

**American College of Radiology
ACR Appropriateness Criteria®
Head Trauma**

Variant 1: **Acute head trauma, mild (GCS 13–15), imaging not indicated by clinical decision rule. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
Radiography skull	Usually Not Appropriate	⦿
Arteriography cervicocerebral	Usually Not Appropriate	⦿⦿⦿
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT head without and with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT head without IV contrast	Usually Not Appropriate	⦿⦿⦿
CTA head and neck with IV contrast	Usually Not Appropriate	⦿⦿⦿
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	⦿⦿⦿
FDG-PET/CT brain	Usually Not Appropriate	⦿⦿⦿

Variant 2: Acute head trauma, mild (GCS 13–15), imaging indicated by clinical decision rule. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CT head without IV contrast	Usually Appropriate	☼☼☼
Radiography skull	Usually Not Appropriate	☼
Arteriography cervicocerebral	Usually Not Appropriate	☼☼☼
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	☼☼☼
CT head without and with IV contrast	Usually Not Appropriate	☼☼☼
CTA head and neck with IV contrast	Usually Not Appropriate	☼☼☼
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	☼☼☼
FDG-PET/CT brain	Usually Not Appropriate	☼☼☼

Variant 3: Acute head trauma, moderate (GCS 9–12) or severe (GCS 3–8) or penetrating. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CT head without IV contrast	Usually Appropriate	☼☼☼
Radiography skull	Usually Not Appropriate	☼
Arteriography cervicocerebral	Usually Not Appropriate	☼☼☼
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	☼☼☼
CT head without and with IV contrast	Usually Not Appropriate	☼☼☼
CTA head and neck with IV contrast	Usually Not Appropriate	☼☼☼
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	☼☼☼
FDG-PET/CT brain	Usually Not Appropriate	☼☼☼

Variant 4: Acute head trauma with unchanged neurologic examination and unremarkable initial imaging. Short-term follow-up imaging.

Procedure	Appropriateness Category	Relative Radiation Level
MRI head without IV contrast	May Be Appropriate	○
CT head without IV contrast	May Be Appropriate	⦿⦿⦿
Radiography skull	Usually Not Appropriate	⦿
Arteriography cervicocerebral	Usually Not Appropriate	⦿⦿⦿
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT head without and with IV contrast	Usually Not Appropriate	⦿⦿⦿
CTA head and neck with IV contrast	Usually Not Appropriate	⦿⦿⦿
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	⦿⦿⦿
FDG-PET/CT brain	Usually Not Appropriate	⦿⦿⦿

Variant 5: Acute head trauma with unchanged neurologic examination and positive finding(s) on initial imaging (eg, subdural hematoma). Short-term follow-up imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CT head without IV contrast	Usually Appropriate	⦿⦿⦿
MRI head without IV contrast	May Be Appropriate	○
Radiography skull	Usually Not Appropriate	⦿
Arteriography cervicocerebral	Usually Not Appropriate	⦿⦿⦿
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT head without and with IV contrast	Usually Not Appropriate	⦿⦿⦿
CTA head and neck with IV contrast	Usually Not Appropriate	⦿⦿⦿
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	⦿⦿⦿
FDG-PET/CT brain	Usually Not Appropriate	⦿⦿⦿

Variant 6: Acute head trauma with new or progressive neurologic deficit(s). Short-term follow-up imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CT head without IV contrast	Usually Appropriate	☼☼☼
MRI head without IV contrast	May Be Appropriate	○
Radiography skull	Usually Not Appropriate	☼
Arteriography cervicocerebral	Usually Not Appropriate	☼☼☼
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	☼☼☼
CT head without and with IV contrast	Usually Not Appropriate	☼☼☼
CTA head and neck with IV contrast	Usually Not Appropriate	☼☼☼
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	☼☼☼
FDG-PET/CT brain	Usually Not Appropriate	☼☼☼

Variant 7: Subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s). Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
MRI head without IV contrast	Usually Appropriate	○
CT head without IV contrast	Usually Appropriate	☼☼☼
Radiography skull	Usually Not Appropriate	☼
Arteriography cervicocerebral	Usually Not Appropriate	☼☼☼
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRA head and neck with IV contrast	Usually Not Appropriate	○
MRA head and neck without and with IV contrast	Usually Not Appropriate	○
MRA head and neck without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	☼☼☼
CT head without and with IV contrast	Usually Not Appropriate	☼☼☼
CTA head and neck with IV contrast	Usually Not Appropriate	☼☼☼
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	☼☼☼
FDG-PET/CT brain	Usually Not Appropriate	☼☼☼

Variant 8:

Head trauma with suspected intracranial arterial injury due to clinical risk factors or positive findings on prior imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CTA head and neck with IV contrast	Usually Appropriate	⦿⦿⦿
Arteriography cervicocerebral	May Be Appropriate	⦿⦿⦿
MRA head and neck with IV contrast	May Be Appropriate	○
MRA head and neck without and with IV contrast	May Be Appropriate (Disagreement)	○
MRA head and neck without IV contrast	May Be Appropriate (Disagreement)	○
CT head without IV contrast	May Be Appropriate (Disagreement)	⦿⦿⦿
Radiography skull	Usually Not Appropriate	⦿
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT head without and with IV contrast	Usually Not Appropriate	⦿⦿⦿
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	⦿⦿⦿
FDG-PET/CT brain	Usually Not Appropriate	⦿⦿⦿

Variant 9:

Head trauma with suspected intracranial venous injury due to clinical risk factors or positive findings on prior imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CTV head with IV contrast	Usually Appropriate	☼☼☼
MRI head without IV contrast	May Be Appropriate	○
MRV head with IV contrast	May Be Appropriate (Disagreement)	○
MRV head without and with IV contrast	May Be Appropriate	○
MRV head without IV contrast	May Be Appropriate	○
CT head without IV contrast	May Be Appropriate	☼☼☼
Radiography skull	Usually Not Appropriate	☼
Arteriography cervicocerebral	Usually Not Appropriate	☼☼☼
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT head with IV contrast	Usually Not Appropriate	☼☼☼
CT head without and with IV contrast	Usually Not Appropriate	☼☼☼
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	☼☼☼
FDG-PET/CT brain	Usually Not Appropriate	☼☼☼

Variant 10:**Head trauma with suspected cerebrospinal fluid (CSF) leak. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
CT maxillofacial without IV contrast	Usually Appropriate	☢☢
CT head without IV contrast	Usually Appropriate	☢☢☢
CT temporal bone without IV contrast	Usually Appropriate	☢☢☢☢
MRI head without IV contrast	May Be Appropriate	○
CT head cisternography	May Be Appropriate	☢☢☢☢
DTPA cisternography	May Be Appropriate	☢☢☢☢
Radiography skull	Usually Not Appropriate	☢
MR spectroscopy head without IV contrast	Usually Not Appropriate	○
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	○
MRI head with IV contrast	Usually Not Appropriate	○
MRI head without and with IV contrast	Usually Not Appropriate	○
MRI head without IV contrast with DTI	Usually Not Appropriate	○
CT maxillofacial with IV contrast	Usually Not Appropriate	☢☢
CT head with IV contrast	Usually Not Appropriate	☢☢☢
CT head without and with IV contrast	Usually Not Appropriate	☢☢☢☢
CT maxillofacial without and with IV contrast	Usually Not Appropriate	☢☢☢☢
CT temporal bone with IV contrast	Usually Not Appropriate	☢☢☢☢
CT temporal bone without and with IV contrast	Usually Not Appropriate	☢☢☢☢
HMPAO SPECT or SPECT/CT brain	Usually Not Appropriate	☢☢☢☢
FDG-PET/CT brain	Usually Not Appropriate	☢☢☢☢

HEAD TRAUMA

Expert Panel on Neurological Imaging: Robert Y. Shih, MD^{a*}; Judah Burns, MD^b; Amna A. Ajam, MD, MBBS^c; Joshua S. Broder, MD^d; Santanu Chakraborty, MBBS, MSc^e; A. Tuba Kendi, MD^f; Mary E. Lacy, MD^g; Luke N. Ledbetter, MD^h; Ryan K. Lee, MD, MBAⁱ; David S. Liebeskind, MD^j; Jeffrey M. Pollock, MD^k; J. Adair Prall, MD^l; Thomas Ptak, MD, PhD, MPH^m; P. B. Raksin, MDⁿ; Matthew D. Shaines, MD^o; A. John Tsiouris, MD^p; Pallavi S. Utukuri, MD^q; Lily L. Wang, MBBS, MPH^r; Amanda S. Corey, MD.^s

Summary of Literature Review

Introduction/Background

Head trauma (ie, head injury) is a significant public health concern and is a leading cause of morbidity and mortality in children and young adults. According to the Centers for Disease Control and Prevention, head trauma resulted in over 2.5 million emergency department (ED) visits in the United States in 2014 (63% increase from 2006) with nearly 290,000 hospitalizations and 57,000 deaths [1]. Common mechanisms of injury include falls, motor vehicle accidents, and acts of violence. Athletic and military personnel are additionally susceptible to sport- and blast-related exposures. Many individuals seek medical attention after a disruption in the normal function of the brain (eg, concussions with transient loss of consciousness [LOC] or post-traumatic amnesia [PTA]); these cases would meet the definition of a traumatic brain injury (TBI).

Neuroimaging plays an important role in the management of head/brain injury, which can be separated into acute (0–7 days), subacute (<3 months), then chronic (>3 months) phases [2]. In the acute phase, closed head trauma due to impact and/or inertial forces has been historically classified as mild, moderate, or severe based on the Glasgow Coma Scale (GCS) score, whereas penetrating head trauma is less common and is considered severe. Variants 1 to 6 address initial and short-term follow-up imaging considerations in the acute phase. In the subacute to chronic phase (Variant 7), the clinical focus shifts from the detection of neurosurgical lesions and prevention of secondary injury toward the prognostication and rehabilitation of long-term neurocognitive sequelae. Variants 8 to 10 address suspected arterial or venous injury and cerebrospinal fluid (CSF) leak.

For discussion of head trauma in the pediatric population (eg, up to 18 years of age), please see the ACR Appropriateness Criteria[®] topic on “[Head Trauma-Child](#)” [3].

Initial Imaging Definition

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient’s care).

OR

- There are complementary procedures (ie, more than one procedure is ordered as a set or simultaneously where each procedure provides unique clinical information to effectively manage the patient’s care).

^aUniformed Services University, Bethesda, Maryland^bPanel Chair, Montefiore Medical Center, Bronx, New York. ^cOhio State University, Columbus, Ohio. ^dDuke University School of Medicine, Durham, North Carolina; American College of Emergency Physicians. ^eOttawa Hospital Research Institute and the Department of Radiology, The University of Ottawa, Ottawa, Ontario, Canada; Canadian Association of Radiologists. ^fMayo Clinic, Rochester, Minnesota. ^gUniversity of New Mexico, Albuquerque, New Mexico; American College of Physicians. ^hUniversity of California Los Angeles, Los Angeles, California. ⁱEinstein Healthcare Network, Philadelphia, Pennsylvania. ^jUniversity of California Los Angeles, Los Angeles, California; American Academy of Neurology. ^kOregon Health & Science University, Portland, Oregon. ^lLittleton Adventist Hospital, Littleton, Colorado; Neurosurgery expert. ^mR. Adams Cowley Shock Trauma Center, University of Maryland Medical Center, Baltimore, Maryland. ⁿJohn H. Stroger, Jr. Hospital of Cook County, Chicago, Illinois; Neurosurgery expert. ^oAlbert Einstein College of Medicine Montefiore Medical Center, Bronx, New York, Internal Medicine Physician. ^pWeill Cornell Medicine, New York, New York. ^qColumbia University Medical Center, New York, New York. ^rUniversity of Cincinnati Medical Center, Cincinnati, Ohio. ^sSpecialty Chair, Atlanta VA Health Care System and Emory University, Atlanta, Georgia.

The American College of Radiology seeks and encourages collaboration with other organizations on the development of the ACR Appropriateness Criteria through representation of such organizations on expert panels. Participation on the expert panel does not necessarily imply endorsement of the final document by individual contributors or their respective organization.

*The views expressed in this manuscript are those of the author and do not reflect the official policy of the Department of the Army/Navy/Air Force, Department of Defense, or United States Government.

Reprint requests to: publications@acr.org

Discussion of Procedures by Variant

Variant 1: Acute head trauma, mild (GCS 13–15), imaging not indicated by clinical decision rule. Initial imaging.

Since its development in the 1970s, head CT has revolutionized the management of acute head trauma and proven its value in the detection of neurosurgical lesions (eg, hemorrhage, herniation, and hydrocephalus) and prevention of secondary injury. Its application has expanded over time from only severe head trauma to encompass moderate, mild (ie, minor), and minimal (GCS 15 without LOC or PTA) head trauma. Over 75% of acute head trauma is classified as mild, of which over 75% have a normal GCS score of 15. At the same time, only 10% or less of mild acute head trauma will have positive finding(s) on head CT, and only 1% or less will have a positive finding that requires neurosurgical intervention [4,5]. For these reasons, clinical practice guidelines universally recommend selective CT scanning in this patient population, which is often based on clinical decision rules [6]. Their sensitivity and advantages in reducing CT utilization are discussed below; please see Variant 2 for discussion of ongoing efforts to improve their specificity. (Note: GCS 13 is sometimes classified as moderate rather than mild to better reflect their positive imaging yield and poorer clinical prognosis; this distinction is not expected to affect imaging considerations under Variants 1–3.)

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the initial imaging evaluation of acute head trauma.

CT Head

There is no relevant literature to support the use of CT in the initial imaging evaluation of mild acute head trauma when imaging is not indicated by a validated clinical decision rule. Mathematical models of quality-adjusted life years gained by 10 diagnostic management strategies in adults with mild head trauma found selective CT scanning with a high-sensitivity clinical decision rule to be effective when compared with “discharge all” or “CT all” strategies [7]. Another analysis calculated a minimum clinical decision rule threshold of 97% sensitivity for the identification of patients with mild head trauma who required neurosurgical intervention in order to outperform “CT all” from a health care system perspective [8]. From a medical provider perspective, a surveyed majority of ED physicians understandably insist that a clinical decision rule must have 100% sensitivity [9].

The most well-known clinical decision rules include the New Orleans Criteria and the Canadian CT Head Rule, originally published in 2000 and 2001, respectively [9,10]. Both have been validated in thousands of patients as essentially 100% sensitive for mild head trauma requiring neurosurgical intervention [4,11]. By design, the New Orleans Criteria is highly sensitive (97.7%–99.4%) for any traumatic finding on CT at the cost of specificity (3.0%–5.6%), whereas the Canadian CT Head Rule accepts lower sensitivity (83.4%–87.2%) for nonneurosurgical traumatic findings in exchange for higher specificity (37.2%–39.7%) and reduced imaging [4]. Neither clinical decision rule addressed coagulopathy or minimal head trauma; a smaller study applied the Canadian CT Head Rule in the latter population with 100% sensitivity and 29% specificity for the presence of intracranial hemorrhage (ICH) [12]. Most clinical practice guidelines recommend CT in all patients who have head trauma with coagulopathy, which is defined as any impaired coagulation or bleeding diathesis including medications (eg, warfarin), but there is some controversy as to whether this remains useful in the setting of only antiplatelet therapy or in the setting of minimal head trauma [13,14].

For clinicians or providers who are not currently committed to a clinical decision rule, one option is the 2008 Clinical Policy from the American College of Emergency Physicians (ACEP), which strikes a balance by applying the more sensitive New Orleans Criteria in patients who have mild head trauma with LOC or PTA, versus the more specific Canadian CT Head Rule criteria in patients who have minimal head trauma without LOC or PTA [15]:

- Level A recommendation: A noncontrast head CT is indicated in patients who have head trauma with LOC or PTA only if one or more of the following are present: headache, vomiting, >60 years of age, drug or alcohol intoxication, deficits in short-term memory, physical evidence of trauma above the clavicle, post-traumatic seizure, GCS score <15, focal neurologic deficit, or coagulopathy.
- Level B recommendation: A noncontrast head CT should be considered in patients who have head trauma with no LOC or PTA if there is a focal neurologic deficit, vomiting, severe headache, ≥65 years of age, physical signs of a basilar skull fracture, GCS score <15, coagulopathy, or a dangerous mechanism of injury (eg, ejection from a motor vehicle, a pedestrian struck by a vehicle, or a fall from a height of >3 feet or 5 stairs).

The ACEP Clinical Policy and Canadian CT Head Rule specify inclusion criteria of ≥ 16 years of age [10,15].

CTA Head and Neck

There is no relevant literature to support the use of CT angiography (CTA) in the initial imaging evaluation of acute head trauma without suspected vascular injury (see Variants 8 and 9 when suspected).

FDG-PET/CT Brain

There is no relevant literature to support the use of fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT in the initial imaging evaluation of acute head trauma.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of hexamethylpropyleneamine oxime (HMPAO) single-photon emission computed tomography (SPECT) or SPECT/CT in the initial imaging evaluation of acute head trauma.

MR Spectroscopy Head

There is no relevant literature to support the use of MR spectroscopy (MRS) in the initial imaging evaluation of acute head trauma.

MRA Head and Neck

There is no relevant literature to support the use of MR angiography (MRA) in the initial imaging evaluation of acute head trauma.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of functional MRI (fMRI) in the initial imaging evaluation of acute head trauma.

MRI Head

There is no relevant literature to support the use of MRI in the initial imaging evaluation of acute head trauma (please see Variant 4 for discussion of MRI after negative head CT).

MRI Head with DTI

There is no relevant literature to support the use of diffusion tensor imaging (DTI) in the initial imaging evaluation of acute head trauma.

Radiography Skull

There is no relevant literature to support the use of radiographs in the initial imaging evaluation of acute head trauma (replaced by CT, which is more sensitive for neurosurgical lesions).

Variant 2: Acute head trauma, mild (GCS 13–15), imaging indicated by clinical decision rule. Initial imaging.

Since its development in the 1970s, head CT has revolutionized the management of acute head trauma and proven its value in the detection of neurosurgical lesions (eg, hemorrhage, herniation, and hydrocephalus) and prevention of secondary injury. Its application has expanded over time from only severe head trauma to encompass moderate, mild (ie, minor), and minimal (GCS 15 without LOC or PTA) head trauma. Over 75% of acute head trauma is classified as mild, of which over 75% have a normal GCS score of 15. At the same time, only 10% or less of mild acute head trauma will have positive finding(s) on head CT, and only 1% or less will have a positive finding that requires neurosurgical intervention [4,5]. For these reasons, clinical practice guidelines universally recommend selective CT scanning in this patient population, which is often based on clinical decision rules [6]. Ongoing efforts to improve their specificity are discussed below; please see Variant 1 for discussion of their sensitivity and advantages in reducing CT utilization. (Note: GCS 13 is sometimes classified as moderate rather than mild to better reflect their positive imaging yield and poorer clinical prognosis; this distinction is not expected to affect imaging considerations under Variants 1–3.)

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the initial imaging evaluation of acute head trauma.

CT Head

Head CT is useful for the evaluation of mild acute head trauma when imaging is indicated by a validated clinical decision rule. Multiplanar reformatted images have been shown to increase diagnostic accuracy and should be included [16,17]. The identification of positive traumatic findings on CT in a small minority of these patients is a predictor of worse functional outcomes and is therefore described as “complicated” mild TBI [2]. For active duty

military personnel, per Department of Defense guidelines, a positive CT would prompt reclassification from mild to moderate TBI [18].

In the vast majority of these patients, CT will be negative for acute traumatic findings, so patients can be safely discharged rather than admitted as long as the neurologic examination is also normal (negative predictive value of 100% for neurologic deterioration requiring surgical intervention) [19]. One analysis quantified the risk of deterioration with both normal CT and neurologic examination as very low (0.006%), recommending discharge regardless of whether there was a responsible adult available to observe the patient [7]. It is important for mild TBI discharge instructions to be provided in written form; they should discuss why or when to return to the ED, plus educational information on postconcussive symptoms [20].

It should be noted that clinical decision rules are not without criticism or room for improvement. One large retrospective study of 4,554 mild head trauma encounters between 2009 and 2014 found a paradoxical increase in CT utilization (81.6%–87.6%) and decrease in CT yield for intracranial findings (12.2%–9.6%) after guideline implementation in 2011 [21]. Comparison studies from Australia and New Zealand determined clinical decision rules to be less specific than usual care by clinicians, contrasting with studies from the United States and reflecting differences in baseline scan rates [22,23]. Ongoing efforts to improve the specificity and positive predictive value of clinical decision rules include the application of machine learning techniques (eg, artificial neural networks and optimal classification trees), which come at the cost of complexity [24,25].

Other researchers are incorporating blood-based biomarkers of astrocytic (glial fibrillary acidic protein [GFAP]), neuronal (ubiquitin C-terminal hydrolase-L1 [UCH-L1]), or axonal (neurofilament light chain and tau) injury to better understand the pathophysiology of acute TBI and to improve the performance of clinical decision rules [5,26]. A combined UCH-L1 and GFAP assay has been shown to be over 97% sensitive and 36% specific for predicting intracranial injury on CT; this became the first mild TBI blood test approved by the FDA in February 2018 [27]. Serum levels of S100B have also been used clinically in Europe, with near 100% sensitivity for positive CT findings but with lower specificity (25%–28%) and shorter window for blood testing (4 hours versus 12 hours) [28,29].

CTA Head and Neck

There is no relevant literature to support the use of CTA in the initial imaging evaluation of acute head trauma without suspected vascular injury (see Variants 8 and 9 when suspected).

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the initial imaging evaluation of acute head trauma.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the initial imaging evaluation of acute head trauma.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the initial imaging evaluation of acute head trauma.

MRA Head and Neck

There is no relevant literature to support the use of MRA in the initial imaging evaluation of acute head trauma.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the initial imaging evaluation of acute head trauma.

MRI Head

There is no relevant literature to support the use of MRI in the initial imaging evaluation of acute head trauma (please see Variant 4 for discussion of MRI after negative head CT).

MRI Head with DTI

There is no relevant literature to support the use of DTI in the initial imaging evaluation of acute head trauma.

Radiography Skull

There is no relevant literature to support the use of radiographs in the initial imaging evaluation of acute head trauma (replaced by CT, which is more sensitive for neurosurgical lesions).

Variant 3: Acute head trauma, moderate (GCS 9–12) or severe (GCS 3–8) or penetrating. Initial imaging.

Since its development in the 1970s, head CT has revolutionized the management of acute head trauma and proven its value in the detection of neurosurgical lesions (eg, hemorrhage, herniation, and hydrocephalus) and prevention

of secondary injury. Its application has expanded over time from only severe head trauma to now encompass moderate, mild (ie, minor), and minimal (GCS 15 without LOC or PTA) head trauma. Because of the greater prevalence of intracranial lesions in moderate to severe head trauma (66% or higher), screening for selective CT scanning is a less effective strategy than “CT all” in this patient population, in contrast to mild head trauma [5]. With penetrating head trauma, CT is effective at detecting entry/exit wounds and foreign bodies, in addition to its near 100% sensitivity for hemorrhage, mass effect, or other neurosurgical lesions [30]. (Note: GCS 13 is sometimes classified as moderate rather than mild to better reflect their positive imaging yield and poorer clinical prognosis; this distinction is not expected to affect imaging considerations under Variants 1–3.)

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the initial imaging evaluation of acute head trauma.

CT Head

Head CT is useful for the evaluation of moderate, severe, or penetrating acute head trauma. Multiplanar reformatted images have been shown to increase diagnostic accuracy and should be included [16,17]. Overall, a normal CT tends to be associated with better outcomes than an abnormal CT, and in one study of 72 patients without systemic injury, focal hemorrhages >4.1 mL predicted a 2-fold greater risk of a poor outcome than patients with smaller lesions [31]. In the setting of penetrating head trauma, most commonly gunshot wounds (including self-inflicted), only 10% survive to reach the hospital, where morbidity and mortality remain extremely high. CT findings associated with an especially poor prognosis include brain stem and bilateral hemispheric injuries [30].

Traditional CT scoring systems for ICH and mass effect (eg, Marshall, Rotterdam) have been shown to predict mortality in moderate to severe head trauma. The NeuroImaging Radiological Interpretation System is a more recently developed CT scoring system, which uses standardized terminology from the National Institutes of Health common data elements for TBI imaging and which offers improved prediction of clinical disposition and management in TBI patients (ie, who will need prolonged admissions or neurosurgical procedures), beyond prediction of mortality alone [32,33].

CTA Head and Neck

There is no relevant literature to support the use of CTA in the initial imaging evaluation of acute head trauma without suspected vascular injury (see Variants 8 and 9 when suspected). Please refer to discussion under Variants 8 and 9 on clinical risk factors that are associated with intracranial vascular injury and would support the use of CTA/CT venography (CTV).

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the initial imaging evaluation of acute head trauma.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the initial imaging evaluation of acute head trauma.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the initial imaging evaluation of acute head trauma.

MRA Head and Neck

There is no relevant literature to support the use of MRA in the initial imaging evaluation of acute head trauma.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the initial imaging evaluation of acute head trauma.

MRI Head

There is no relevant literature to support the use of MRI in the initial imaging evaluation of acute head trauma (please see Variant 4 for discussion of MRI after negative head CT).

MRI Head with DTI

There is no relevant literature to support the use of DTI in the initial imaging evaluation of acute head trauma.

Radiography Skull

There is no relevant literature to support the use of radiographs in the initial imaging evaluation of acute head trauma (replaced by CT, which is more sensitive for neurosurgical lesions).

Variant 4: Acute head trauma with unchanged neurologic examination and unremarkable initial imaging. Short-term follow-up imaging.

Head CT is useful for the evaluation of acute head trauma, regardless of mechanism or severity, and is usually performed in the first 24 hours when indicated. This variant addresses short-term follow-up imaging in the acute phase (0–7 days) when the patient’s neurologic examination is stable or unchanged after a negative or unremarkable initial head CT. It focuses on some of the controversies regarding whether to repeat the head CT or to perform a conventional MRI in the clinical absence of neurologic deterioration. Research efforts on the early or “semi-acute” use of advanced neuroimaging techniques for detection of lesions occult on conventional CT/MRI and prognostication of chronic neurocognitive sequela often include subjects from both acute and early subacute phases (>7 days); they will be discussed under Variant 7.

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the short-term follow-up imaging evaluation of acute head trauma.

CT Head

Head CT is highly sensitive for the detection of findings that may require neurosurgical intervention in the acute phase. One analysis quantified the risk of deterioration with both normal CT and neurologic examination as very low (0.006%), recommending discharge regardless of whether there was a responsible adult available to observe the patient [7]. Patients with a normal CT but with an abnormal neurologic examination (eg, GCS <15) are typically admitted, with the United Kingdom’s National Institute for Health and Clinical Excellence recommending documented observations on a half-hourly basis, until GCS 15 has been achieved [13]. In a patient with a normal initial CT scan who has not achieved GCS 15 after 24 hours, this guideline suggests that “further CT scan or MRI scanning should be considered and discussed with the radiology department.”

There is some controversy about the necessity, with other guidelines recommending against routine repeat CT in the presence of a normal initial CT and in the absence of neurologic deterioration [2]. A single-center 2-year retrospective study of 2,444 ED patients with head trauma of varying severity and a negative head CT (80.8% of all scans) found a very low rate (1 case or 0.04%) of intracranial complications within 72 hours. Of the discharged patients (74.1%), <1% returned to the ED and received a repeat CT (all negative). Of the admitted patients (25.9%), <10% received a repeat CT, with only one positive for a small parietal lobe contusion, which was not visible on the initial CT and did not require neurosurgical intervention [34].

There is also some controversy about the necessity of routine observation and repeat CT in head trauma patients with coagulopathy and a normal initial CT. One prospective cohort study of 859 older adults (>55 years of age) with head trauma and a negative CT found a very low rate (3 cases or 0.3%) of delayed traumatic ICH within 14 days, and only 1 of the 3 cases occurred in a patient on anticoagulant or antiplatelet medication (warfarin with a positive repeat CT at 5 days) [35]. The authors conclude the risk of delayed ICH is low, even on anticoagulant or antiplatelet medication, and does not merit routine observation and repeat CT; however, the study is limited by the small number of patients in each anticoagulant and antiplatelet group.

CTA Head and Neck

There is no relevant literature to support the use of CTA in the short-term follow-up imaging evaluation of acute head trauma without suspected vascular injury (see Variants 8 and 9 when suspected).

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the short-term follow-up imaging evaluation of acute head trauma.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the short-term follow-up imaging evaluation of acute head trauma.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the short-term follow-up imaging evaluation of acute head trauma.

MRA Head and Neck

There is no relevant literature to support the use of MRA in the short-term follow-up imaging evaluation of acute head trauma.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the short-term follow-up imaging evaluation of acute head trauma.

MRI Head

Although brain MRI is not the most useful initial imaging modality for the evaluation of acute head trauma, it may be indicated as a follow-up study when there are persistent neurologic deficits that remain unexplained after the head CT [2]. MRI is more sensitive than CT for subtle findings adjacent to the calvarium or skull base (eg, small cortical contusions and subdural hematomas) [29]. It is also more sensitive for small white matter lesions in traumatic or diffuse axonal injury (DAI). Only 10% of DAI is positive on CT because >80% of lesions are not associated with macroscopic hemorrhage and therefore have a higher chance of detection on MRI using a combination of T2-weighted, T2*-weighted, and diffusion-weighted images [18].

There is some controversy about the necessity of MRI in the acute phase. A single-center 2-year retrospective study of all TBI patients with both CT and MRI in the acute phase found MRI to be more sensitive for small intracranial lesions, especially shearing injuries (DAI), which could be of prognostic value in patients with unexplained poor GCS scores. However, none of these additional findings affected management plans in the acute phase [36]. A single-center 3-year prospective study of all TBI patients with both CT and MRI in the acute phase also found MRI to be more sensitive for subtle contusions, shearing injuries, and extra-axial hematomas (33% of cases). Once again, the additional information did not affect management in the acute phase [37].

If the clinical focus has transitioned from short-term management to long-term prognostication in the acute phase, then an early MRI may be of greater value, particularly in patients who have mild TBI with normal CTs (approximately 15% will have persistent neurocognitive sequelae at 1 year). A prospective Level 1 trauma multicenter study has found that approximately 27% of patients who have mild TBI with normal CTs show abnormalities on early MRI (eg, small cortical contusions or hemorrhagic axonal injury) and that these findings may be clinically relevant in improving prediction of 3-month outcomes [38]. There is ongoing research in the utility of blood-based biomarkers (eg, GFAP) to determine which patients who have mild TBI and negative CT were more likely to benefit from MRI [39].

MRI Head with DTI

There is no relevant literature to support the use of DTI in the short-term follow-up imaging evaluation of acute head trauma.

Radiography Skull

There is no relevant literature to support the use of radiographs in the short-term follow-up imaging evaluation of acute head trauma.

Variant 5: Acute head trauma with unchanged neurologic examination and positive finding(s) on initial imaging (eg, subdural hematoma). Short-term follow-up imaging.

Head CT is useful for the evaluation of acute head trauma, regardless of mechanism or severity, and is usually performed in the first 24 hours when indicated. This variant addresses short-term follow-up imaging in the acute phase (0–7 days), when the patient's neurologic examination is stable or unchanged, after a positive CT with acute traumatic intracranial findings.

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the short-term follow-up imaging evaluation of acute head trauma.

CT Head

In the presence of an abnormal initial CT and in the absence of neurologic deterioration, the decision to perform a routine repeat CT should depend on the estimated risk for subclinical progression of intracranial findings. A large systematic review and meta-analysis of 41 studies enrolling 10,501 patients with TBI suggested there is overutilization of repeat CT, which changed management in only 11.4% of patients across prospective studies and 9.6% of patients across retrospective studies (2.3% and 3.9% in a subgroup analysis of patients with mild TBI) [40].

Routine follow-up CT after an abnormal initial CT is supported for moderate to severe TBI and for anticoagulated patients [2]. Patients on anticoagulant or antiplatelet medication had a 3-fold increase in frequency of bleeding progression on repeat head CT (26% versus 9%) in one retrospective analysis of 508 CT-positive TBIs [41].

For patients with mild TBI and positive CT (who are not on anticoagulation), the appropriateness of routine repeat CT may depend on the size and type of intracranial findings. A retrospective review of 321 patients with mild TBI with ICH on initial CT found imaging progression in only 6% (and neurologic deterioration in only 1%). Subfrontal/temporal parenchymal contusion and volume of ICH >10 mL were imaging predictors of progression (use of anticoagulation and >65 years of age were clinical predictors). Based on outcomes analysis, the authors conclude that patients with mild TBI with a small convexity contusion or extra-axial hemorrhage <10 mL do not require routine repeat CT or admission to the intensive care unit in the absence of neurologic deterioration [42].

In the presence of an abnormal initial CT, other patient factors such as intoxication or pharmacologic sedation often affect the reliability of serial examinations in the acute trauma setting and lower the threshold for follow-up imaging, even in the absence of neurologic deterioration.

CTA Head and Neck

There is no relevant literature to support the use of CTA in the short-term follow-up imaging evaluation of acute head trauma without suspected vascular injury (see Variants 8 and 9 when suspected). Please refer to discussion under Variants 8 and 9 on imaging risk factors that are associated with intracranial vascular injury and would support the use of CTA/CTV.

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the short-term follow-up imaging evaluation of acute head trauma.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the short-term follow-up imaging evaluation of acute head trauma.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the short-term follow-up imaging evaluation of acute head trauma.

MRA Head and Neck

There is no relevant literature to support the use of MRA in the short-term follow-up imaging evaluation of acute head trauma.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the short-term follow-up imaging evaluation of acute head trauma.

MRI Head

Although brain MRI is not the most useful initial imaging modality for the evaluation of acute head trauma, it may be indicated as a follow-up study when there are persistent neurologic deficits that remain unexplained after the head CT [2]. MRI is more sensitive than CT for subtle findings adjacent to the calvarium or skull base (eg, small cortical contusions and subdural hematomas) [29]. It is also more sensitive for small white matter lesions in traumatic axonal injury or DAI. Only 10% of DAI is positive on CT because >80% of lesions are not associated with macroscopic hemorrhage and therefore have a higher chance of detection on MRI using a combination of T2-weighted, T2*-weighted, and diffusion-weighted images [18].

There is some controversy about the necessity of MRI in the acute phase. A single-center 2-year retrospective study of all patients with TBI who underwent both CT and MRI in the acute phase found MRI to be more sensitive for small intracranial lesions, especially shearing injuries (DAI), which could be of prognostic value in patients with unexplained poor GCS scores. However, none of these additional findings affected management plans in the acute phase [36]. A single-center 3-year prospective study of all patients with TBI who underwent both CT and MRI in the acute phase also found MRI to be more sensitive for subtle contusions, shearing injuries, and extra-axial hematomas (33% of cases). Once again, the additional information did not affect management in the acute phase [37].

MRI Head with DTI

There is no relevant literature to support the use of DTI in the short-term follow-up imaging evaluation of acute head trauma.

Radiography Skull

There is no relevant literature to support the use of radiographs in the short-term follow-up imaging evaluation of acute head trauma.

Variant 6: Acute head trauma with new or progressive neurologic deficit(s). Short-term follow-up imaging.

Head CT is useful for the evaluation of acute head trauma, regardless of mechanism or severity, and is usually performed in the first 24 hours when indicated. This variant addresses short-term follow-up imaging in the acute phase (0–7 days), when the patient’s neurologic examination has deteriorated since the time of the most recent neuroimaging study.

For neurologic deficit(s) of hyperacute onset, please see the ACR Appropriateness Criteria® topic on “[Cerebrovascular Disease](#)” [43] for further guidance on neuroimaging in the setting of suspected stroke.

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the short-term follow-up imaging evaluation of acute head trauma.

CT Head

Head CT is useful for the evaluation of any trauma patient with neurologic deterioration, especially in the acute setting and regardless of whether the initial imaging was positive or negative [2]. CT is highly sensitive for the detection of findings that may require neurosurgical intervention (eg, new or worsening hemorrhage, herniation, and hydrocephalus). Multiplanar reformatted images have been shown to increase diagnostic accuracy and should be included [16,17]. In patients with a positive initial CT, reported predictors of imaging progression include subfrontal/temporal parenchymal contusion, volume of ICH >10 mL, use of anticoagulation, and >65 years of age [42]. In patients with a negative initial CT, delayed ICH is a rare but possible complication (overall incidence <0.5%) [35].

CTA Head and Neck

There is no relevant literature to support the use of CTA in the short-term follow-up imaging evaluation of acute head trauma without suspected vascular injury (see Variants 8 and 9 when suspected).

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the short-term follow-up imaging evaluation of acute head trauma.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the short-term follow-up imaging evaluation of acute head trauma.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the short-term follow-up imaging evaluation of acute head trauma.

MRA Head and Neck

There is no relevant literature to support the use of MRA in the short-term follow-up imaging evaluation of acute head trauma.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the short-term follow-up imaging evaluation of acute head trauma.

MRI Head

Head CT is the most useful follow-up imaging modality for the evaluation of any trauma patient with neurologic deterioration, especially in the acute setting, and regardless of whether the initial imaging was positive or negative [2]. Brain MRI may be indicated as a second-line study when there are persistent neurologic deficits that remain unexplained after the head CT. MRI is more sensitive than CT for subtle findings adjacent to the calvarium or skull base (eg, small cortical contusions and subdural hematomas) [29]. MRI is also more sensitive for small white matter

lesions in traumatic axonal injury or DAI. MRI with diffusion-weighted imaging can detect acute ischemic stroke (specifically infarct core) with higher sensitivity than head CT.

There is some controversy about the necessity of MRI in the acute phase. A single-center 2-year retrospective study of all patients with TBI who underwent both CT and MRI in the acute phase found MRI to be more sensitive for small intracranial lesions, especially shearing injuries (DAI), which could be of prognostic value in patients with unexplained poor GCS scores. However, none of these additional findings affected management plans in the acute phase [36]. A single-center 3-year prospective study of all patients with TBI who underwent both CT and MRI in the acute phase also found MRI to be more sensitive for subtle contusions, shearing injuries, and extra-axial hematomas (33% of cases). Once again, the additional information did not affect management in the acute phase [37].

MRI Head with DTI

There is no relevant literature to support the use of DTI in the short-term follow-up imaging evaluation of acute head trauma.

Radiography Skull

There is no relevant literature to support the use of radiographs in the short-term follow-up imaging evaluation of acute head trauma.

Variant 7: Subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s). Initial imaging.

As noted in the introduction/background section, head trauma is a significant public health concern and is also a leading cause of morbidity and mortality in children and young adults, especially in the setting of moderate, severe, or penetrating head trauma. Even mild head trauma, which accounts for >75% of cases, can be associated with a significant risk of persistent neurocognitive/postconcussive symptoms, affecting approximately 58% at 1 month and 15% at 1 year after injury (postconcussive syndrome is defined as >3 months) [20].

There has been increasing recognition of the chronic sequelae from repetitive concussions (mild TBI) in athletic and military personnel, which can lead to neurodegenerative disease in some cases (chronic traumatic encephalopathy) [2]. A survey of 2,525 infantry soldiers returning from Operations Iraqi Freedom and Enduring Freedom found that 15% reported experiencing events associated with mild TBI, which has been termed a signature injury of those conflicts (80% secondary to improvised explosive devices) [18].

For subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s), the goals of imaging are to better characterize any intracranial injuries and to enhance understanding of persistent symptoms [2]. Research efforts on the early or “semi-acute” use of advanced neuroimaging techniques for detection of lesions occult on conventional CT/MRI and prognostication of chronic neurocognitive sequela often include subjects from both acute and early subacute phases (>7 days); they will be discussed under this variant.

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the initial imaging evaluation of subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s).

CT Head

Although head CT is the most useful initial imaging for the evaluation of acute head trauma, brain MRI is typically recommended as the most useful initial imaging for the evaluation of subacute or chronic head trauma, when rapid detection of acute ICH and neurosurgical lesions is no longer the primary clinical focus. MRI is more sensitive than CT for subtle findings adjacent to the calvarium or skull base (eg, focal encephalomalacia at the inferior frontal or anterior temporal lobes as chronic sequelae of previous contusions). It is also more sensitive for small white matter lesions (microbleeds) as chronic sequelae of previous traumatic axonal injury or DAI, which may help to explain persistent cognitive or neurologic deficit(s) [32]. CT is a valid option when there is a specific question that does not require the high soft-tissue contrast resolution of MRI (eg, possible shunt failure in chronic severe TBI). It is also a valid option for patients who present in a delayed fashion after head trauma (eg, gradual decline after a fall due to subacute or chronic subdural hematoma).

CTA Head and Neck

There is no relevant literature to support the use of CTA in the initial imaging evaluation of subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s) unless there is also suspected intracranial vascular injury (see Variants 8 and 9 when suspected).

FDG-PET/CT Brain

FDG is the most widely used PET radiopharmaceutical and is a glucose analog. Glucose is the primary energy source for the brain; therefore, FDG uptake on PET is a marker of local metabolism, which is closely coupled to local neuronal activity and can be quantified as the cerebral metabolic rate of glucose [18]. In normally functioning brain tissue, local metabolism is also closely coupled to perfusion; therefore, findings on metabolic PET imaging will often (but not always) parallel findings on perfusion SPECT imaging [32]. In acute severe TBI with brain contusion, FDG-PET has found both pericontusion and distant/global hypometabolism, whereas in chronic mild TBI, FDG-PET has found regional hypometabolism that may correlate with cognitive and behavioral impairments [18]. One study in combat veterans with chronic postconcussive syndrome found hypometabolism in the infratentorial and medial temporal regions, which may be unique to blast exposures [44]. Aside from FDG, other research studies have used oxygen (^{15}O), neuronal ($[^{11}\text{C}]$ flumazenil), inflammation ($[^{11}\text{C}]$ PK11195), amyloid ($[^{11}\text{C}]$ PiB), and tau ($[^{18}\text{F}]$ T807) radiopharmaceuticals [18]. Despite the promise of molecular imaging for advancing our understanding of TBI pathophysiology, there is insufficient evidence to support the routine clinical use of PET at the individual patient level [45].

HMPAO SPECT or SPECT/CT Brain

Although SPECT is used clinically with a wide variety of radiopharmaceuticals, brain SPECT most commonly refers to cerebral perfusion or blood flow imaging using either Tc-99m-hexamethylpropyleneamine oxime or Tc-99m-ethyl cysteinate dimer. Measurement of regional cerebral blood flow is also an indicator of metabolic or neuronal activity; therefore, SPECT is utilized in epilepsy or neurodegenerative disorders in addition to cerebrovascular diseases. Other radiopharmaceuticals (eg, imaging of benzodiazepine or dopamine receptors) are generally confined to research studies. Perfusion SPECT is potentially a complementary tool to conventional CT/MRI and has been applied in research studies on mild, moderate, and severe TBI to identify additional lesions (eg, regional cerebral blood flow deficits) beyond anatomic imaging [18]. A study using early subacute SPECT in patients with mild to moderate TBI found that severe hypoperfusion was an independent predictor of unfavorable outcomes at 3 months; conversely, a normal initial SPECT has been shown to have high negative predictive value for persistent clinical deficits at 12 months [46]. Despite the promise of perfusion imaging (whether employing SPECT or CT/MRI-based techniques) for the detection of functional injury that may be occult on structural imaging, there is insufficient evidence to support the routine clinical use of SPECT at the individual patient level [45].

MR Spectroscopy Head

MRS measures very small differences in the precessional frequencies of proton nuclei in order to differentiate their molecular environments (chemical shift effect). Single-voxel versus multi-voxel spectroscopy offers different strengths and weaknesses in signal-to-noise ratio versus spatial coverage; both have lower spatial resolution than other MRI-based techniques. Commonly detected brain metabolites at intermediate (TE = 144 ms) to long (TE = 288 ms) echo time include *N*-acetylaspartate for neuronal integrity, creatine for cellular energy, choline for membrane turnover, and lactate for anaerobic metabolism. MRS at short (TE = 35 ms) echo time can further detect glutamate/glutamine for excitatory brain injury and myo-inositol for astroglial proliferation. The most commonly reported finding in the setting of head trauma is a reduction in *N*-acetylaspartate or *N*-acetylaspartate/creatine, sometimes accompanied by an elevation in choline and sometimes in otherwise normal-appearing brain, which may reflect microscopic DAI and/or Wallerian degeneration [32,45,46]. A study in concussed athletes found that decreased *N*-acetylaspartate/creatine took a longer time to resolve than the symptoms, suggesting that metabolic recovery is slower than clinical recovery [18]. Despite the interesting findings in MRS research, there is insufficient evidence to support the routine clinical use of MRS at the individual patient level [45].

MRA Head and Neck

There is no relevant literature to support the use of MRA in the initial imaging evaluation of subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s).

MRI Functional (fMRI) Head

Typically, fMRI refers to the use of a blood oxygen level–dependent (BOLD) technique to indirectly detect changes or fluctuations in brain activity. Neuronal activity stimulates a hemodynamic response to bring in more glucose and oxygen; the associated decrease in paramagnetic deoxyhemoglobin can be detected on dynamic T2*-weighted

images (BOLD). This indirect imaging of brain activity can be performed while the patient focuses on a specific task or rests with their eyes open [18]. Research studies of task-based fMRI in patients with mild TBI have employed working memory or cognitive tasks (eg, N-back) and have shown different directions of BOLD signal change, with one explanatory hypothesis being that BOLD signal increases represent a compensatory response in the setting of brain injury (neuronal recruitment) and that BOLD signal decreases represent performance deficits. There is also the possibility for mild TBI-induced decoupling between neuronal activity and blood flow [47]. In contrast to task-based activation, resting-state fMRI detects the BOLD signal changes associated with spontaneous fluctuations in brain activity, whose degree of synchrony is used to assess “functional connectivity” between different regions. One study of early subacute resting-state fMRI in patients with mild TBI found reductions in connectivity that correlated with cognitive performance and postconcussive symptoms at 6 months [48]. Another study of resting-state fMRI in patients with chronic TBI found increased connectivity in brain regions with elevated tau burden on PET; this finding may reflect compensatory processes [49]. Despite the interesting findings in fMRI research, there is insufficient evidence to support the routine clinical use of fMRI at the individual patient level [45].

MRI Head

Brain MRI is the most useful initial imaging for the evaluation of subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s). Conventional MRI will include a combination of T1-weighted, T2-weighted, T2*-weighted (gradient-echo), and diffusion-weighted imaging. It is more sensitive than CT for subtle findings adjacent to the calvarium or skull base (eg, focal encephalomalacia at the inferior frontal or anterior temporal lobes as chronic sequelae of previous contusions). It is also more sensitive for small white matter lesions (microbleeds) as chronic sequelae of previous traumatic axonal injury or DAI, although it is still far less sensitive than neuropathological investigation (microscopic analysis) [32]. Susceptibility-weighted imaging is a high-resolution 3-D T2*-weighted sequence that uses both magnitude and phase information to increase sensitivity for paramagnetic blood products (eg, pediatric TBI studies have detected 6 times as many microbleeds with susceptibility-weighted imaging than with older gradient-echo T2*-weighted sequences) [18].

In addition to detecting subtle structural injury, conventional MRI may help with the prognostication of long-term neurocognitive sequelae. Regarding mild head trauma, a prospective Level 1 trauma multicenter study found that abnormalities on early subacute MRI (eg, small cortical contusions or hemorrhagic axonal injury) are clinically relevant in improving prediction of 3-month outcomes [38]. Another prospective study in patients with mild TBI found a correlation between frontal-temporal-parietal microbleeds on early MRI susceptibility-weighted imaging and the presence or absence of depressive symptoms at 1 year after injury [50]. Regarding moderate to severe head trauma, one study found DAI on subacute MRI in almost three-quarters of patients who survived the acute phase, and only in those patients was GCS score (which tended to be lower) related to 12-month outcomes. It also found similar outcomes for DAI Stage 1 (lobar white matter lesions only) and DAI Stage 2 (callosal lesions), with poor outcomes for DAI Stage 3 (dorsolateral brain stem lesions) [51]. Another study on subacute MRI in post-TBI vegetative states found that depth/stage of DAI lesions helps predict recovery or nonrecovery at 1 year [52].

There is no relevant literature to support the added value or routine use of contrast-enhanced brain MRI instead of noncontrast brain MRI in the initial imaging evaluation of subacute or chronic head trauma.

MRI Head with DTI

Diffusion-weighted imaging generates a scalar coefficient for each voxel, which represents the average or mean diffusivity (mm^2/s) of the water molecules in that location. DTI applies the diffusion-sensitizing gradients in many (at least 6) different directions in order to generate a second-order tensor that characterizes directionality of water molecule diffusion. This can be visualized as a diffusion ellipsoid, where the long axis represents axial diffusivity, and the short axes represent radial diffusivity. An important summary measure of the degree of asymmetry between the long and short axes is fractional anisotropy. Fractional anisotropy is higher in white matter than gray matter or CSF because of its microstructure (fiber-tract architecture); therefore, fractional anisotropy has been studied extensively as a potential marker of axonal integrity, especially in the setting of persistently symptomatic mild TBI [18]. Multiple studies have shown regions of decreased fractional anisotropy and increased mean diffusivity in patients with mild, moderate, and severe TBI, as compared with healthy controls [53]. Other DTI studies performed in the early subacute phase have shown paradoxically increased fractional anisotropy, which has been attributed to cytotoxic edema or to postinjury repair [54,55]. Overall, there is significant heterogeneity in fractional anisotropy measurements among both TBI and healthy subjects, with published data based primarily upon group-level analyses. Despite continuing improvements in scanner gradients and diffusion techniques (eg, intravoxel resolution

of crossing fibers), there is insufficient evidence to support the routine clinical use of DTI at the individual patient level [45].

Radiography Skull

There is no relevant literature to support the use of radiographs in the initial imaging evaluation of subacute or chronic head trauma with unexplained cognitive or neurologic deficit(s).

Variant 8: Head trauma with suspected intracranial arterial injury due to clinical risk factors or positive findings on prior imaging.

The reported incidence of blunt cerebrovascular injury (BCVI) has increased from approximately 0.1% to 1.0% of patients with closed head/neck trauma, with increased screening of asymptomatic patients. Symptomatic patients will have developed secondary strokes, which are associated with significant morbidity of up to 80% and mortality of up to 40% [56]. There is a variable latent period between vascular injury and symptom onset, with 17% to 36% developing symptoms >24 hours after injury, and when screening appropriately based on clinical or imaging risk factors, approximately 52% to 79% of patients with detected BCVI are asymptomatic [57]. Cerebrovascular injury is also a potential concern in the less common setting of penetrating head/neck trauma.

In addition to indirect evidence of arterial injury on prior imaging (eg, hemorrhage or infarct), BCVI has a known association with head/face and cervical fractures. For example, with regard to intracranial arterial injury, positive imaging findings of a skull base fracture that involves the carotid canal or abnormal enlargement of the superior ophthalmic vein and cavernous sinus should prompt evaluation for a petrous or cavernous internal carotid artery injury, respectively [58]. Above the level of the skull base, the branches of the middle and anterior cerebral arteries are often at risk in the setting of penetrating head trauma [30].

Regarding clinical risk factors for BCVI, there are various screening criteria available, which involve tradeoffs in sensitivity (ranging between 63% and 84%) and positive predictive value or screening yield (ranging between 6% and 29%), similar to the clinical decision rules for selective CT scanning in mild head trauma [57]. The 2 original clinical decision rules were the Denver criteria (from University of Colorado) and the Memphis criteria (from University of Tennessee). Both have since been broadened into the modified Denver criteria and the modified Memphis criteria, with the more recently introduced Boston criteria being based on the modified Denver criteria.

For clinicians or providers who are not currently committed to a screening criteria for BCVI, one simple option is the 2010 guidelines from the Eastern Association for the Surgery of Trauma [56]:

Who should be evaluated for BCVI?

- Patients presenting with any neurologic abnormality that is unexplained by a diagnosed injury,
- Patients presenting with epistaxis from a suspected arterial source,
- Asymptomatic patients with any of the following risk factors:
 - Severe head trauma (GCS 3–8)
 - Petrous bone fracture
 - Diffuse axonal injury
 - Cervical spine fracture with fracture of C1 to C3 or fracture through the foramen transversarium
 - Cervical spine fracture with subluxation or rotational component
 - Lefort II or III facial fractures

Please see the ACR Appropriateness Criteria® topic on “[Cerebrovascular Disease](#)” [43] or the ACR Appropriateness Criteria® topic on “[Penetrating Neck Injury](#)” [59] for further guidance on neurovascular imaging in the setting of suspected stroke or penetrating trauma.

Arteriography Cervicocerebral

Although catheter angiography is the historical reference standard and offers the highest spatial/temporal resolution for imaging evaluation of vascular pathology, noninvasive CTA is faster, has fewer safety concerns, and is most useful in the initial imaging evaluation of suspected intracranial arterial injury [45]. With modern CT equipment, accuracy has been shown to be comparable. One prospective study of 146 trauma patients who received both catheter angiography and CTA (16-slice multidetector-row) reported the latter to have a sensitivity of 97.7% and a specificity of 100% for the diagnosis of vascular injury [60]. Catheter angiography may be useful when CTA is inconclusive (eg, possible arteriovenous fistula) or when endovascular intervention is being considered [45].

CT Head

Please refer to CTA for neurovascular imaging evaluation of suspected intracranial arterial injury. Concurrent CT may be useful in the clinical setting of suspected intracranial arterial injury for assessing structural changes to the brain since the most recent neuroimaging study (eg, new or progressive neurologic deficit). Concurrent head CT is also useful in the initial imaging evaluation of head trauma when there is no prior imaging.

CTA Head and Neck

Although catheter angiography is the historical reference standard and offers the highest spatial/temporal resolution for imaging evaluation of vascular pathology, noninvasive CTA is faster, has fewer safety concerns, and is most useful in the initial imaging evaluation of suspected intracranial arterial injury [45]. With modern CT equipment, accuracy has been shown to be comparable. One prospective study of 146 trauma patients who received both catheter angiography and CTA (16-slice multidetector-row) reported the latter to have a sensitivity of 97.7% and a specificity of 100% for the diagnosis of vascular injury [60]. The development of >8-slice multidetector-row CT has allowed CTA to become the standard in diagnosis of suspected cerebrovascular injury, with reported sensitivities up to 100% (somewhat dependent on both CT technology and radiologist expertise) [57].

There is a Biffl grading scale for arterial injury, which was originally developed for catheter angiography and carotid artery injury but has also been shown to be reliable for CTA and vertebral artery injury [56]. Grade I = dissection with <25% luminal narrowing (intimal irregularity), Grade II = dissection with >25% luminal narrowing (intramural hematoma), Grade III = pseudoaneurysm (contained hematoma), Grade IV = occlusion, and Grade V = transection or hemodynamically significant arteriovenous fistula (eg, carotid cavernous fistula). Medical therapy with antiplatelet or anticoagulation may be appropriate management for the lower grades of arterial injury, whereas the higher grades of arterial injury are more likely to require endovascular or surgical treatment [56,57].

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the imaging evaluation of suspected intracranial arterial injury.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the imaging evaluation of suspected intracranial arterial injury.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the imaging evaluation of suspected intracranial arterial injury.

MRA Head and Neck

In the setting of acute trauma, MRA is considered a second-line noninvasive option behind CTA, which is faster, has fewer safety concerns, and is most useful in the initial imaging evaluation of suspected intracranial arterial injury [45]. MRA may be useful outside of the acute setting or when CTA is inconclusive (eg, for detection of T1 hyperintense subacute intramural hematoma in traumatic arterial dissection) [57]. Noncontrast MRA, using time-of-flight technique, can be used in patients who cannot receive iodinated or gadolinium-based contrast.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the imaging evaluation of suspected intracranial arterial injury.

MRI Head

Please refer to MRA for neurovascular imaging evaluation of suspected intracranial arterial injury. Concurrent MRI may be useful in the clinical setting of suspected intracranial arterial injury for assessing structural changes to the brain since the most recent neuroimaging study (eg, new or progressive neurologic deficit).

MRI Head with DTI

There is no relevant literature to support the use of DTI in the imaging evaluation of suspected intracranial arterial injury.

Radiography Skull

There is no relevant literature to support the use of radiographs in the imaging evaluation of suspected intracranial arterial injury.

Variant 9: Head trauma with suspected intracranial venous injury due to clinical risk factors or positive findings on prior imaging.

Traumatic venous injury is an often-overlooked pathology that includes epithelial injury with thrombus formation and venous laceration with compressive hematoma [57]. The most common symptoms are highly variable and nonspecific (eg, headache and papilledema from intracranial hypertension or focal neurologic deficits from venous ischemia); they may be mistakenly attributed to other traumatic injuries [61].

From an imaging standpoint, the most important risk factor for traumatic venous injury is a skull fracture (or less commonly a penetrating foreign body) that involves a dural venous sinus or jugular bulb/foramen. In a retrospective study of 195 patients with closed head trauma who received multidetector-row CTV, acute traumatic venous sinus thrombosis was seen only in those patients with fractures extending to a dural sinus or jugular bulb (41% rate of thrombosis), and hemorrhagic venous infarctions were seen only in the setting of occlusive dural venous sinus thrombosis (55% of all thromboses) [62]. Another retrospective study of 472 patients with closed head trauma with skull fracture crossing a dural venous sinus also identified a high incidence of small epidural hemorrhages (81%), which can be compressive and misdiagnosed as venous sinus thrombosis [61].

Direct observation of hyperattenuating thrombus within a dural venous sinus on a noncontrast CT should prompt further evaluation; however, this is present in only one-third of venous sinus thrombosis. Indirect evidence of dural sinus thrombosis includes venous infarcts (subcortical edema), one-third of which develop parenchymal hemorrhage [30].

Arteriography Cervicocerebral

There is no relevant literature to support the use of catheter angiography in the imaging evaluation of suspected intracranial venous injury.

CT Head

Please refer to CTV for neurovascular imaging evaluation of suspected intracranial venous injury. Concurrent CT may be useful in the clinical setting of suspected intracranial venous injury for assessing structural changes to the brain since the most recent neuroimaging study (eg, new or progressive neurologic deficit). Concurrent head CT is also useful in the initial imaging evaluation of head trauma when there is no prior imaging.

CTV Head

In the acute setting, CTV is the most useful study in the imaging evaluation of suspected intracranial venous injury (eg, prior imaging with a skull fracture or, less commonly, a penetrating foreign body that involves a dural venous sinus or jugular bulb/foramen) [58]. Abnormally decreased contrast opacification of a dural venous sinus on CTV may result from an intrinsic filling defect (eg, “empty delta” sign of acute dural venous sinus thrombosis) versus extrinsic mass effect (eg, compressive epidural hemorrhage) [61].

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the imaging evaluation of suspected intracranial venous injury.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the imaging evaluation of suspected intracranial venous injury.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the imaging evaluation of suspected intracranial venous injury.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the imaging evaluation of suspected intracranial venous injury.

MRI Head

Please refer to MRV for neurovascular imaging evaluation of suspected intracranial venous injury. Concurrent MRI may be useful in the clinical setting of suspected intracranial venous injury for assessing structural changes to the brain since the most recent neuroimaging study (eg, new or progressive neurologic deficit).

MRI Head with DTI

There is no relevant literature to support the use of DTI in the imaging evaluation of suspected intracranial venous injury.

MRV Head

In the setting of acute trauma, MRV is considered a second-line noninvasive option behind CTV, which is faster, has fewer safety concerns, and is most useful in the initial imaging evaluation of suspected intracranial venous injury [58]. MRV may be useful outside of the acute setting, and noncontrast MRV using time-of-flight or phase-contrast techniques can be used in patients who cannot receive iodinated or gadolinium-based contrast.

Radiography Skull

There is no relevant literature to support the use of radiographs in the imaging evaluation of suspected intracranial venous injury.

Variant 10: Head trauma with suspected cerebrospinal fluid (CSF) leak. Initial imaging.

It is estimated that CSF leaks are seen in 1% to 3% of all closed head trauma cases (10%–30% of skull base fractures) and that head trauma is responsible for 80% to 90% of all CSF leaks [63]. Most cases present as CSF rhinorrhea (80%) in the setting of an anterior skull base fracture. Less common presentations include CSF otorrhea in the setting of a posterior skull base (temporal bone) fracture or recurrent meningitis due to an occult CSF fistula. Most cases present in the first 48 hours after injury (80%), with nearly all cases by the 3-month mark (95%) [58]. Clear watery nonmucoid fluid drainage from the nose or ear can be tested for the presence of β 2-transferrin or β 2-trace protein to confirm a CSF leak (note: β 2-trace has sensitivity and specificity approaching 100% in patients without chronic renal failure) [64]. Despite the often acute presentation, surgical repair with preoperative neuroimaging localization of a traumatic CSF leak may be delayed or reserved for patients who fail 1 to 2 weeks of conservative management (eg, bedrest with head elevated 30°) [63].

CT Head Cisternography

CT cisternography is high-resolution CT (HRCT) of the skull base after a lumbar puncture for intrathecal administration of approximately 10 mL of an iodinated contrast agent (eg, 3 g of iodine). Its sensitivity for contrast leakage from the subarachnoid space into the sinonasal or tympanomastoid cavities depends on the rate of CSF leak and ranges between 85% and 92% in patients with an active leak versus 40% in patients with an inactive or intermittent leak [64]. Noninvasive noncontrast HRCT has a high sensitivity of 84% to 95% and has replaced traditional use of minimally invasive contrast-enhanced CT cisternography in the initial imaging evaluation of suspected CSF leak with laboratory confirmation [64,65]. No additional preoperative neuroimaging is necessary when a single skull base defect is identified on the HRCT; when there are multiple potential CSF leak sites, then follow-up CT cisternography is indicated [58,64].

CT Head

HRCT is the most useful study in the initial imaging evaluation of suspected CSF leak with laboratory confirmation (ie, positive for β 2-transferrin or β 2-trace) [58,64,66]. Thin-section bone algorithm images of the skull base with multiplanar reformation may be requested as a maxillofacial CT for CSF rhinorrhea versus a temporal bone CT for CSF otorrhea. Although face and temporal bone CT both offer better spatial resolution (due to a smaller field of view) and sensitivity for subtle or nondisplaced skull base defects, a standard head CT is a higher priority in a head trauma patient, if not already performed.

CT Maxillofacial

HRCT is the most useful study in the initial imaging evaluation of suspected CSF leak with laboratory confirmation (ie, positive for β 2-transferrin or β 2-trace) [58,64,66]. Thin-section bone algorithm images of the skull base with multiplanar reformation may be requested as a maxillofacial CT for CSF rhinorrhea versus a temporal bone CT for CSF otorrhea. HRCT has a reported accuracy of 93% and sensitivity of 92%, which is higher than the other noninvasive imaging option, MR cisternography [66]. HRCT is also more sensitive than the minimally invasive imaging options (eg, radionuclide cisternography and CT cisternography), whose sensitivities depend on the rate of CSF leak. In one retrospective study of 21 patients who underwent surgical repair, HRCT correctly identified the site of CSF leak in all 21 cases (radionuclide cisternography was positive in 16, CT cisternography was positive in 10) [65]. No additional preoperative imaging is necessary when a single skull base defect is identified on the HRCT; when there are multiple potential CSF leak sites, then follow-up CT cisternography is indicated [58,64].

CT Temporal Bone

HRCT is the most useful study in the initial imaging evaluation of suspected CSF leak with laboratory confirmation (ie, positive for β 2-transferrin or β 2-trace) [58,64,66]. Thin-section bone algorithm images of the skull base with multiplanar reformation may be requested as a maxillofacial CT for CSF rhinorrhea versus a temporal bone CT for CSF otorrhea. HRCT has a reported accuracy of 93% and sensitivity of 92%, which is higher than the other noninvasive imaging option, MR cisternography [66]. HRCT is also more sensitive than the minimally invasive imaging options (eg, radionuclide cisternography and CT cisternography), whose sensitivities depend on the rate of CSF leak. In one retrospective study of 21 patients who underwent surgical repair, HRCT correctly identified the site of CSF leak in all 21 cases (radionuclide cisternography was positive in 16, CT cisternography was positive in 10) [65]. No additional preoperative imaging is necessary when a single skull base defect is identified on the HRCT; however, when there are multiple potential CSF leak sites, then follow-up CT cisternography is indicated [58,64].

DTPA Cisternography

Radionuclide cisternography is a nuclear medicine study that involves a lumbar puncture for intrathecal administration of a radiopharmaceutical tracer: diethylenetriamine pentaacetic acid (DTPA) labeled with indium-111. In addition to scintigraphy for direct visualization of radiotracer leakage from the subarachnoid space into the sinonasal or tympanomastoid cavities (with optional delayed imaging up to 72 hours), pledgets can be placed in the nasal cavity and tested for radiotracer absorption. Radionuclide cisternography is most useful for confirming the presence of a CSF leak and therefore may be applied in the initial imaging evaluation of suspected CSF leak without laboratory confirmation (ie, negative for β 2-transferrin or β 2-trace) [66]. In the setting of suspected CSF leak with laboratory confirmation, radionuclide cisternography's lower spatial resolution will not be sufficient for preoperative planning purposes, and HRCT is the most useful study [65].

FDG-PET/CT Brain

There is no relevant literature to support the use of FDG-PET/CT in the initial imaging evaluation of suspected CSF leak.

HMPAO SPECT or SPECT/CT Brain

There is no relevant literature to support the use of SPECT in the initial imaging evaluation of suspected CSF leak.

MR Spectroscopy Head

There is no relevant literature to support the use of MRS in the initial imaging evaluation of suspected CSF leak.

MRI Functional (fMRI) Head

There is no relevant literature to support the use of fMRI in the initial imaging evaluation of suspected CSF leak.

MRI Head

MR cisternography is the use of high-resolution T2-weighted or steady-state free precession sequences to look for CSF communication or meningoencephalocele across a defect in the skull base. It is a second-line noninvasive imaging option in the setting of suspected CSF leak with laboratory confirmation that has a reported accuracy of 89% and sensitivity of 87%, which is lower than HRCT [66]. It may be useful as a follow-up study when there is a suspected meningoencephalocele on HRCT (eg, soft-tissue mass with bone erosion) or when preoperative HRCT is unable to pinpoint a single osseous defect in the skull base.

Contrast-enhanced MR cisternography is an uncommon procedure that involves a lumbar puncture for intrathecal administration of approximately 0.1 to 0.5 mL of a gadolinium-based contrast agent (note: this is an off-label use or unapproved indication, which should be discussed with the patient during the informed consent). Its sensitivity for contrast leakage from the subarachnoid space into the sinonasal or tympanomastoid cavities is better than CT cisternography and ranges between 92% and 100% in patients with an active leak versus 70% in patients with an inactive or intermittent leak [64]. Contrast-enhanced MR cisternography is a potential second-line minimally invasive imaging option, when HRCT and CT cisternography are both unable to localize a laboratory-confirmed CSF leak.

There is no relevant literature to support the added value or routine use of contrast-enhanced brain MRI instead of noncontrast brain MRI in the initial imaging evaluation of head trauma with suspected CSF leak (unlike spinal CSF leaks, skull base CSF leaks are not causally associated with intracranial hypotension).

MRI Head with DTI

There is no relevant literature to support the use of DTI in the initial imaging evaluation of suspected CSF leak.

Radiography Skull

There is no relevant literature to support the use of radiographs in the initial imaging evaluation of suspected CSF leak.

Summary of Recommendations

- **Variant 1:** Imaging is usually not appropriate for the initial imaging of patients with acute head trauma that is mild (GCS 13–15) when imaging is not indicated by clinical decision rule (eg, 2008 ACEP Clinical Policy).
- **Variant 2:** Noncontrast head CT is usually appropriate for the initial imaging of patients with acute head trauma that is mild (GCS 13–15) when imaging is indicated by clinical decision rule (eg, 2008 ACEP Clinical Policy).
- **Variant 3:** Noncontrast head CT is usually appropriate for the initial imaging of patients with acute head trauma that is moderate (GCS 9–12) or severe (GCS 3–8) or penetrating. Please refer to Variants 8 and 9 for suspected intracranial arterial or venous injury due to clinical risk factors.
- **Variant 4:** Noncontrast brain MRI or noncontrast head CT may be appropriate for the short-term follow-up imaging of patients with acute head trauma who have unchanged neurologic examination and unremarkable initial imaging, especially when the neurologic examination is abnormal (GCS < 15).
- **Variant 5:** Noncontrast head CT is usually appropriate for the short-term follow-up imaging of patients with acute head trauma who have unchanged neurologic examination and positive finding(s) on initial imaging (eg, subdural hematoma). Some of these patients (eg, neurologic examination is normal and intracranial hemorrhage <10 mL) may not require routine repeat imaging.
- **Variant 6:** Noncontrast head CT is usually appropriate for the short-term follow-up imaging of patients with acute head trauma who have new or progressive neurologic deficit(s).
- **Variant 7:** Noncontrast brain MRI or noncontrast head CT is usually appropriate for the initial imaging of patients with subacute or chronic head trauma and unexplained cognitive or neurologic deficit(s). These procedures are equivalent alternatives (ie, only one initial procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 8:** Head and neck CTA is usually appropriate for patients with head trauma and suspected intracranial arterial injury due to clinical risk factors or positive findings on prior imaging.
- **Variant 9:** Head CTV is usually appropriate for patients with head trauma and suspected intracranial venous injury due to clinical risk factors or positive findings on prior imaging.
- **Variant 10:** Noncontrast head CT, noncontrast maxillofacial CT, and noncontrast temporal bone CT are usually appropriate for the initial imaging of patients with head trauma and suspected CSF leak. These procedures can be complementary or concurrent depending on the clinical setting (eg, maxillofacial CT for CSF rhinorrhea and/or temporal bone CT for CSF otorrhea).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at <https://acsearch.acr.org/list>. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® [Radiation Dose Assessment Introduction](#) document [67].

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
○	0 mSv	0 mSv
☼	<0.1 mSv	<0.03 mSv
☼☼	0.1-1 mSv	0.03-0.3 mSv
☼☼☼	1-10 mSv	0.3-3 mSv
☼☼☼☼	10-30 mSv	3-10 mSv
☼☼☼☼☼	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

References

- Centers for Disease Control and Prevention, National Center for Injury Prevention and Control. TBI-related Emergency Department (ED) Visits. Available at: <https://www.cdc.gov/traumaticbraininjury/data/tbi-ed-visits.html>. Accessed September 30, 2020.

2. Wintermark M, Sanelli PC, Anzai Y, et al. Imaging evidence and recommendations for traumatic brain injury: conventional neuroimaging techniques. *J Am Coll Radiol* 2015;12:e1-14.
3. Ryan ME, Pruthi S, Desai NK, et al. ACR Appropriateness Criteria® Head Trauma-Child. *J Am Coll Radiol* 2020;17:S125-S37.
4. Smits M, Dippel DW, de Haan GG, et al. External validation of the Canadian CT Head Rule and the New Orleans Criteria for CT scanning in patients with minor head injury. *JAMA* 2005;294:1519-25.
5. Su YS, Schuster JM, Smith DH, Stein SC. Cost-Effectiveness of Biomarker Screening for Traumatic Brain Injury. *J Neurotrauma* 2019;36:2083-91.
6. Tavender EJ, Bosch M, Green S, et al. Quality and consistency of guidelines for the management of mild traumatic brain injury in the emergency department. *Acad Emerg Med* 2011;18:880-9.
7. Holmes MW, Goodacre S, Stevenson MD, Pandor A, Pickering A. The cost-effectiveness of diagnostic management strategies for adults with minor head injury. *Injury* 2012;43:1423-31.
8. Smits M, Dippel DW, Nederkoorn PJ, et al. Minor head injury: CT-based strategies for management--a cost-effectiveness analysis. *Radiology* 2010;254:532-40.
9. Haydel MJ, Preston CA, Mills TJ, Luber S, Blaudeau E, DeBlieux PM. Indications for computed tomography in patients with minor head injury. *N Engl J Med* 2000;343:100-5.
10. Stiell IG, Wells GA, Vandemheen K, et al. The Canadian CT Head Rule for patients with minor head injury. *Lancet* 2001;357:1391-6.
11. Stiell IG, Clement CM, Rowe BH, et al. Comparison of the Canadian CT Head Rule and the New Orleans Criteria in patients with minor head injury. *JAMA* 2005;294:1511-8.
12. Davey K, Saul T, Russel G, Wassermann J, Quaas J. Application of the Canadian Computed Tomography Head Rule to Patients With Minimal Head Injury. *Ann Emerg Med* 2018;72:342-50.
13. *Head Injury: Triage, Assessment, Investigation and Early Management of Head Injury in Infants, Children and Adults*. London: National Collaborating Centre for Acute Care (UK); 2007.
14. Mason SM, Evans R, Kucawski M. Understanding the management of patients with head injury taking warfarin: who should we scan and when? Lessons from the AHEAD study. *Emerg Med J* 2019;36:47-51.
15. Jagoda AS, Bazarian JJ, Bruns JJ, Jr., et al. Clinical policy: neuroimaging and decisionmaking in adult mild traumatic brain injury in the acute setting. *Ann Emerg Med* 2008;52:714-48.
16. Wei SC, Ulmer S, Lev MH, Pomerantz SR, Gonzalez RG, Henson JW. Value of coronal reformations in the CT evaluation of acute head trauma. *AJNR Am J Neuroradiol* 2010;31:334-9.
17. Zacharia TT, Nguyen DT. Subtle pathology detection with multidetector row coronal and sagittal CT reformations in acute head trauma. *Emerg Radiol* 2010;17:97-102.
18. Amyot F, Arciniegas DB, Brazaitis MP, et al. A Review of the Effectiveness of Neuroimaging Modalities for the Detection of Traumatic Brain Injury. *J Neurotrauma* 2015;32:1693-721.
19. Shackford SR, Wald SL, Ross SE, et al. The clinical utility of computed tomographic scanning and neurologic examination in the management of patients with minor head injuries. *J Trauma* 1992;33:385-94.
20. Bruns JJ, Jr., Jagoda AS. Mild traumatic brain injury. *Mt Sinai J Med* 2009;76:129-37.
21. Pons E, Foks KA, Dippel DWJ, Hunink MGM. Impact of guidelines for the management of minor head injury on the utilization and diagnostic yield of CT over two decades, using natural language processing in a large dataset. *Eur Radiol* 2019;29:2632-40.
22. Babl FE, Oakley E, Dalziel SR, et al. Accuracy of Clinician Practice Compared With Three Head Injury Decision Rules in Children: A Prospective Cohort Study. *Ann Emerg Med* 2018;71:703-10.
23. Dalziel K, Cheek JA, Fanning L, et al. A Cost-Effectiveness Analysis Comparing Clinical Decision Rules PECARN, CATCH, and CHALICE With Usual Care for the Management of Pediatric Head Injury. *Ann Emerg Med* 2019;73:429-39.
24. Bertsimas D, Dunn J, Steele DW, Trikalinos TA, Wang Y. Comparison of Machine Learning Optimal Classification Trees With the Pediatric Emergency Care Applied Research Network Head Trauma Decision Rules. *JAMA Pediatr* 2019;173:648-56.
25. Hale AT, Stonko DP, Lim J, Guillaumondegui OD, Shannon CN, Patel MB. Using an artificial neural network to predict traumatic brain injury. *J Neurosurg Pediatr* 2018;23:219-26.
26. Korley FK, Yue JK, Wilson DH, et al. Performance Evaluation of a Multiplex Assay for Simultaneous Detection of Four Clinically Relevant Traumatic Brain Injury Biomarkers. *J Neurotrauma* 2018.
27. Bazarian JJ, Biberthaler P, Welch RD, et al. Serum GFAP and UCH-L1 for prediction of absence of intracranial injuries on head CT (ALERT-TBI): a multicentre observational study. *Lancet Neurol* 2018;17:782-89.

28. Calcagnile O, Uden L, Uden J. Clinical validation of S100B use in management of mild head injury. *BMC Emerg Med* 2012;12:13.
29. Linsenmaier U, Wirth S, Kanz KG, Geyer LL. Imaging minor head injury (MHI) in emergency radiology: MRI highlights additional intracranial findings after measurement of trauma biomarker S-100B in patients with normal CCT. *Br J Radiol* 2016;89:20150827.
30. Vakil MT, Singh AK. A review of penetrating brain trauma: epidemiology, pathophysiology, imaging assessment, complications, and treatment. *Emerg Radiol* 2017;24:301-09.
31. Kido DK, Cox C, Hamill RW, Rothenberg BM, Woolf PD. Traumatic brain injuries: predictive usefulness of CT. *Radiology* 1992;182:777-81.
32. Haacke EM, Duhaime AC, Gean AD, et al. Common data elements in radiologic imaging of traumatic brain injury. *J Magn Reson Imaging* 2010;32:516-43.
33. Zhou B, Ding VY, Li Y, et al. Validation of the NeuroImaging Radiological Interpretation System for Acute Traumatic Brain Injury. *J Comput Assist Tomogr* 2019;43:690-96.
34. Isokuortti H, Luoto TM, Kataja A, et al. Necessity of monitoring after negative head CT in acute head injury. *Injury* 2014;45:1340-4.
35. Chenoweth JA, Gaona SD, Faul M, Holmes JF, Nishijima DK, Sacramento County Prehospital Research C. Incidence of Delayed Intracranial Hemorrhage in Older Patients After Blunt Head Trauma. *JAMA Surg* 2018;153:570-75.
36. Fiser SM, Johnson SB, Fortune JB. Resource utilization in traumatic brain injury: the role of magnetic resonance imaging. *Am Surg* 1998;64:1088-93.
37. Manolakaki D, Velmahos GC, Spaniolas K, de Moya M, Alam HB. Early magnetic resonance imaging is unnecessary in patients with traumatic brain injury. *J Trauma* 2009;66:1008-12; discussion 12-4.
38. Yuh EL, Mukherjee P, Lingsma HF, et al. Magnetic resonance imaging improves 3-month outcome prediction in mild traumatic brain injury. *Ann Neurol* 2013;73:224-35.
39. Yue JK, Yuh EL, Korley FK, et al. Association between plasma GFAP concentrations and MRI abnormalities in patients with CT-negative traumatic brain injury in the TRACK-TBI cohort: a prospective multicentre study. *Lancet Neurol* 2019;18:953-61.
40. Reljic T, Mahony H, Djulbegovic B, et al. Value of repeat head computed tomography after traumatic brain injury: systematic review and meta-analysis. *J Neurotrauma* 2014;31:78-98.
41. Joseph B, Sadoun M, Aziz H, et al. Repeat head computed tomography in anticoagulated traumatic brain injury patients: still warranted. *Am Surg* 2014;80:43-7.
42. Washington CW, Grubb RL, Jr. Are routine repeat imaging and intensive care unit admission necessary in mild traumatic brain injury? *J Neurosurg* 2012;116:549-57.
43. Salmela MB, Mortazavi S, Jagadeesan BD, et al. ACR Appropriateness Criteria® Cerebrovascular Disease. *J Am Coll Radiol* 2017;14:S34-S61.
44. Peskind ER, Petrie EC, Cross DJ, et al. Cerebrocerebellar hypometabolism associated with repetitive blast exposure mild traumatic brain injury in 12 Iraq war Veterans with persistent post-concussive symptoms. *Neuroimage* 2011;54 Suppl 1:S76-82.
45. Wintermark M, Sanelli PC, Anzai Y, Tsiouris AJ, Whitlow CT, American College of Radiology Head Injury Institute. Imaging evidence and recommendations for traumatic brain injury: advanced neuro- and neurovascular imaging techniques. *AJNR Am J Neuroradiol* 2015;36:E1-E11.
46. Dhandapani S, Sharma A, Sharma K, Das L. Comparative evaluation of MRS and SPECT in prognostication of patients with mild to moderate head injury. *J Clin Neurosci* 2014;21:745-50.
47. Jantzen KJ. Functional magnetic resonance imaging of mild traumatic brain injury. *J Head Trauma Rehabil* 2010;25:256-66.
48. Palacios EM, Yuh EL, Chang YS, et al. Resting-State Functional Connectivity Alterations Associated with Six-Month Outcomes in Mild Traumatic Brain Injury. *J Neurotrauma* 2017;34:1546-57.
49. Wooten DW, Ortiz-Teran L, Zubcevik N, et al. Multi-Modal Signatures of Tau Pathology, Neuronal Fiber Integrity, and Functional Connectivity in Traumatic Brain Injury. *J Neurotrauma* 2019;36:3233-43.
50. Wang X, Wei XE, Li MH, et al. Microbleeds on susceptibility-weighted MRI in depressive and non-depressive patients after mild traumatic brain injury. *Neurol Sci* 2014;35:1533-9.
51. Skandsen T, Kvistad KA, Solheim O, Strand IH, Folvik M, Vik A. Prevalence and impact of diffuse axonal injury in patients with moderate and severe head injury: a cohort study of early magnetic resonance imaging findings and 1-year outcome. *J Neurosurg* 2010;113:556-63.

52. Kampfl A, Schmutzhard E, Franz G, et al. Prediction of recovery from post-traumatic vegetative state with cerebral magnetic-resonance imaging. *Lancet* 1998;351:1763-7.
53. Douglas DB, Muldermans JL, Wintermark M. Neuroimaging of brain trauma. *Curr Opin Neurol* 2018;31:362-70.
54. Mayer AR, Ling J, Mannell MV, et al. A prospective diffusion tensor imaging study in mild traumatic brain injury. *Neurology* 2010;74:643-50.
55. Strauss SB, Kim N, Branch CA, et al. Bidirectional Changes in Anisotropy Are Associated with Outcomes in Mild Traumatic Brain Injury. *AJNR Am J Neuroradiol* 2016;37:1983-91.
56. Bromberg WJ, Collier BC, Diebel LN, et al. Blunt cerebrovascular injury practice management guidelines: the Eastern Association for the Surgery of Trauma. *J Trauma* 2010;68:471-7.
57. George E, Khandelwal A, Potter C, et al. Blunt traumatic vascular injuries of the head and neck in the ED. *Emerg Radiol* 2019;26:75-85.
58. Baugnon KL, Hudgins PA. Skull base fractures and their complications. *Neuroimaging Clin N Am* 2014;24:439-65, vii-viii.
59. Schroeder JW, Ptak T, Corey AS, et al. ACR Appropriateness Criteria® Penetrating Neck Injury. *J Am Coll Radiol* 2017;14:S500-S05.
60. Eastman AL, Chason DP, Perez CL, McAnulty AL, Minei JP. Computed tomographic angiography for the diagnosis of blunt cervical vascular injury: is it ready for primetime? *J Trauma* 2006;60:925-9; discussion 29.
61. Slasky SE, Rivaud Y, Suberlak M, et al. Venous Sinus Thrombosis in Blunt Trauma: Incidence and Risk Factors. *J Comput Assist Tomogr* 2017;41:891-97.
62. Delgado Almandoz JE, Kelly HR, Schaefer PW, Lev MH, Gonzalez RG, Romero JM. Prevalence of traumatic dural venous sinus thrombosis in high-risk acute blunt head trauma patients evaluated with multidetector CT venography. *Radiology* 2010;255:570-7.
63. Oh JW, Kim SH, Whang K. Traumatic Cerebrospinal Fluid Leak: Diagnosis and Management. *Korean J Neurotrauma* 2017;13:63-67.
64. Hiremath SB, Gautam AA, Sasindran V, Therakathu J, Benjamin G. Cerebrospinal fluid rhinorrhea and otorrhea: A multimodality imaging approach. *Diagn Interv Imaging* 2019;100:3-15.
65. Stone JA, Castillo M, Neelon B, Mukherji SK. Evaluation of CSF leaks: high-resolution CT compared with contrast-enhanced CT and radionuclide cisternography. *AJNR Am J Neuroradiol* 1999;20:706-12.
66. Zapalac JS, Marple BF, Schwade ND. Skull base cerebrospinal fluid fistulas: a comprehensive diagnostic algorithm. *Otolaryngol Head Neck Surg* 2002;126:669-76.
67. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: <https://www.acr.org/-/media/ACR/Files/Appropriateness-Criteria/RadiationDoseAssessmentIntro.pdf>. Accessed September 30, 2020.

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.