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ACR–ASNR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE BRAIN

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the *ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures* (Revised 2008) sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the American Society of Neuroradiology (ASNR), and the Society for Pediatric Radiology (SPR).

Magnetic resonance imaging (MRI) is a proven and well-established imaging modality in the evaluation and assessment of the brain. MRI of the brain is the most sensitive technique available because of its high sensitivity in exploiting inherent contrast differences of tissues as a result of variable magnetic relaxation properties and magnetic susceptibilities. MRI is a rapidly evolving technology, and ongoing technical advancements will continue to improve the diagnosis of brain disorders. This practice parameter outlines the principles for performing high-quality MRI of the brain.

II. INDICATIONS

Indications for MRI of the brain include, but are not limited to:

1. Neoplastic conditions or other mass or mass-like conditions of the brain parenchyma, meninges, or cranium, either primary or secondary [1-8]
2. Vascular
   a. Acute ischemia and infarction [9-15]
   b. Chronic vascular disease [16-19]
   c. Vascular malformations, such as developmental venous anomaly, capillary telangiectasia, cavernous angioma, arteriovenous malformation, arteriovenous fistulas and aneurysm [20-22]
   d. Arterial or venous/dural venous sinus abnormalities, including congenital and acquired disorders and thrombosis [23,24]
   e. Additionally, MR angiography/arteriography (MRA) and MR venography (MRV) may provide more detailed noninvasive vascular information. (See the ACR–ASNR–SNIS–SPR Practice Parameter for the Performance of Cervicocerebral Magnetic Resonance Angiography [MRA] [25].)
3. Congenital disorders and anatomical abnormalities, including the evaluation of brain maturation [26-29]
4. Congenital or acquired neurodegenerative disorders [16,30-34]
5. Congenital or acquired hydrocephalus [35,36]
6. Metabolic, nutritional, and dysmyelinating disorders [37-39]
7. Trauma [40-43]
   a. Certain benefits over computed tomography (CT), such as detection of diffuse axonal injury
   b. Assessment of unexplained posttraumatic neurological deficits
   c. Posttraumatic brain injury
   d. Nonaccidental trauma
8. Hemorrhage
   a. Certain benefits over CT, such as determining the age of hemorrhage, evaluation of chronic hemorrhage, and detection of microhemorrhages [44,45]
   b. MRI with gradient echo/susceptibility weighted imaging has sensitivity comparable to or higher than CT in specific settings, such as detection of hemorrhagic transformation in the rapid evaluation of acute ischemic stroke [46].
9. Inflammatory and autoimmune disorders, including disorders of demyelination [47-50]
10. Infectious disorders: encephalitis, meningitis, empyema, abscess [51-53]
11. Endocrine disorders [54,55]
    a. High-resolution assessment of hypothalamic/pituitary axis
12. Evaluation of the cranial nerve anatomy or pathology [56]
13. Epilepsy and movement disorders [33,57-61]
14. Organic psychiatric disorders [62]
15. Follow-up of treatment, including iatrogenic sequelae such as radiation necrosis [63-66]
16. Image guidance for treatment planning, surgery, or interventional [67-71] (see the ACR–ASNR Practice Parameter for the Performance of Non-Breast MRI-Guided Procedures [72])
17. Evaluation of headaches with associated neurological findings or suspected brain structural abnormality [73,74]

18. Elevated or decreased intracranial pressure
19. For further characterization of abnormalities (or suspected abnormalities) detected on other imaging tests (eg, CT or sonography)

Extended indications for brain MRI include techniques that provide additional real-time, dynamic, or quantitative information that assists in therapeutic guidance or clinical decision making.

1. Cerebral spinal fluid (CSF) flow, blood flow, and brain perfusion [13,35,36,75-79]
2. Spectroscopy [10,38,76,80-83]
3. Functional imaging [67,84-87]
4. Volumetry [16,31,88]
5. Morphometry [61,62,89]
6. Diffusion tensor imaging/diffusion kurtosis/tractography [29,90-95]
7. Combination with positron emission tomography [96-98]
8. Radiogenomics [99]
9. Radiomics [100]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [101].

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI), the ACR Manual on Contrast Media, and the ACR Guidance Document on MR Safe Practices [101].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis.

V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures [102-105]. The physician must be familiar with potential hazards associated with MRI, including conditional, legacy, or unsafe implants; foreign bodies; and potential adverse reactions to contrast media. The physician should be familiar with relevant ancillary studies that the patient may have undergone. (See the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [106].) The physician performing MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The clinical request form should be initiated by the referring physician or any appropriate allied health care professional acting within his or her scope of practice. It should contain pertinent information regarding the clinical indication for the procedure.

The written or electronic request for MRI of the brain should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35, adopted in 2006 – revised in 2016, Resolution 12-b)

The supervising physician must also understand the pulse sequences to be used and their effect on the appearance of the images, including the potential generation of image artifacts. Standard imaging protocols may be established and varied on a case-by-case basis when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination should supervise patient selection and preparation and be available in person or by phone for consultation. Patients and all other persons entering the MRI safety zone (employees and nonemployees) must be screened and interviewed (when their condition permits) prior to the examination to exclude individuals who may be at risk by exposure to the MRI environment.

Certain indications require administration of intravenous (IV) contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast utilization. Patients receiving IV gadolinium chelates should be evaluated for risk factors or contraindications to IV MRI contrast media, especially the potential risk of nephrogenic systemic fibrosis (NSF) [107]. (See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media, the ACR Manual on Contrast Media, the ACR Guidance Document on MR Safe Practices, and the ACR website.)

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Sedation of pediatric patients (and in some cases nonsedated patients) may benefit from child life support staff. Administration of anxiolytics or moderate sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [108].

B. Facility Requirements

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

C. Examination Technique

MRI examination of the brain can be performed on closed and open MRI systems of various field strengths using a local surface coil (head coil) and a wide array of pulse sequences [7,10,12,26,28,32,33,36,49,50,53,54,76,85,86,109-131]. This is a rapidly evolving field, and the appropriate pulse sequences and plane of imaging must be individualized and tailored to the clinical question at hand under the supervision of the MRI physician. A typical imaging protocol for MRI of the brain includes a sagittal T1-weighted (or a T1-weighted volumetric acquisition), axial T2-weighted and axial T2-weighted fluid-attenuated inversion recovery (FLAIR), and fast spin-echo or turbo-spin-echo (or equivalent) sequences. If T2-weighted FLAIR is not used in children under the age of 2 years, proton density–weighted sequences may be performed. Under certain clinical circumstances (uncooperative or pediatric patients), very rapid acquisitions, such as echo planar imaging or single-shot fast spin-echo imaging, can be performed to obtain T2 information. Diffusion imaging is essential for many indications, particularly in the assessment of infarction, abscess, epidermoid lesion, active demyelination, and hypercellular neoplasm. Inclusion of gradient recall echo (GRE) or susceptibility weighted imaging (SWI) markedly improves the detection/assessment of calcifications, microhemorrhages, and intravascular thrombosis. The entire brain should be covered in multiple imaging planes. (See the Clinical Image Quality Guide section of the ACR MR Accreditation Program Testing Instructions.)

The recovery time (TR) and echo time (TE) required to optimize image quality depends on the field strength of the magnet. These parameters must therefore be adjusted for image optimization. For example, lower-field-strength magnets may require lower TRs, whereas higher-field-strength magnets may require longer TRs for image optimization.

Slice thickness, spatial resolution, signal-to-noise ratio, acquisition time, and contrast are all interrelated. To optimize spatial resolution, imaging of the brain should be performed with a slice thickness of no greater than 5 mm

and an interslice gap of no greater than 2.5 mm. Thinner slices (less than 5 mm) and smaller interslice gaps (less than 2.5 mm) or interleaved images without a slice gap provide superior image detail if clinical circumstances warrant.

Gadolinium chelates may be administered by IV when there is suspicion of breakdown of the blood-brain barrier [6,132-135]. Recently, controversy has arisen regarding reports of gadolinium deposition in tissues, and questions have been raised about the safety of these chelates [136,137]. The clinical significance of tissue deposition remains unknown, but most experts believe that gadolinium chelates are safe. However, any contrast agent should only be administered under the supervision of a physician when clinically indicated [136]. Alternatives to gadolinium chelates might also be contemplated in the appropriate setting [138]. Postcontrast images, when indicated, should be obtained in at least one plane but preferably in two or more perpendicular planes. (Alternatively, one postcontrast series could be obtained using a T1-weighted volumetric acquisition.) Postcontrast FLAIR images may add value in the assessment of meningeal disease [139]. (Please see the ACR Manual on Contrast Media [140].)

With the advent of high-performance gradient coil assemblies, amplifiers, and other technical enhancements, advanced imaging applications are also an option with the appropriate hardware and software. Improvements in the receiver and data acquisition systems also allow for more rapid imaging. Higher-field-strength MR (eg, 3T and 7T) may provide added utility in some clinical situations [57,141-147].

While a detailed discussion of all the evolving advanced imaging techniques is beyond the scope of this practice parameter, it should be noted that rapid pulse sequences and other advanced imaging techniques may provide added value for MRI of the brain [148]. These can include, but are not limited to, echo planar imaging [149], parallel imaging [32,110,119,150,151], diffusion-weighted imaging [50,109,112,152-158], diffusion-tensor imaging [28,29,91,92,94,110,123,156,159-162], rapid gradient echo pulse sequences (capable of providing T1 or T2 information and enabling 3-D acquisitions) [163], SWI [164-170], functional imaging [159,171-186], perfusion imaging [187-194], volumetric [36,195-199], morphometric [200-210], magnetic source imaging [211], and other quantitative applications [156,212-222].

Certain clinical circumstances may warrant the use of proton MR spectroscopy [80-82,223-229] as an adjunct to routine MR brain imaging. (See the ACR–ASNR–SPR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Spectroscopy of the Central Nervous System [230].) Additional techniques that may be useful under the appropriate clinical circumstances include 3-D imaging techniques [231-234], neuronavigation, and intraoperative MRI [68,115,124,235], magnetization transfer imaging [236-240], CSF flow study using phase-contrast pulse sequences [241], and variations of single-shot fast spin-echo or turbo spin-echo imaging.

It is the responsibility of the supervising physician to determine whether additional pulse sequences or nonconventional pulse sequences and imaging techniques confer added benefit for the diagnosis and management of the patient. Generally, MRI examination of the brain should be performed within parameters approved by the Food and Drug Administration (FDA). Examinations that use techniques not approved by the FDA can be considered when they are judged to be medically appropriate.

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [106].

VII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels [242,243].

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

Specific policies and procedures related to MRI safety should be in place with documentation that is updated annually and compiled under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with the MRI examination of the patient as well as to others in the immediate area. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination.

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [244].

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