MRI for Emergency Clinicians

Indications, Cautions, and Helpful Hints Sure to "Resonate" with Your Practice

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As the use of magnetic resonance imaging by emergency physicians (EPs) increases steadily, it is critically important that EPs understand the basics of this imaging modality, its uses, limitations, cautions, and contraindications.

The use of magnetic resonance imaging (MRI) by emergency physicians (EPs) is increasing steadily, as new MRI indications arise, technology evolves, and machines become faster and more widely available. It is therefore critically important that EPs understand the basics of this imaging modality, its uses, limitations, cautions, and contraindications.

A full explanation of the physics underpinning MRI is beyond this article's scope. However, a comprehensive discussion of the topic is available in a 2013 review entitled, "Understanding MRI: basic MR physics for physicians."[1] In short, three elements are necessary for an MRI machine to generate images: a strong magnetic field, radio waves, and a computer system. The body's hydrogen nuclei with their single protons and north-south poles act as mini bar magnets with randomly aligned axes. However, when the body is subjected to the MRI machine magnetic field, these axes line up. When radio waves are applied to the magnetic field, the strength and direction of the magnetic field changes. Then, when the radio waves are turned off, the magnetic field strength and direction return to baseline and a signal is emitted. It is this signal that is interpreted by a computer system to generate images.[2]

Cautions and Limitations

Although limited availability is often cited as a reason for not obtaining MRI studies in the emergency department (ED), this limitation is institution specific and will likely improve over time. Recent statistics indicate that MRI availability in the United States is second only to that in Japan and climbing. MRI usage in the United States is the highest in the world.[3]

MRI cost (and the resultant patient bill) exceeds that of other commonly performed ED imaging roughly by a factor of 2:1 when compared to computed tomography (CT). This is unlikely to improve in the near term.

The time to complete an MRI study continues to fall for some indications, but signifi-

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cantly exceeds the time to obtain CT images. MRI scan times range from 20 to 60 minutes depending on test type.

Body habitus, particularly obesity, may limit the ability of certain patients to undergo MRI. Claustrophobia or the inability to lie still for the test's entire duration may present a challenge for some patients. Be prepared to safely sedate patients with these issues. This is particularly relevant for pediatric patients. Consider a pre-MRI trial of sedation to assess which medication is best suited for individual patients.

Patients with certain medical devices may be unable to undergo MRI. Medical devices and implants from the U.S. and Europe manufactured within the past 30 years are non-ferromagnetic. This generally means they are MR-safe or MR-conditional. Realize, however, that certain non-ferromagnetic implants can heat during MR imaging.[4] A free searchable database exists listing MRI-safe devices and implants along with limitations and cautions (http://www.mrisafety.com/TheList_search.asp).[5]

Pacemakers and defibrillators are worthy of special mention. Some are now considered MR-conditional in limited circumstances, and this situation will continue to evolve. Consult your radiologist and/or the physician who placed the medical device with any safety concerns.

Intraocular metallic foreign bodies are an MRI contraindication. If any concern exists for an intraocular metallic foreign body, perform an orbital CT before considering an MRI. Headphones and ear plugs are used during MRI examinations to prevent hearing damage due to machine noise or nerve and muscle stimulation.

A 2016 *JAMA* study of MRI in pregnancy involving more than 1.4 million deliveries concluded "exposure to MRI during the first trimester of pregnancy compared with nonexposure was not associated with increased risk of harm to the fetus or in early childhood. Gadolinium MRI at any time during pregnancy was associated with an increased risk of a broad set of rheumatological, inflammatory, or infiltrative skin conditions and for stillbirth or neonatal death."[6]

There is limited data on the use of MRI in pediatric patients, but a 2015 study noted, "to date, no studies have demonstrated any definite risk to the fetus, mother, or neonate when MR scanners are operated within the regulatory guidelines set forth by the FDA and other regulatory agencies."[7]

A variety of gadolinium-based contrast agents (GBCAs) are currently used. GBCA administrations in renally impaired patients has been linked to nephrogenic systemic fibrosis (NSF), a rare, progressive, potentially fatal, incompletely understood, systemic disorder with a spectrum of manifestations. Its occurrence has prompted alerts, and a recent set of recommendations for at-risk patients (ie, those with acute kidney injury or an eGFR < 30 mL/min/1.73 m^2 and those who are dialysis dependent) specifies that (1) a low-risk GBCA should be used; (2) GBCA dose should be as low as possible; and (3) dialysis should be performed as indicated immediately after GBCA-enhanced MRI.[8,9] Additionally, the EP may wish to obtain informed consent from at-risk patients prior to the administration of GBCAs.

Common MRI indications in the ED

Central nervous system MRI

Spinal cord compression may occur due to a neoplastic process, either primary or metastatic, infection (epidural abscess is a particular concern), or hematoma. CT myelography is another diagnostic option, but MRI offers ease of performance, superior resolution, multiplanar imaging, lack of ionizing radiation, and the ability to detect multiple lesions with a single scan. For non-traumatic myelopathy evaluation (most commonly due to

cancer), perform a non-contrast MRI of the entire spinal canal since multiple lesions may be present. Repeat the MRI with contrast if the cause of the myelopathy is not clear after the non-contrast study.[10] Gadolinium does help detect and define inflammatory, infectious, and neoplastic lesions, but spinal cord compression can be diagnosed without it if the patient cannot receive gadolinium (see Cautions and Limitations section).[11] Only a non-enhanced MRI, limited to the traumatized area, is required in the evaluation of trauma-induced myelopathy.[10]

Dural venous sinus thrombosis (DVST) is best assessed with a combination of MRI and MR venography.[10] DVST is clot formation within any of five major dural venous sinuses. DVST risk factors include: dehydration; infections, both systemic and local; pregnancy and the puerperium; neoplastic incursion; trauma; and coagulopathies.[10,12] MR venography is an essential part of DVST evaluation since it assesses patency of the involved dural venous sinus.[10]

Carotid artery dissection is a leading cause of stroke in those younger than 45 years of age.[13] Carotid and vertebral artery dissection, due to trauma, hypertension, vascular disease, or local infections, can be diagnosed with endovascular angiography.[10,14] However, MRI in combination with MRA can be diagnostic as well.[10,13,14] MRI delineates the intramural clots while MRA shows the degree and extent of endovascular compromise.[10,13]

Meningoencephalitis and vasculitis are usually diagnosed with a combination of clinical findings, laboratory data, CT, and lumbar puncture results. However, MRI is highly sensitive for the CNS lesions associated with infection or vasculitis. Consider MRI as an alternative to the usual work up in selected patients if aggressive early therapy for viral infection (eg, herpes) or vasculitis is being contemplated.[10]

Acute subarachnoid hemorrhage (SAH) is usually best demonstrated on CT. However, MRI may have a role, especially in posterior fossa SAH.[10]

Cerebral Ischemia (TIA and Stroke) - The 2018 guidelines for early management of patients with acute ischemic stroke both recommended and considered equal (in patients selected for mechanical thrombectomy) CT, diffusion weighted MRI or MRI perfusion.[15] This guideline was promulgated by the American Heart Association/American Stroke Association and endorsed by the Society for Academic Emergency Medicine, among other professional organizations.

In a joint statement published by the American Society of Neuroradiology, the American College of Radiology, and the Society of Neurointerventional Surgery, MRI was reported to be equivalent to a non-contrast brain CT. MRI was also found to have superior accuracy in detecting microhemorrhages.[16]

Spine MRI

Spine and spinal cord emergencies must be promptly and correctly diagnosed to avoid or minimize functional loss. Knowledge of the most appropriate imaging modalities is essential to facilitate diagnosis and treatment for patients presenting with spine-related emergencies.

Low back pain prompts many ED visits and is a major cause of disability in the United States.

MRI is unwarranted for those patients with acute (< 6 weeks duration) low back pain in whom serious pathology, such as cauda equina, malignancy, epidural hematoma, or infection is not suspected. Manage most low back pain patients conservatively and without imaging.[17]

Trauma is the most common reason for spine MRI. CT, and now increasingly MRI, have supplanted plain radiography in the evaluation of spinal trauma. Currently, CT alone is

considered sufficient in the evaluation of thoracic and lumbar skeletal injuries. This is not true for cervical spine injuries.[18]

Initially, use either the NEXUS or Canadian C-Spine Rule criteria to determine if a trauma patient needs *any* imaging. Then, consider whether CT or MRI or both will be required, while realizing that the literature on this thorny issue continues to evolve. CT is the current standard for detecting bony injuries. MRI is usually reserved for patient in whom a soft-tissue, particularly ligamentous, injury is suspected. MRI is also required for the evaluation of any patient suspected of having sustained spinal cord injury.[18] The downside of our increased MRI usage in the evaluation of potentially spine-injured patients has been the detection of many clinically insignificant findings.

Acute cauda equina syndrome is a neurosurgical emergency requiring prompt recognition, imaging, and immediate neurosurgical consultation. Common findings include: recent onset or worsening severe low back pain; bowel and/or bladder dysfunction; neurological deficits; and saddle anesthesia. Many processes can lead to the syndrome, but the most common is disc herniation with resultant cauda equina compression. The American College of Radiology appropriateness criteria cite MRI as the correct imaging modality for the diagnosis of acute cauda equina syndrome.[19] In patients who've undergone previous herniated disc surgery, MRI with and without contrast must be obtained to differentiate between contrast-enhancing granulation tissue at the site of the surgery and nonenhancing herniated disc tissue.[18]

Infection is an important item in the differential diagnosis of back pain, with or without radiculopathy, and particularly important to consider if the patient has infectious disease risk factors. These risk factors include: spinal instrumentation via injections or surgery; intravenous drug use; prosthetic heart valves; systemic infections; other infectious sources in the body; and immunocompromising conditions.[18] All spinal elements, including the spinal cord, meninges, joints, discs, and vertebrae can be affected. Realize that infection can occur by direct inoculation or contiguous or hematogenous spread. An MRI with and without contrast is essential to confirm the diagnosis.[19] Your neurosurgical consultant will likely recommend imaging the entire spinal axis, since infectious lesions may be present at multiple levels.[18]

Pregnant patients with abdominal pain - concern for appendicitis (see the Cautions and Limitations section above on MRI in pregnancy)

Appendicitis occurs commonly in pregnancy. Missing the diagnosis can lead to fetal loss and other untoward outcomes. The 2018 American College of Radiology guidelines list MRI and ultrasound as imaging studies of choice in gravid patients in whom appendicitis is a concern.[20] Ultrasound is more commonly available and less expensive but is limited by high rates of appendiceal non-visualization, likely due to appendix displacement by the uterus, patient habitus, bowel gas, and discomfort during the exam.[21]

MRI has high sensitivity and very high specificity for the diagnosis of appendicitis. Abnormal diagnostic findings include an appendiceal diameter > 7 mm and surrounding inflammatory changes.[22] The low negative predictive value of MRI obviates the need for risky surgeries in pregnant patients in whom appendicitis is ruled out. MRI also allows for the diagnosis of other etiologies of abdominal pain in these patients.[21]

Pediatric patients with abdominal pain -concern for appendicitis (see the Cautions and Limitations section above on MRI in pediatric patients)

For pediatric patients with possible appendicitis, ultrasound is the first imaging modality of choice, followed by CT. However, ultrasound is operator dependent, with wide

variability in its ability to correctly diagnose appendicitis, often leading to equivocal results. CT involves ionizing radiation exposure.[20] Non-contrast MRI is the emerging imaging modality for these patients. A systematic review of almost 2000 pediatric patients found MRI sensitivity and specificity to be 97% and 97% with a low negative appendectomy rate.[23]

Cost and image acquisition time are limitations for MRI use for children. Pediatric patients may require sedation with long acquisition times in order to ensure that high-quality images are obtained, potentially introducing more associated costs and safety concerns. Shorter image-acquisition times would make MRI a more widely applicable test.[23]

Orthopedics

Various orthopedic conditions can be investigated by MRI, but this is not commonly done in the ED. Acute knee trauma with a concern for ligamentous, cartilaginous, or meniscal injury is one example. The patient with a concern for occult fracture or injury to the shoulder, elbow, or scaphoid represent others.

However, the special case of the patient with hip trauma with negative radiographs who will not weight bear or has significant pain is worth considering. MRI to either diagnose or exclude occult hip, pelvic, or acetabular fracture is traditionally considered to be the criterion standard. However, a 2016 study called this widely-held belief into question. It found that CT and MRI were similarly sensitive and concluded that starting with CT was a reasonable approach.[24] MRI can be considered if the diagnosis remains in doubt.

Musculoskeletal infections

A wide variety of bone, joint, and soft-tissue infections can be diagnosed by MRI, which is often the imaging modality of choice. Some of these infections may be limb- or even life-threatening. One, epidural abscess, is both life-threatening and function-threatening and has been discussed briefly already.

If you are concerned about the possibility of a serious soft-tissue or bone infection, strongly consider giving gadolinium contrast, which is particularly useful for detecting

Summary of Cautions and Limitations of MRI Use

- Lack of availability
- Cost
- Exam completion time
- Claustrophobia
- Patient's inability to lie still
- Implanted medical devices
- Metallic foreign bodies
- Obesity
- Hearing damage
- Pregnancy
- Pediatric patients (the developing brain)
- Nephrogenic systemic fibrosis due to gadolinium-based contrast agents

Common ED MRI indications

- Central Nervous System
  - Spinal cord compression
  - Dural venous sinus thrombosis
  - Arterial dissections - carotid or vertebral
  - Meningoencephalitis and vasculitis evaluation (possible)
  - Subarachnoid hemorrhage (possible)
  - Cerebral ischemia - TIA/Stroke
- Spinal cord/surrounding structure disease or trauma - epidural abscess, cauda equina syndrome, cord/nerve trauma
- Pregnant patients with abdominal pain (concern for appendicitis)
- Children with abdominal pain (concern for appendicitis)
- Musculoskeletal infections
- Orthopedic trauma

abscesses, sinus tracts, and spine infections, and for providing other important anatomic details.[25]

Conclusion

MRI utilization by EPs will continue to increase as the factors governing its use evolves. These factors include: decreasing scan times; wider availability; possible cost reductions; new and changing indications; more research; and the always-present pressure on EPs to care for a broader spectrum of evermore challenging patients. It therefore benefits us to understand more about this dynamic part of our practice. Look to the scientific literature on stroke, neurosurgical emergencies, orthopedics, pediatrics, infectious disease and other fields that impact emergency medicine practice and MRI use as they continue to change.

References

1. Currie S, Hoggard N, Craven IJ, Hadjivassiliou M, Wilkinson ID. Understanding MRI: Basic MR physics for physicians. *Postgrad Med J*. 2013;89:209-223.
2. Berger A. How does it work? Magnetic resonance imaging. *BMJ*. 2002;324:35.
3. Chung M, Dahabreh IJ, Hadar N, et al. Emerging MRI technologies for imaging musculoskeletal disorders under loading stress. Comparative Effectiveness Technical Briefs, No. 7. Rockville, MD: Agency for Healthcare Research and Quality (US); 2011. https://www.ncbi.nlm.nih.gov/books/NBK82287/
4. Sammet S. Magnetic resonance safety. *Abdom Radiol (NY)*. 2016;41(3):444-451.
5. MRI Safety. http://www.mrisafety.com/TheList_search.asp.
6. Ray JG, Vermeulen MJ, Bharatha A, Montanera WJ, Park AL. Association between MRI exposure during pregnancy and fetal and childhood outcomes. *JAMA*. 2016;316(9):952961.
7. Tocchio S, Kline-Fath B, Kanal E, Schmithorst VJ, Panigrahy A. MRI evaluation and safety in the developing brain. *Semin Perinatol*. 2015;39(2):73-104.
8. Khawaja AZ, Cassidy DB, Al Shakarchi J, McGrogan DG, Inston NG, Jones RG. Revisiting the risks of MRI with Gadolinium based contrast agents—review of literature and guidelines. *Insights Imaging*. 2015;6(5):553-558.
9. Schieda N, Blaichman JI, Costa AF, et al. Gadolinium-based contrast agents in kidney disease: A comprehensive review and clinical practice guideline issued by the Canadian Association of Radiologists. *Can J Kidney Health Dis*. 2018;5:1-17.
10. Quint DJ. Indications for emergent MRI of the central nervous system. *JAMA*. 2000;283(7):853-855.
11. Broder J. Imaging the cervical, thoracic, and lumbar spine. In: Broder J, ed. *Diagnostic Imaging for the Emergency Physician*. Philadelphia, PA: Elsevier; 2011:73-157.
12. Villringer A, Einhäupl KM. Dural sinus and cerebral venous thrombosis. *New Horiz*. 1997;5(4):332-341.
13. Ben Hassen W, Machet A, Edjlali-Goujon M, et al. Imaging of cervical artery dissection. *Diagn Interv Imaging*. 2014;95(12):1151-1161.
14. Jacobs A, Lanfermann H, Neveling M, Szelies B, Schröder R, Heiss W-D. MRI-and MRI-guided therapy of carotid and vertebral artery dissections. *J Neurol Sci*. 1997;147(1):27-34.
15. Powers WJ, Rabinstein AA, Ackerson T, et al. 2018 guidelines for the early management of patients with acute ischemic stroke: A guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2018;49(3):e46-e110.
16. Wintermark M, Sanelli PC, Albers GW, et al. Imaging recommendations for acute stroke and transient ischemic attack patients: A joint statement by the American Society of Neuroradiology, the American College of Radiology, and the Society of NeuroInterventional Surgery. *AJNR Am J Neuroradiol*. 2013;34(11):E117-127.
17. Lavi ES, Pal A, Bleicher D, Kang K, Sidani C. MR imaging of the spine: Urgent and emergent indications. *Semin Ultrasound CT MR*. (2018), doi: https://doi.org/10.1053/j.sult.2018.10.006
18. Kawakyu-O'Connor D, Bordia R, Nicola R. Magnetic resonance imaging of spinal emergencies. *Magn Reson Imaging Clin N Am*. 2016;24(2):325-344.
19. Patel ND, Broderick DF, Burns J, et al. ACR appropriateness criteria low back pain. *J Am Coll of Radiol*. 2016;13(9):1069-1078.
20. Garcia EM, Camacho MA, Karolyi DR, et al. ACR appropriateness criteria -right lower quadrant pain-suspected appendicitis. *J Am Coll Radiol*. 2018;15(11):S373-S387.
21. Duke E, Kalb B, Arif-Tiwari H, et al. A systematic review and meta-analysis of diagnostic performance of MRI for evaluation of acute appendicitis. *AJR Am J Roentgenol*. 2016;206(3):508-517.
22. Yu HS, Gupta A, Soto JA, et al. Emergency abdominal MRI: Current uses and trends. *Br J Radiol*. 2016;89(1061). doi:10.1259/bjr.20150804
23. Kim JR, Suh CH, Yoon HM, et al. Performance of MRI for suspected appendicitis in pediatric patients and negative appendectomy rate: A systematic review and metaanalysis. *J Magn Reson Imaging*. 2017;47(3):767-778.
24. Rehman H, Clement RG, Perks F, White TO. Imaging of occult hip fractures: CT or MRI? *Injury*. 2016;47(6): 1297-1301.
25. Simpfendorfer CS. Radiologic approach to musculoskeletal infections. *Infect Dis Clin N Am*. 2017;31:299-324.