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

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The American College of Radiology will periodically define new practice parameters and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice parameters and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

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.

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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 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 is the most comprehensive imaging technique available to evaluate the brain *in vivo* because of its high sensitivity in exploiting inherent contrast differences of tissues as a result of variable magnetic relaxation properties and magnetic susceptibilities. It provides detailed anatomic information on congenital or acquired conditions involving the cranium, brain parenchyma, meninges, and subarachnoid spaces, and is often used to further characterize abnormalities (or suspected abnormalities) detected on other imaging tests (eg, CT or sonography). Brain MRI is frequently employed sequentially to monitor progression of disease and effects of treatment. 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 AND CONTRAINDICATIONS

A. Indications

Primary indications for MRI of the brain include the following:

1. Headache with neurological findings or suspected brain structural abnormality (see ACR Appropriateness Criteria® Headache [3])
2. Acute mental status change, delirium, or new onset psychosis (see ACR Appropriateness Criteria® Acute Mental Status Change, Delirium, and New Onset Psychosis [4])
3. Head trauma (diffuse axonal injury, unexplained neurologic deficit, nonaccidental trauma, traumatic brain injury) (see ACR Appropriateness Criteria® Head Trauma [5])
4. Cerebrovascular disease: acute or chronic ischemia or infarction, arterial or venous (see ACR Appropriateness Criteria® Cerebrovascular Disease [6])
5. Cerebrovascular disease: aneurysm, vascular malformation, and subarachnoid hemorrhage (see ACR Appropriateness Criteria® Cerebrovascular Diseases-Aneurysm, Vascular Malformation, and Subarachnoid Hemorrhage [7])
6. MR angiography/arteriography and MR venography may provide more detailed noninvasive vascular information (see the ACR–ASNR–SNIS–SPR Practice Parameter for the Performance of Cervicocerebral Magnetic Resonance Angiography [MRA] [8])
7. Hemorrhage (determining age, evaluating chronic, detecting microhemorrhages, hemorrhagic transformation of stroke) [9-11]
8. Neoplasm (primary or secondary/metastatic disease) or other mass-like conditions [12-15]
9. Evaluation of response to and potential iatrogenic effects of treatment (radiation, chemotherapy) [16-18]
10. Infectious, inflammatory, toxic/metabolic, and autoimmune (including demyelinating) disorders [19-27]
11. Dementia (see ACR Appropriateness Criteria® Dementia [28])
12. Seizures and epilepsy (see ACR Appropriateness Criteria® Seizures and Epilepsy [29])
13. Ataxia (see ACR Appropriateness Criteria® Dizziness and Ataxia [30])
14. Movement disorders and neurodegenerative disease (see ACR Appropriateness Criteria® Movement Disorders and Neurodegenerative Diseases [31])
15. Neuroendocrine imaging (hypothalamic/pituitary axis) (see ACR Appropriateness Criteria® Neuroendocrine Imaging [267])
16. Cranial neuropathy (see ACR Appropriateness Criteria® Cranial Neuropathy [32])
17. Hearing loss and/or vertigo (see ACR Appropriateness Criteria® Hearing Loss and/or Vertigo [33])
18. Alterations in cerebrospinal fluid pressure (spontaneous intracranial hypotension, idiopathic intracranial hypertension, hydrocephalus) [34-36]
19. Congenital anatomic and developmental abnormalities [37-44]
20. To further characterize abnormalities (or suspected abnormalities) detected on other imaging tests (eg, CT or sonography)
21. Hypoxic ischemic encephalopathy

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. Image guidance for surgical or interventional treatment planning [82-86] (see the ACR–ASNR Practice Parameter for the Performance of Non-Breast Magnetic Resonance Imaging (MRI) Guided Procedures [87])
2. Cerebral spinal fluid (CSF) flow, blood flow, and brain perfusion [34,35,53,88-92]
3. Spectroscopy [,50,89,93-96]
4. Functional imaging [82,97-100]
5. Volumetry [40,44,101]
6. Morphometry [79,80,102]
7. Diffusion tensor imaging/diffusion kurtosis/tractography [65,103-108]
8. Combination with positron emission tomography [109-111]
9. Radiogenomics [112]
10. Radiomics [113]

II. INDICATIONS AND CONTRAINDICATIONS

B. Contraindications

All patients should be screened for potential contraindications before MRI scanning (see the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [114]).

II. INDICATIONS AND CONTRAINDICATIONS

C. Safety

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI), the ACR Manual on Contrast Media, and the ACR Manual on MR Safety [114-116].

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

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [114].

IV. SPECIFICATIONS OF THE EXAMINATION

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 have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures [116-119]. 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

[120]). 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 healthcare professional acting within their scope of practice. It should contain pertinent information regarding the clinical indication for the procedure.

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) before 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 [121]. (See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [122], the ACR Manual on Contrast Media [115], the ACR Manual on MR Safety [116], and the ACR website.)

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. 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 Minimal and/or Moderate Sedation/Analgesia [123]. For pediatric patients, support from child life specialists can be beneficial and may avoid sedation in some cases.

B. Facility Requirements

The facility must be adequately staffed with appropriately trained personnel as per the ACR Manual on MR Safety [124].

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 [,,27,35,37,39,42,43,,50,52,64,72,89,98,,125-146]. In less usual circumstances, when there is a need to minimize patient radiofrequency exposure and reduce the specific absorption rate while scanning patients with various devices, examinations of the brain may be performed with transmit/receive coils or receive-only coils [268].

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 with the available imaging equipment and software. A typical imaging protocol for MRI of the brain includes sagittal T1-weighted (or a 3-D T1-weighted volumetric acquisition), axial fast spin-echo or turbo spin-echo (or equivalent) T2-weighted and axial T2-weighted fluid-attenuated inversion recovery (FLAIR) images, and diffusion weighted images..

Under certain clinical circumstances in which patient motion may be unavoidable (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 weighted imaging is essential for many indications, particularly in the assessment of infarction, abscess, dermoid/epidermoid, active demyelination, and hypercellular neoplasm [26,125,147-153]. Inclusion of gradient recall echo 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 ACR MRI Accreditation webpage [154]).

The repetition time (TR) and echo time required to optimize image quality depend on the field strength of the magnet and therefore need adjustment from magnet to magnet. 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 [155]. Thinner slices (<5 mm) and smaller interslice gaps (<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 a breakdown of the blood-brain barrier . Recently, controversy has arisen regarding reports of gadolinium deposition in tissues, and questions have been raised about the safety of these chelates [160,161]. 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 [160]. Alternatives to gadolinium chelates might also be contemplated in the appropriate setting [162]. Postcontrast images, when indicated, should be obtained preferably in two or more orthogonal planes. (Alternatively, one postcontrast series could be obtained using a T1-weighted 3-D volumetric acquisition and reconstructed in orthogonal planes). Postcontrast FLAIR images may add value in the assessment of meningeal disease [163]. (Please see the ACR Manual on Contrast Media [115].)

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 [75,164-170]. Although 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 [171]. These can include, but are not limited to, echo planar imaging [172], parallel imaging [43,126,134,173,174], compressed sensing [175,176] , diffusion-tensor imaging [39,65,104,105,107,126,138,151,177-180], rapid gradient echo pulse sequences (capable of providing T1 or T2 information and enabling 3-D acquisitions) [181], SWI [182-188], functional imaging [177,189-204], perfusion imaging [205-212], chemical exchange saturation transfer [213-216], volumetric imaging [35,217-221], morphometric imaging [222-232], magnetic source imaging [233], and other quantitative applications [151,234-244].

Certain clinical circumstances may warrant the use of proton MR spectroscopy [93-95,245-251] 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 [252].) Additional techniques that may be useful under the appropriate clinical circumstances include 3-D imaging techniques [253-256], neuronavigation, and intraoperative MRI [83,,139,257], magnetization transfer imaging [258-262], CSF flow study using phase-contrast pulse sequences [263], 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.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [120].

VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance (MR) Imaging Equipment [264].

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 [265,266].

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.

VII. 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).

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