American College of Radiology
ACR Appropriateness Criteria®
Seizures and Epilepsy

Variant: 1 New-onset seizure. Unrelated to trauma. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
MRI head without IV contrast	Usually Appropriate	O
CT head without IV contrast	Usually Appropriate	☢☢☢
MRI head without and with IV contrast	May Be Appropriate	O
MEG	Usually Not Appropriate	O
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	O
CT head with IV contrast	Usually Not Appropriate	☢☢☢
CT head without and with IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/CT brain	Usually Not Appropriate	☢☢☢
SPECT or SPECT/CT brain perfusion ictal and interictal	Usually Not Appropriate	☢☢☢

Variant: 2 New-onset seizure. History of trauma. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CT head without IV contrast	Usually Appropriate	☢☢☢
MRI head without and with IV contrast	May Be Appropriate	O
MRI head without IV contrast	May Be Appropriate	O
MEG	Usually Not Appropriate	O
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	O
CT head with IV contrast	Usually Not Appropriate	☢☢☢
CT head without and with IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/CT brain	Usually Not Appropriate	☢☢☢
SPECT or SPECT/CT brain perfusion ictal and interictal	Usually Not Appropriate	☢☢☢

Variant: 3 Known seizure disorder. Unchanged seizure semiology.

Procedure	Appropriateness Category	Relative Radiation Level
MRI head without and with IV contrast	May Be Appropriate	O
MRI head without IV contrast	May Be Appropriate (Disagreement)	O
CT head without IV contrast	May Be Appropriate	☢☢☢
FDG-PET/CT brain	May Be Appropriate (Disagreement)	☢☢☢
MEG	Usually Not Appropriate	O
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	O
CT head with IV contrast	Usually Not Appropriate	☢☢☢
CT head without and with IV contrast	Usually Not Appropriate	☢☢☢
SPECT or SPECT/CT brain perfusion ictal and interictal	Usually Not Appropriate	☢☢☢

Variant: 4 Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.

Procedure	Appropriateness Category	Relative Radiation Level

MRI head without and with IV contrast	Usually Appropriate	O
MRI head without IV contrast	Usually Appropriate	O
CT head without IV contrast	Usually Appropriate	☢☢☢
FDG-PET/CT brain	May Be Appropriate	☢☢☢
MEG	Usually Not Appropriate	O
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	O
CT head with IV contrast	Usually Not Appropriate	☢☢☢
CT head without and with IV contrast	Usually Not Appropriate	☢☢☢
SPECT or SPECT/CT brain perfusion ictal and interictal	Usually Not Appropriate	☢☢☢

Variant: 5 Known seizure disorder. History of tumor.

Procedure	Appropriateness Category	Relative Radiation Level
MRI head without and with IV contrast	Usually Appropriate	O
MRI head without IV contrast	Usually Appropriate	O
CT head without and with IV contrast	May Be Appropriate (Disagreement)	☢☢☢
CT head without IV contrast	May Be Appropriate	☢☢☢
FDG-PET/CT brain	May Be Appropriate (Disagreement)	☢☢☢
MEG	Usually Not Appropriate	O
MRI functional (fMRI) head without IV contrast	Usually Not Appropriate	O
CT head with IV contrast	Usually Not Appropriate	☢☢☢
SPECT or SPECT/CT brain perfusion ictal and interictal	Usually Not Appropriate	☢☢☢

Variant: 6 Known seizure disorder. Surgical candidate or surgical planning.

Procedure	Appropriateness Category	Relative Radiation Level
MRI head without and with IV contrast	Usually Appropriate	O
MRI head without IV contrast	Usually Appropriate	O
FDG-PET/CT brain	Usually Appropriate	☢☢☢
MEG	May Be Appropriate	O
MRI functional (fMRI) head without IV contrast	May Be Appropriate	O
CT head with IV contrast	May Be Appropriate	☢☢☢
CT head without IV contrast	May Be Appropriate	☢☢☢
SPECT or SPECT/CT brain perfusion ictal and interictal	May Be Appropriate	☢☢☢
CT head without and with IV contrast	Usually Not Appropriate	☢☢☢

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Summary of Literature Review

Introduction/Background

A seizure is defined as a transient occurrence of signs and/or symptoms due to abnormal excessive or synchronous neuronal activity in the brain [1]. The International League Against Epilepsy (ILAE) defines epilepsy as having 1) at least two unprovoked seizures occurring more than 24 hours apart, 2) one unprovoked seizure and a probability of further seizures similar to the general recurrence risk after two unprovoked seizures, occurring over the next 10 years, or 3) diagnosis of an epilepsy syndrome.

Active epilepsy—defined as someone who has history of doctor-diagnosed epilepsy or seizure disorder and is currently taking medication for control or has had one or more seizures in the past year—affects 1.2% of the United States population, corresponding to approximately 3.4 million people [2] and approximately 50 million people worldwide [3]. It is estimated that about 10% of the population experiences at least one epileptic seizure during their lifetime [3]. Despite extensive research, the basic mechanism of epileptic seizures as of yet has not been fully elucidated, and as such, the classification of seizures is operational and not based on fundamental mechanisms [1].

The classification of seizures by the ILAE was last revised in 2017 [4]. The classification is important because etiologic diagnosis, appropriate treatment, and accurate prognostication all depend on the correct identification of seizures and epilepsy. In addition, an important goal of the Task Force on Classification of Status Epilepticus [5] was to devise a classification system that would be useful for the purposes of communication, whether it be for teaching, research, or patient care. Seizures are classified as focal onset, generalized onset, or unknown onset [4]. Focal seizures are those arising within networks of a single cerebral hemisphere and may remain localized or subsequently become more widely distributed [4]. Focal seizures can be further characterized by having motor onset or nonmotor onset symptoms and can also be characterized by being aware or having impaired awareness [4]. Generalized seizures rapidly affect both hemispheres as well as both sides of the body, even when caused by a "focal" lesion. Generalized seizures are further subdivided into tonic-clonic, other motor, or nonmotor (absence) [4]. Certain types of seizure disorders are likely to be associated with structural brain lesions, including tumors, infection, infarction, traumatic brain injury (TBI), vascular malformations, developmental abnormalities, and seizure-associated brain pathology [6]. Furthermore, seizures related to trauma can be subdivided into immediate and late seizures, with immediate seizures thought to be secondary to the force of the injury itself, and late seizures representing permanent changes in the brain, implying true epilepsy [7]. Hence, knowledge of seizure types helps to determine whether neuroimaging is clinically indicated and what type of study is appropriate.

Special Imaging Considerations

In addition to the known benefits of using fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET for the localization of epileptogenic foci, there are known alterations of neurotransmitters and receptors in epilepsy [8]. Gamma aminobutyric acid is an inhibitory neurotransmitter known to be important in the regulation of epileptic activity and is evaluated using 11C-flumazenil [9]. Opioids can reduce the spread of electrical activity, can have an anticonvulsant effect [10], and can be evaluated with several tracers including 11C-carfentanil. Serotonin can also have an anticonvulsant effect and can be evaluated with different tracers including 18F-MPPF [11]. Changes in dopamine receptors have also been associated with various forms of epilepsy [12] and can be evaluated with 18F-fallypride.

Alpha-[11C]methyl-L-tryptophan is a tryptophan analogue and has been shown to be a useful radiotracer in assessing seizures in patients with tuberous sclerosis, temporal lobe epilepsy (TLE), and cortical dysplasia [13].

Diffusion tensor imaging that utilizes data from directionally encoded diffusion-weighted imaging has also been utilized to assess disruption in white matter tracks following trauma; however, its use in this capacity remains investigational [14].

Discussion of Procedures by Variant

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.
A. CT Head

Noncontrast CT has a central role in the emergent situation of acute seizures as it can accurately and rapidly identify structural pathology, such as intracranial hemorrhage, stroke, vascular malformation, hydrocephalus, and tumors, which may require either supportive treatment or neurosurgical care [15,16]. CT is also sensitive in detection of calcified and bony lesions. It is less sensitive in detection of lesions in the orbitofrontal and medial temporal regions, and also in the detection of small cortical lesions [17]. Contrast-enhanced CT can be considered to better define tumors and evaluate for infection; however, MRI is a better option in this situation. Overall success in detecting lesions in focal epilepsies with CT is much lower than with MRI at only 30% [17]. Importantly, the ILAE recommendation for neuroimaging in the acute situation is for CT if there is a need to have ready access to the patient during scanning. [15].

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.
B. FDG-PET/CT Brain

There is no relevant literature regarding the use of FDG-PET/CT as an initial imaging study in the evaluation of new-onset seizure unrelated to trauma.

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.
C. MEG

There is no relevant literature regarding the use of magnetoencephalography (MEG) as an initial imaging study in the evaluation of new-onset seizure unrelated to trauma.

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.
D. MRI Functional (fMRI) Head

There is no relevant literature regarding the use of functional MRI (fMRI) as an initial imaging study in the evaluation of new-onset seizure unrelated to trauma.

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.
E. MRI Head

MRI serves multiple purposes for new-onset seizures, including identifying and characterizing focal causative lesions as well as assessing progression. MRI is an important tool for determining prognosis as well as a treatment strategy. In the nonemergent situation, MRI is the imaging study of choice when indicated [15-18]. In an emergent setting, CT may be quicker as it does not require additional safety screening and has decreased requirements for extended patient monitoring [16]. In general, all patients with epilepsy should undergo an MRI. Some forms of epilepsy, however, have a low yield of structural lesions on MRI, such as those with typical forms of primary

generalized epilepsy, benign focal epilepsies of childhood with characteristic clinical and electroencephalography (EEG) features, and early onset childhood epilepsy with occipital spikes and adequate response to antiepileptic drugs, so in these cases, some authors do not advocate utilizing MRI [17].

Priority for obtaining imaging for those patients who have focal findings on neurologic examination, persistent headache, recent history of head trauma [17], and abnormalities on EEG are correlated to have a high probability of finding structural abnormalities [16]. As hippocampal sclerosis is the most common cause of temporal lobe seizures [16], protocols should include coronal T1-weighted (≤3 mm) imaging perpendicular to the long axis of the hippocampus, high-resolution volume (3-D) acquisition (T1-weighted, gradient echo [GRE]) with 1-mm isotropic voxels, and coronal T2 and coronal and axial (or 3-D) fluid-attenuated inversion recovery sequences to assess for hippocampal signal abnormality, atrophy, and loss of internal structure [17]. The high-resolution volume (3-D) T1-weighted GRE and 3-D fluid-attenuated inversion recovery sequences are also useful to assess for malformations of cortical development such as focal cortical dysplasia and focal polymicrogyria potentially amenable to surgery as well as lissencephaly, pachygyria, and polymicrogyria, which are unlikely to be amenable to surgery [17]. The use of intravenous (IV) contrast is not routinely necessary; however, it is useful when images without IV contrast are not sufficient or if neoplasm or inflammatory condition is suspected [17].

Variant 1: New-onset seizure. Unrelated to trauma. Initial imaging.
F. HMPAO SPECT or SPECT/CT Brain Ictal and Interictal

There is no relevant literature regarding the use of single-photon emission computed tomography (SPECT) or SPECT/CT as an initial imaging study in the evaluation of new-onset seizure unrelated to trauma.

Variant 2: New-onset seizure. History of trauma. Initial imaging.

Variant 2: New-onset seizure. History of trauma. Initial imaging.
A. CT Head

Noncontrast CT has a central role in the emergent situation of immediate post-traumatic seizures as it can accurately and rapidly identify pathology related to trauma, such as acute intracranial hemorrhages, and other pathology that may be the cause of the apparent traumatic condition, including stroke, cerebral edema, vascular malformation, hydrocephalus, skull fractures, foreign bodies, and tumors [14-16,19]. CT can quickly identify mass effect, such as tonsillar herniation or midline shift, that requires urgent intervention. CT can be performed quickly and without the need for screening for ferromagnetic materials. However, note that the overall success of CT in detecting focal lesions in epilepsy is low at approximately 30% [17]. There is no role for contrast-enhanced CT in the setting of trauma.

Variant 2: New-onset seizure. History of trauma. Initial imaging.
B. FDG-PET/CT Brain

There is no relevant literature regarding the use of FDG-PET/CT as an initial imaging study in the evaluation of new-onset seizure with history of trauma. Recent literature has described increases in amyloid levels in TBI using PET amyloid; however, the use of this modality remains investigational [20].

Variant 2: New-onset seizure. History of trauma. Initial imaging.
C. MEG

There is no relevant literature regarding the use of MEG as an initial imaging study in the evaluation of new-onset seizure with history of trauma.

Variant 2: New-onset seizure. History of trauma. Initial imaging.
D. MRI Functional (fMRI) Head

There is no relevant literature regarding the use of fMRI as an initial imaging study in the evaluation of new-onset seizure with history of trauma. There is evidence that TBI can be associated with both increases and decreases in cerebral blood flow during the acute stages of injury; however, the use of this modality remains investigational [20].

Variant 2: New-onset seizure. History of trauma. Initial imaging.
E. MRI Head

MRI is effective in assessing for traumatic pathology; however, because of the longer duration of the examination compared with CT and the additional evaluation necessary for safety clearance, MRI has a secondary role in the acute traumatic setting [15,16,18]. Nevertheless, MRI is recommended in patients with acute TBI if noncontrast CT is normal and there are persistent unexplained neurologic findings [19]. Compared with CT, MRI is more sensitive in assessment of smaller hemorrhages related to contusions and microhemorrhages related to diffuse axonal injury due to the use of GRE, with susceptibility-weighted imaging, which is even more sensitive. In addition, diffusion-weighted images are sensitive in detection of nonhemorrhagic diffuse axonal injury lesions [21]. The identification of microhemorrhages is important as it may predict injury severity and outcome; however, this is controversial [19,22]. In the setting of seizures with history of trauma, MRI can be considered if there are focal neurologic findings [17] as MRI is effective in the assessment of chronic blood deposition, gliosis, and encephalomacia. There is no indication for IV contrast in the setting of TBI; however, subacute contusions can enhance because of disruption of the blood-brain barrier [19].

Variant 2: New-onset seizure. History of trauma. Initial imaging.
F. HMPAO SPECT or SPECT/CT Brain Ictal and Interictal

There is no relevant literature regarding the use of SPECT or SPECT/CT as an initial imaging study in the evaluation of new-onset seizure with history of trauma.

Variant 3: Known seizure disorder. Unchanged seizure semiology.

Variant 3: Known seizure disorder. Unchanged seizure semiology.
A. CT Head

CT is less sensitive to focal pathologies when compared with MRI and is less specific in its characterization of findings, limiting its utility in the setting of known seizures that are unchanged [16,23]. However, CT can be helpful for characterizing structural findings in seizure etiologies that contain dystrophic calcifications, such as with oligodendrogliomas and tuberous sclerosis. [23].

Variant 3: Known seizure disorder. Unchanged seizure semiology.
B. FDG-PET/CT Brain

FDG-PET is well established as a modality to localize an epileptogenic focus and can provide additional information regarding the functional status of the uninvolved brain. Reported sensitivities of PET in the assessment of TLE ranges from 87% to 90% and extra-TLE ranges from 38% to 55% [24-27]. FDG when combined with perfusion ictal-interictal SPECT and subtraction ictal SPECT co-registered to MRI demonstrated improved detection of the epileptogenic zone [28]. A major limitation of interictal FDG-PET is that it cannot precisely identify the surgical margin because the area of hypometabolism often extends beyond the epileptogenic zone [8]. FDG-PET allows for higher-resolution and better-quality images compared with SPECT [29]. In cases of unchanged seizure semiology yet are refractive to medical therapy, FDG-PET can identify lesions missed on CT or MRI [30].

Variant 3: Known seizure disorder. Unchanged seizure semiology.
C. MEG

There is no relevant literature regarding the use of MEG in the evaluation of known seizure disorder with unchanged seizure semiology.

Variant 3: Known seizure disorder. Unchanged seizure semiology.
D. MRI Functional (fMRI) Head

There is no relevant literature regarding the use of fMRI in the evaluation of known seizure disorder with unchanged seizure semiology.

Variant 3: Known seizure disorder. Unchanged seizure semiology.
E. MRI Head

The excellent gray-white matter differentiation and multiplanar imaging capability of MRI are characteristics that contribute to greater sensitivity and accuracy of MRI compared with CT [8,17,31]. Low-grade gliomas have been identified on MRI in patients with a history of epilepsy for >20 years [17], and so there is use in assessment of seizures that are chronic and longstanding to assess for changes in structural abnormalities. Some authors suggest that priority for imaging with MRI should be given to patients who have focal findings on a neurologic examination [17]. Patients being evaluated for seizures with normal MRI scans on a 1.5T scanner may have findings identified on repeat MRI imaging on 3.0T scanners, even with unchanged seizure semiology [32,33].

Variant 3: Known seizure disorder. Unchanged seizure semiology.
F. HMPAO SPECT or SPECT/CT Brain Ictal and Interictal

There is no relevant literature regarding the use of SPECT or SPECT/CT in the evaluation of known seizure disorder with unchanged seizure semiology.

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.
A. CT Head

CT can rapidly assess for intracranial hemorrhage, stroke, vascular malformation, hydrocephalus, or progression of tumors in the setting of changes in seizure semiology or new neurologic deficit. However, CT has decreased sensitivity and specificity to pathology in the brain with overall less gray-white matter differentiation compared with MRI [16,17,23].

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.
B. FDG-PET/CT Brain

Changes in seizure semiology may be secondary to interval changes in an epileptogenic focus, and as such, FDG-PET may identify these changes and can provide additional information regarding the functional status of the uninvolved brain, including assessment of the functional deficit zone. Reported sensitivities of PET in the assessment of TLE ranges from 87% to 90% and extra-TLE ranges from 38% to 55% [24-27]. FDG when combined with perfusion ictal-interictal SPECT and subtraction ictal SPECT co-registered to MRI demonstrated improved detection of the epileptogenic zone [28]. A major limitation of interictal FDG-PET is that it cannot precisely identify the surgical margin because the area of hypometabolism often extends beyond the epileptogenic zone [8]. FDG-PET allows for higher-resolution and better-quality images compared with SPECT [29]. FDG-PET is an effective problem-solving tool in the workup of seizures in the

setting of a negative MRI scan [30].

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.
C. MEG

There is no relevant literature regarding the use of MEG in the evaluation of known seizure disorder with changes in seizure semiology unless it is in the setting of presurgical planning.

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.
D. MRI Functional (fMRI) Head

There is no relevant literature regarding the use of fMRI in the evaluation of known seizure disorder with changes in seizure semiology unless it is in the setting of presurgical planning.

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.
E. MRI Head

In the setting of interval changes of seizure semiology, MRI is the study of choice to evaluate for new structural lesions [17,34]. MRI is the modality of choice in assessment of the progression of known lesions, and as such is an important tool for prognostic considerations [17], and the use of specific protocols IV contrast considered depending on the underlying etiology. Some authors advocate neuroimaging only if there are focal findings on a neurologic examination [17]. One study, which evaluated repeat MRI in seizure patients, including those with change in seizure semiology, demonstrated a 21% increase of findings, which were not identified in initial MRI scans [32].

Variant 4: Known seizure disorder. Change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline.
F. HMPAO SPECT or SPECT/CT Brain Ictal and Interictal

There is no relevant literature regarding the use of SPECT or SPECT/CT in the evaluation of known seizure disorder with changes in seizure semiology unless it is in the setting of presurgical planning.

Variant 5: Known seizure disorder. History of tumor.

Variant 5: Known seizure disorder. History of tumor.
A. CT Head

CT can assess for interval changes in tumor and associated edema, mass effect, hydrocephalus, and tumor-associated hemorrhage. These features can be assessed without IV contrast, often using secondary signs of underlying mass; however, adding IV contrast adds sensitivity and specificity to directly visualize smaller lesions. Overall, CT has decreased sensitivity and specificity to pathology in the brain with overall less gray-white matter differentiation compared with MRI [16,17,23]. CT is effective in the assessment of tumors that contain dystrophic calcifications, such as oligodendrogliomas and tuberous sclerosis [23]. CT has limited value in assessment of tumor recurrence versus radiation necrosis given the overlap of imaging characteristics whether IV contrast is used or not [35].

Variant 5: Known seizure disorder. History of tumor.
B. FDG-PET/CT Brain

FDG-PET is well established in the literature for the assessment of residual or recurrent tumors following therapy [36]. FDG-PET can also be used to follow low-grade tumors for evidence of degeneration or transformation into a higher-grade malignancy [36]. FDG-PET can differentiate radiation necrosis versus

tumor recurrence with sensitivity of 65% to 81% and specificity of 40% to 94% [36]. More recently, FDG-PET co-registered with MRI may have a higher sensitivity in distinguishing radiation necrosis from tumor recurrence at 86% [37].

Variant 5: Known seizure disorder. History of tumor.
C. MEG

There is no relevant literature regarding the use of MEG in the evaluation of known seizure disorder with history of tumor unless it is in the setting of presurgical planning.

Variant 5: Known seizure disorder. History of tumor.
D. MRI Functional (fMRI) Head

There is no relevant literature regarding the use of fMRI in the evaluation of known seizure disorder with history of tumor unless in the setting of presurgical planning.

Variant 5: Known seizure disorder. History of tumor.
E. MRI Head

MRI of the brain with and without IV contrast is a first-line imaging study in the assessment of residual or recurrent tumors following therapy and is routinely used to monitor malignancy [35,38]. In the setting of stability or resolution, MRI can be used for surveillance; however, in the case of new MRI findings, there can be overlap of imaging characteristics of malignancy versus radiation necrosis [35,36]. Nevertheless, certain characteristics are associated more with recurrent tumor, such as lower apparent diffusion coefficient values compared with radiation necrosis [35]. In addition, the phenomenon of pseudoprogression, a transient period of apparent radiographic deterioration when early delayed radiation effects (<3 months following radiation) can be seen, which can also complicate interpretation of the MRI. Pseudoresponse can also be problematic, with an apparent decrease in contrast enhancement in a tumor due to changes in vascular permeability as opposed to true tumor response also resulting in a complicated interpretation [39]. MR spectroscopy and MR perfusion can be effective adjunct imaging examinations to complement conventional MRI [38].

Variant 5: Known seizure disorder. History of tumor.
F. HMPAO SPECT or SPECT/CT Brain Ictal and Interictal

There is no relevant literature regarding the use of SPECT or SPECT/CT in the evaluation of known seizure disorder with history of tumor unless in the setting of presurgical planning.

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.
A. CT Head

Evaluation of seizures was greatly advanced by the clinical introduction of CT in the early 1970s [40,41] because of its cross-sectional capabilities that were not possible with radiographs. However, CT is outperformed by MRI in having less contrast resolution between gray and white matter differentiation [16], and overall CT is less sensitive to detecting lesions compared with MRI [41,42]. CT is useful in the assessment of calcification pathologies, such as tuberous sclerosis and oligodendrogliomas [23]. CT can be used for stereotactical surgical planning, and high-resolution CT can be used to assess the position of subdural grid or depth electrodes [23], which can be done without IV contrast administration. Noncontrast CT and MRI have been advocated equally for accurate electrode localization [43].

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.
B. FDG-PET/CT Brain

Clinical FDG-PET/CT provides a measure of glucose uptake and thus a measure of metabolism and has been shown to be highly sensitive in the presurgical localization of epileptogenic foci [8]. A seizure focus will typically manifest as a focus of hypometabolism on interictal (between episodes of seizure activity) PET examinations. One study demonstrated that presurgical ipsilateral PET hypometabolism showed predictive value of 86% for good surgical outcomes [44]. Presurgical FDG-PET also provides information regarding the functional deficit zone, the area of the brain that shows abnormal function during the interictal period. FDG-PET can identify focal abnormalities in the setting of a negative anatomic MRI brain scan [16]. Poor seizure outcomes following surgery have been described in the setting of bilateral temporal lobe hypometabolism in TLE [8]. A limitation of FDG-PET is the lack of precision in defining the margins of the epileptogenic zone [8]. Comparison of interictal PET and ictal SPECT demonstrated localization of lesions in 77.7% and 7.3% of patients, respectively [45]. FDG-PET, combined with other localizing modalities, such as perfusion ictal-interictal SPECT and MRI gray matter segmentation, has shown improved abilities to detect and predict the extent of epileptic foci [28]. FDG-PET co-registered with MRI may be an effective adjunctive study as it has been shown that MRI gray matter segmentation co-registered with FDG-PET resulted in higher correspondence to intracranial EEG than without segmentation [46].

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.
C. MEG

MEG records brain electrical activity, which can be localized in 3-D by using detectors and induction coils in a superconducting environment [47]. In contrast to EEG, MEG does not suffer from deterioration of signals due to the skull and scalp [48]. In one study, 85% of patients with concordant and specific MEG findings were seizure-free following surgery, compared with only 37% of individuals with MEG findings that were nonspecific or discordant with the region of resection [49]. One of the largest cases series of MEG utilization in 455 patients demonstrated a 70% sensitivity in detecting epileptic activity [50].

Though there have been significant advances in source localization techniques, MEG is still performed in only a minority of presurgical evaluation of epilepsy, and the clinical value of MEG in surgical epilepsy treatment is less clear compared with MRI [48]. Nevertheless, it can be useful as a complementary modality in assessment of location of seizures in preoperative brain mapping as well as identification of eloquent cortex to determine safe resection margins [51].

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.
D. MRI Functional (fMRI) Head

The utility of fMRI has been well described in the literature in the setting of presurgical evaluation of patients with epilepsy [44,52] and perhaps even more so in the setting of MRI-negative epilepsy [18]. For patients with drug-resistant focal epilepsy, functional neuroimaging techniques, such as FDG-PET, ictal SPECT, or fMRI, may assist in surgical planning, especially in patients with MRI-negative epilepsy, whose prognosis for a seizure-free outcome after surgery is worse than for patients with an epileptogenic lesion on structural MRI. fMRI demonstrated 89% concordance in language lateralization with an intracarotid amobarbital procedure (IAP) with right TLE and 85% for left TLE [53]. The same study also demonstrated 83% concordance with IAP in language lateralization extra-TLE [53], and as such, fMRI can be considered as a replacement for IAP for language lateralization [52]. One study demonstrated that strong left frontal activation was predictive of postresection decline [53], and thus fMRI can be considered for predicting postsurgical language deficits in presurgical evaluation for possible temporal lobectomy [52]. fMRI can be an option to lateralize memory functions with good correlation on one study ($r = 0.31$; $P = .007$) between hippocampal fMRI laterality index and IAP memory laterality index [54]; however, conflicting data showing no correlation were also found in the literature [55]. fMRI using model paradigms is a promising method to

noninvasively predict memory decline [56].

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.
E. MRI Head

MRI demonstrates excellent gray-white matter differentiation and multiplanar imaging capability, characteristics that contribute to greater sensitivity and accuracy of MRI compared with CT [8,31]. As a result, MRI has become the modality of choice for high-resolution structural imaging in epilepsy, with the use of IV contrast dependent on the underlying etiology of the seizures. Dedicated seizure protocols and acquisition on 3T magnets are important considerations to improve lesion detection [31]. MRI is the study of choice in the assessment of structural lesions that are potentially resectable [16]. It can define the epileptogenic zone, that is, the minimum amount of cortex that should be resected to provide seizure-free outcome [16]. It should be noted that 20% to 30% of temporal epilepsy and 20% to 40% of patients with extra-TLE have no clear lesion seen on MRI [17]. Nevertheless, patients are more likely to be seizure-free when focal circumscribed lesions are identified on presurgical MRI compared with those patients who do not have these lesions [57,58]. Noncontrast CT and MRI have been advocated equally for accurate electrode localization [43].

Variant 6: Known seizure disorder. Surgical candidate or surgical planning.
F. HMPAO SPECT or SPECT/CT Brain Ictal and Interictal

SPECT that uses perfusion agents like Tc-99m-HMPAO (hexamethyl-propylamine-oxime) or Tc-99m-neurolite provides an assessment of regional cerebral blood flow rather than brain metabolism. A seizure focus is typically demonstrated as an area of hypoperfusion on interictal examinations and hyperperfusion on ictal examinations [6]. The utility of isolated interictal cerebral perfusion assessment in patients without an anatomic imaging abnormality is limited, with one study finding that of all patients with seizures only 60% of interictal cerebral perfusion imaging was abnormal [59]. However, perfusion SPECT is complementary to structural imaging in presurgical planning. Statistical ictal SPECT co-registered to MRI was noted to identify a hyperperfusion focus in 84% of patients compared with 66% using subtraction ictal SPECT co-registered to MRI for seizure localization before TLE surgery and may be indicated for these cases [43].

Summary of Highlights

riant 1: MRI of the brain without IV contrast is usually appropriate in the assessment of new-onset seizures unrelated to trauma; however, in the emergent situation, a noncontrast CT of the head may be a more appropriate choice.

riant 2: CT head without IV contrast is usually appropriate for the initial imaging of patients with new-onset seizures and a history of trauma in the emergent situation. However, in the nonemergent setting, MRI of the brain is usually appropriate and results in a more comprehensive assessment of TBI.

riant 3: The panel did not agree on recommending FDG-PET/CT brain or MRI head without IV contrast in patients with known seizures and unchanged seizure semiology. There is insufficient medical literature to conclude whether these patients would benefit from these procedures. The use of FDG-PET/CT brain or MRI head without IV contrast in this patient population is controversial but may be appropriate.

riant 4: MRI head without IV contrast or MRI head without and with IV contrast is usually appropriate for the initial imaging of patients with known seizure disorder and a change in seizure semiology or new neurologic deficit or no return to previous neurologic baseline. However, in the emergent situation, CT of the head without IV contrast is also usually appropriate.

riant 5: MRI head without and with IV contrast or MRI head without IV contrast is usually appropriate for the initial imaging of patients with known seizure disorder and a history of tumor. These procedures are

equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). The panel did not agree on recommending CT head without and with IV contrast or FDG-PET/CT brain in patients with known seizure disorder and a history of tumor. There is insufficient medical literature to conclude whether or not these patients would benefit from these procedures. The use of CT head without and with IV contrast or FDG-PET/CT brain in this patient population is controversial but may be appropriate.

ıriant 6: MRI head without and with IV contrast or MRI head without IV contrast is usually appropriate for the initial imaging of surgical patients with known seizure disorder requiring surgical planning. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). FDG-PET/CT brain may be complementary as a functional tool to structural imaging using MRI.

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, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

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.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	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 (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

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Disclaimer

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.

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