing practices in other countries; when baseline CT utilization for blunt head injury is low, the NEXUS, Canadian, and New Orleans rules may result in smaller decreases in utilization or could actually increase utilization.

Can We “Mix And Match” The Rules?
It may be tempting to adopt a combination of features of the above decision rules in order to manufacture a superior decision rule. Unfortunately, there is little evidence to support this practice. The NEXUS investigators and the New Orleans investigators tested a variety of other combinations of clinical criteria besides the final suggested rule.108,110 Eliminating criteria not surprisingly improved specificity but impaired sensitivity, and adding additional criteria improved sensitivity but impaired specificity. A rule with large numbers of criteria fails the original purpose of developing a clinical decision rule; it detects all injuries by mandating CT for all blunt head trauma patients.

Some Commonalities Among The Rules
An important take-home point for all of the decision rules described here is the notable absence of loss of consciousness alone as an indication for head CT. In each study, loss of consciousness was a required inclusion criterion, but in none of the studies did isolated loss of consciousness identify patients at risk of significant injury. Prior studies had shown little association between loss of consciousness and significant traumatic brain injury.129 In fact, neither NEXUS II nor the Canadian CT Head Rule found post-traumatic headache to be an indication for head CT. The New Orleans Criteria did identify headache as a

Key Points For Imaging Of Acute Neurological Conditions

1. For stroke, CT is sensitive for ruling out hemorrhage. MRI may be even better for chronic hemorrhage.

2. For cervical artery dissections, CTA and MRA have similar high sensitivity and specificity.

3. Following an episode of syncope, head CT is not routinely indicated unless head trauma is suspected. The diagnostic yield of CT for syncope appears to be less than 1%.

4. A negative non-contrast head CT is not widely accepted to rule out subarachnoid hemorrhage without lumbar puncture. Although CT appears to be very sensitive, it is thought to become less sensitive with elapsed time since symptom onset, and the decline in sensitivity is not fully understood for new generation scanners.

5. Extensive early ischemic changes, especially those in an area greater than one-third of the middle cerebral artery territory, are a contraindication to TPA administration. The radiologist should be specifically queried about these, not just for the presence or absence of hemorrhage.

6. For patients presenting with apparent TIA, the risk of progression to stroke is high. Some have advocated admission, while others have recommended rapid outpatient evaluation. The modifiable structural risk factors for stroke include carotid stenosis and cardiac defects. One imaging strategy from the emergency department is imaging of the carotids (by CTA, ultrasound, or MRA), and echocardiography to evaluate cardiac causes of stroke.

7. Neuroimaging is not indicated for simple febrile seizures or a single occurrence of the typical seizure of a patient with prior seizure disorder. Imaging findings relevant to management are unlikely in this setting.

8. Following blunt traumatic head injury, loss of consciousness alone is not an indication for head CT. Clinical decision rules exist for selecting patients to forgo CT following closed head injury.
“severe headache,” so emergency physicians must scrupulously apply the rules if they expect the rules to function as described in the original studies.130-134

### Decision Rules For Elderly

The elderly have a high rate of injury with few clinical predictors.135 NEXUS-II found that the rate of clinically significant injury in patients 65 years of age or older was 12.6%, compared with 7.8% in patients under 65 years of age.131 The CCHR classifies patients greater than 65 years of age as high risk and therefore in need of imaging in the case of traumatic loss of consciousness.

### Is A Repeated Head CT Required For Patients With Abnormal Head CT After Blunt Trauma?

A wide range of reported progression in CT findings has been published, with few clear-cut indications for safely omitting repeat scan. A systematic review from 2006 found that the range of reported progression of injury on repeat head CT varied from 8 to 67%, with

### Risk Management Pitfalls For Neurological Conditions

1. **Ruling out subarachnoid hemorrhage based on normal non-contrast head CT without lumbar puncture.** Although some recent studies suggest that modern CT scanners may be able to detect subarachnoid hemorrhage with extremely high sensitivity, the sensitivity of CT is thought to decline with the passage of time, and lumbar puncture is still recommended.

2. **Failure to obtain head CT after blunt head injury with loss of consciousness in an anticoagulated patient.** The existing head CT clinical decision rules for blunt trauma all exclude anticoagulated patients or classify them as high-risk for clinically significant injury.

3. **Obtaining head CT in all patients with traumatic loss of consciousness.** Traumatic loss of consciousness alone does not appear to be associated with clinically significant head injury.

4. **Discharging a patient with TIA symptoms after a normal head CT and without further diagnostic testing.** Head CT is often normal in TIA, and a substantial minority of TIA patients will progress to stroke in the 48 hours after symptoms. Additional imaging of the carotid arteries and heart are advised.

5. **Administering TPA to patients with early ischemic changes in greater than one-third of the middle cerebral artery territory.** The greater the extent of early ischemic changes, the greater the risk of hemorrhage. Early ischemic changes of this magnitude are associated with high risk of intracerebral hemorrhage, and TPA is contraindicated.

6. **Advising a pregnant patient not to undergo head CT for a suspected serious neurological condition.** The radiation exposure to the fetus during non-contrast head CT is not considered to pose significant fetal threat. The mother’s health is paramount.

7. **Ruling out intracranial injury based on normal skull films.** Although skull films are still widely used internationally, they are insensitive for intracranial injury and are not advised by the American College of Emergency Physicians (ACEP).

8. **Relying on a normal head CT to determine safety for lumbar puncture.** Head CT may not accurately estimate intracranial pressure. Lumbar puncture may be contraindicated in patients with examination evidence of high intracranial pressure, such as obtundation, even if CT appears normal.

9. **Mistaking complex febrile seizure for simple febrile seizure.** Simple febrile seizures are generalized, last less than 15 minutes, and do not recur within 24 hours. Febrile seizures which are focal, last greater than 15 minutes, or recur within 24 hours are complex and may require neuroimaging – although a recent study suggests a very low rate of neuroimaging findings requiring emergent intervention.

10. **Relying on a point estimate of sensitivity when 95% confidence intervals are wide.** The point estimate is frequently the value cited in an abstract or manuscript conclusions, but the 95% confidence intervals provide best and worst case scenarios. A diagnostic test with a high point estimate of sensitivity but confidence intervals from 60-100%, such as the ABCD score for TIA progression to stroke, may have sensitivity as low as 60%.
resulting neurosurgical intervention in 0-54% of patients. The review’s authors cited a variety of explanations for this dramatic variability in study outcomes, including selection bias, spectrum bias (studies with more severely injured patients being more likely to show unfavorable outcomes), and poor definitions of injury progression. Risk factors such as coagulopathy, poor GCS, and high overall injury severity appear to be associated with worsening CT abnormalities, but methodologic flaws in the studies reviewed make more specific recommendations impossible. Since the publication of that review, a prospective study of level I trauma center patients with an abnormal head CT addressed some of the issues raised by that review. The study stratified patients by GCS (mild: GCS 13-15; moderate: GCS 9-12; and severe: GCS < 9) and indication for repeat CT (routine versus indicated by neurological deterioration). Among patients undergoing CT for neurological deterioration, a medical or surgical intervention followed CT in 38%. In contrast, among patients undergoing routine repeat CT, 1% underwent an intervention – in both cases in patients with GCS < 9. The authors concluded that repeat CT is warranted in any patient with neurological deterioration, and routine repeat CT may be warranted among patients with GCS < 9. No interventions occurred in patients with GCS 9 or higher undergoing routine head CT, but this study is too small to conclude with certainty that routine repeat CT is never necessary in this group. Other recent retrospective studies also suggest that routine repeat head CT is not likely to change clinical management in the absence of a deteriorating neurological examination, but a larger prospective study will be needed to more stringently define those patients with abnormal CT after blunt trauma in whom repeat CT can be deferred.

What Is The Best Imaging Modality For Diffuse Axonal Injury?
As the name implies, diffuse axonal injury (DAI) is damage to white matter tracts throughout the brain, thought to occur as the result of shearing from rapid deceleration, often with a rotational component. There is some debate as to the clinical scenarios in which this injury occurs, with some arguing that DAI is a feature only of severe injury while others suggest it as a mechanism underlying post-concussive syndromes in patients with normal CT. Studies in patients with mild head injury are problematic, as it is unclear whether MR abnormalities are truly evidence of CT-negative DAI or rather false-positive MR findings. CT is generally thought to be poor in detecting these changes, though a gold standard for comparison is often lacking or limited to comparison with MRI. A prospective study in 1988 compared CT and MR for identification of blunt traumatic head injuries, but advances in both modalities have rendered its results invalid. A 1994 study found the modalities to be complementary for head trauma, with MR substantially more sensitive for DAI. Subsequent studies have often compared new MR image sequences such as FLAIR (fluid attenuated inversion recovery) and diffusion-weighted imaging to other MR sequences, using as a gold standard a clinical definition of DAI (loss of consciousness persisting greater than six hours after injury, no hemorrhage on CT) plus imaging criteria (presence of white matter injury on MRI). This type of study, in which the gold standard or reference used to determine the accuracy of the experimental test incorporates that test, suffers from incorporation bias.

Controversies And Cutting Edge

Is Emergency Physician Reading Of Head CTs Becoming A "Best Practice" In Emergency Care?
Head CT is rapid to obtain but delays in interpretation could result in adverse patient outcomes if clinical treatment decisions cannot be made in a timely fashion. Surveys of emergency medicine residency programs suggest that, in many cases, radiology interpretation is not rapidly available for clinical decisions and that emergency physicians often perform the initial interpretation of radiographic studies. A study simulating a teleradiology support system estimated the time to interpretation of a non-contrast head CT at 39 minutes, potentially wasting precious time in patients with intracranial hemorrhage or ischemic stroke. The ability of the on-scene emergency physician to interpret the CT could be extremely valuable.

Can Emergency Physicians Accurately Interpret Head CTs?
Multiple studies have examined the ability of emergency medicine residents and attending physicians to interpret head CTs. A 1995 study showed that, in an EM residency program, although up to 24% of potentially significant CT abnormalities were not identified by the EM residents, only 0.6% of patients appear to have been mismanaged as a result. Studies have shown that substantial and sustained improvements in interpretation ability can occur with brief training. Perron et al showed an improvement from 60% to 78% accuracy after a two hour training session based on a mnemonic, sustained at three months. In the setting of stroke, emergency medicine attendings perform relatively poorly in the recognition of both hemorrhage and early ischemic changes which may contraindicate TPA administration, with accuracy of approximately 60%, but neurologists and general radiologists achieve only about 80% accuracy compared with the gold standard interpretation by neuroradiologists. Undoubtedly, improvements in training are needed, but the pragmatic limitations on the availability of subspecialist radiologists, even with teleradiology, mean that emergency physicians must become
proficient first-line readers of emergent CT.

Case Conclusions

...the 75-year-old man with hemiplegia had greater than one-third of the MCA territory showing ischemic changes. You held TPA and admitted the patient to the ICU where he experienced an intracranial hemorrhage in the region of his infarct. The neurologist commended you for recognizing the patient’s risk of hemorrhage and the family was grateful that you withheld thrombolysis.

...the 55-year-old male with syncope was reassured when you told him that he did not require a CT, given the extremely low likelihood of abnormal findings. He was admitted for telemetry and was found to have non-sustained ventricular tachycardia as the cause of his event.

...the 19-year-old female with a thunderclap headache underwent lumbar puncture at your urging, since you recalled that the sensitivity of CT for SAH declines with time. Her LP showed xanthochromia, and angiography confirmed an aneurysm which was treated with endovascular coil placement.

...the 20-year-old male with new onset seizure had a completely normal, well documented, neurological exam, as well as normal serum glucose and electrolytes. His history did not reveal any potential etiologies for the event. A decision to initiate anti-epileptic drug therapy will likely depend on the findings of a MRI and an EEG. Although he is at a relatively low risk for seizure recurrence, ACEP policy recommends neuroimaging for first-time seizure patients and you decide to perform a CT since the scanner is now available.

...the 52-year-old male with transient loss of consciousness after a collision was evaluated using the Canadian CT Head Rule. He had no high or moderate risk factors so imaging was forgone. You saw the patient in the supermarket two weeks later and he thanked you for the excellent care he received.

References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study, will be included in bold type following the reference, where available.


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33. Dzialowski, L, et al. Extent of early ischemic changes on computed tomography (CT) before thrombolysis: prognostic value of the Alberta Stroke Program Early CT Score in ECASS II. *Stroke*. 2006;37(4):973-978. (Retrospective analysis of 800 patients previously prospectively enrolled and randomized to tPA or placebo in ECASS II trial)


35. FDA product labelling for Genetech Alteplase.


56. Tatlisumak, T. Is CT or MRI the method of choice for imaging patients with acute stroke? Why should men divide if fate has united?[see comment]. *Stroke*. 2002;33(9):2144-2145. (Editorial)

57. FDA warning on gadolinium associated fatal nephrogenic systemic fibrosis. 2006. (FDA warning based on case series)


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CME Questions

1. A patient presents with symptoms and signs of ischemic stroke. Early ischemic changes in what portion of the middle cerebral artery distribution contraindicate TPA?
   - a. Early ischemic changes do not contraindicate TPA administration
   - b. > 33%
   - c. > 25%
   - d. > 10%
   - e. Any early ischemic change

2. A patient presents with sudden onset of headache three days prior. Non-contrast head CT is normal. Subarachnoid hemorrhage can be ruled out:
   - a. After a negative lumbar puncture
   - b. Based on the CT findings
   - c. After CT angiography
   - d. After conventional angiography
   - e. After MR angiography

3. A patient presents with a GCS 15 after blunt head trauma. According to the Canadian CT Head Rule, CT is indicated if:
   - a. Loss of consciousness occurred
   - b. A severe headache is present
   - c. A single posttraumatic seizure occurred
   - d. Persistent vomiting is present
   - e. The patient is greater than 50 years of age

4. A simple febrile seizure does not require neuroimaging. Features of simple febrile seizures include all of the following EXCEPT:
   - a. Age three months to five years
   - b. Generalized seizure
   - c. Duration < 15 minutes
   - d. No recurrence within 24 hours
   - e. Preceding history of seizure
5. A patient presents with syncope. When should head CT be ordered?
   a. When head trauma is suspected
   b. When other diagnoses such as stroke or seizure are suspected
   c. In every patient with syncope
   d. Answers a and b
   e. Head CT should not be ordered for evaluation of syncope

6. Non-contrast head CT may detect early ischemic changes in stroke within:
   a. 3 hours
   b. 6 hours
   c. 8 hours
   d. 12 hours
   e. 24 hours

7. In stroke, MRI with comparison of DWI and PWI sequences may allow identification of the ischemic penumbra with what potential clinical advantage?
   a. Extension of the window for thrombolytic therapy
   b. Triage to ICU or floor status
   c. Identification of patients with possible TIA
   d. Measurement of intracranial pressure
   e. Decreased hospital length of stay

8. The ACEP clinical policy for adult ED patients with new-onset seizure and return to baseline neurological status recommends neuroimaging for:
   a. Fever
   b. Immunocompromise
   c. Age greater than 50 years
   d. History of anticoagulation
   e. All patients

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Needs Assessment: The need for this educational activity was determined by a survey of medical staff, including the editorial board of this publication; review of morbidity and mortality data from the CDC, AHA, NCHS, and ACEP; and evaluation of prior activities for emergency physicians.

Target Audience: This enduring material is designed for emergency medicine physicians, physician assistants, nurse practitioners, and residents.

Goals & Objectives: Upon completion of this article, you should be able to: (1) demonstrate medical decision-making based on the strongest clinical evidence; (2) cost-effectively diagnose and treat the most critical ED presentations; and (3) describe the most common medicolegal pitfalls for each topic covered.

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In compliance with all ACCME Essentials, Standards, and Guidelines, all faculty for this CME activity were asked to complete a full disclosure statement. The information received is as follows: Dr. Broder, Dr. Preston, Dr. Chan, and Dr. Preston report no significant financial interest or other relationship with any manufacturer(s) of any commercial product(s) discussed in this educational presentation.

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