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PICTORIAL ESSAY

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Emergency MR imaging of the central nervous system

Abstract Magnetic resonance (MR) of the central nervous system has few, but important indications for use in the acute setting. This report reviews the few true current clinical indications for emergency MR imaging, including ruling out spinal cord compression, vascular dissection or dural venous sinus thrombosis. Possible indications for emergency MR, including evaluation of acute stroke symptomatology, potential meningoencephalitis or vasculitis, are also presented. Future applications for MR, including MR angiography in the setting of acute subarachnoid hemorrhage and spectroscopy in acute ischemia, are mentioned.

Key words Magnetic resonance, Magnetic resonance, angiography, Magnetic resonance, diffusion, Spinal cord, compression, Carotid arteries, dissection, Brain, ischemia

Introduction

While MR is clearly the imaging modality of choice for evaluation of almost all non-traumatic CNS pathology, when MR should be performed on an *emergency* basis is not as clear. This has important implications with respect to MR machine availability (the need for 24-h service), staffing (both technical and professional) and software packages.

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In the appropriate clinical setting, suspected spinal cord compression should definitely initially be evaluated with MR imaging, and suspected vascular dissection or dural venous sinus thrombosis are relative indications for initial emergency evaluation with MR imaging. It could be argued that in some clinical settings, suspected meningoencephalitis or vasculitis may also warrant emergency MR evaluation. Rapid evaluation of the extent of involved brain in the setting of acute cerebral ischemia is also becoming an indication for emergency MR imaging.

Non-traumatic spinal cord compression

The importance of detecting non-traumatic spinal cord compression (usually due to spread of neoplasm, but also occasionally due to hematoma or abscess) is that if such compression can be detected before a patient loses the ability to walk, there is a 90–100 % chance that they will still be walking after the lesion is treated [1]. However, if a patient is not walking at the time spinal cord compression is diagnosed, there is a significantly poorer chance they will walk after treatment. Therefore, suspected spinal cord compression, particularly if the patient is becoming weak and losing the ability to walk, needs to be evaluated urgently.

MRI is well known to be the examination of choice to rule out spinal cord compression [2, 3] (Fig. 1) due to its superior contrast resolution, multiplanar capabilities, lack of ionizing radiation, ability to detect tandem lesions (Fig. 2), avoidance of spinal needle placement (and the associated risk of decompressing the spinal canal below the level of a spinal cord compression with exacerbation of patient symptoms) and avoidance of intrathecal instillation of iodinated contrast material and its attendant risk.

There is no role for plain radiographs in the evaluation of acute spinal cord compression, as such studies cannot show a compressed spinal cord (Fig. 1). Myelography, followed by high-resolution post-myelography

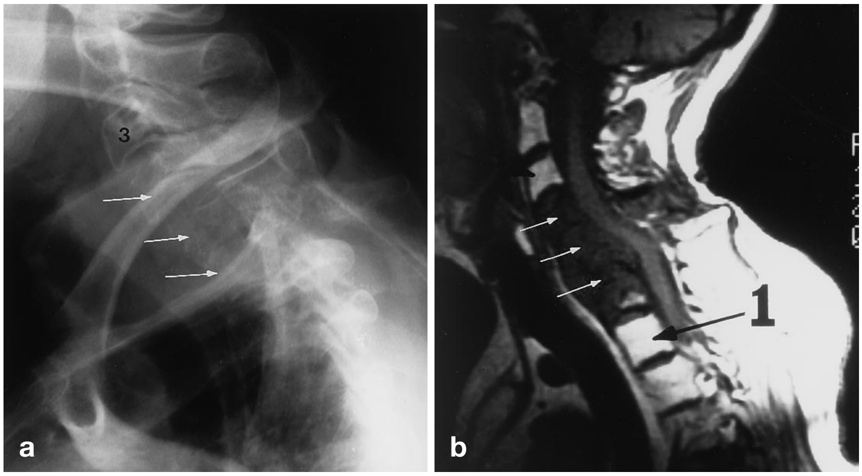


Fig. 1 Lateral cervical spine X-ray (**a**) demonstrates destructive changes of multiple lower cervical spine vertebra due to metastatic breast carcinoma *(arrows);* however, the spinal canal invasion by tumor with spinal cord compression is seen only on the sagittal T1-weighted MR scan (**b**). *3* C3 vertebral body, *1* T1 vertebral body

Fig. 2 Sagittal T1-weighted MR scans of the mid (**a**) and upper (**b**) thoracic spine demonstrate two separate (tandem) lung metastases *(arrows)* at the T3 and T6 levels. *3* T3 vertebral body, *6* T6 vertebral body

CT, remains an excellent test for detecting spinal cord compression of any etiology. Though inferior to MR, it is still an important alternative to MR in patients with spinal internal fixation hardware (Fig. 3) or when MR imaging is not possible.

Traumatic spinal cord compression

Emergency MR imaging should be performed in the setting of myelopathy following trauma [2] to assess for (a) frank impingement on the spinal cord by a fracture fragment (Fig. 4) (though this can usually be inferred from a CT scan), (b) an associated herniated disc acutely compressing the spinal cord or (c) a spinal canal hematoma compressing the spinal cord (Fig. 5). Each of these findings may warrant acute surgical intervention.

In the setting of significant trauma, the spine also always needs to be evaluated for fracture with either plain radiographs or preferably CT before MR imaging is performed. This is done so that appropriate stabilization and monitoring of the spine can be performed before the patient is transported to the MR area and placed into the MR scanner.

It should be noted that in the setting of post-traumatic myelopathy, only the traumatized region of the spine needs to be evaluated and contrast-enhanced MR scans are not necessary. However, in the setting of non-traumatic myelopathy, the entire spinal cord (from the cervicomedullary junction to the conus medullaris) should be evaluated in two planes. Also, contrast-enhanced scans should be obtained as infectious/carcinomatous meningitis may only be detected on such scans.

Vascular dissection

Dissections of vascular structures that supply the central nervous system can be devastating, as involved vessels can be (a) partially occluded, which can lead to “slow-flow” that can increase the risk of thrombus formation

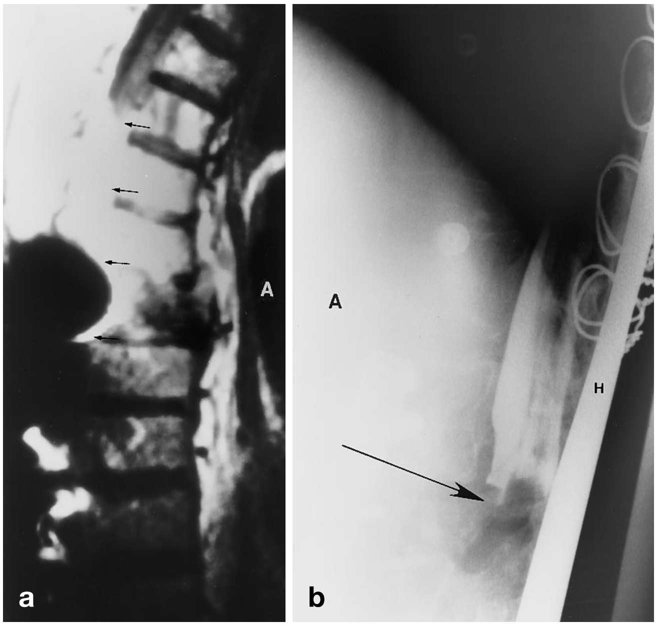


Fig. 3 Recurrent chordoma invading the spinal canal and compressing the thecal sac is obscured by internal fixation hardware artifact *(small arrows)* on a sagittal T1-weighted MR scan (**a**), but is easily diagnosed on myelography (**b**) *(large arrow)*. *A* anterior, *H* Harrington rod

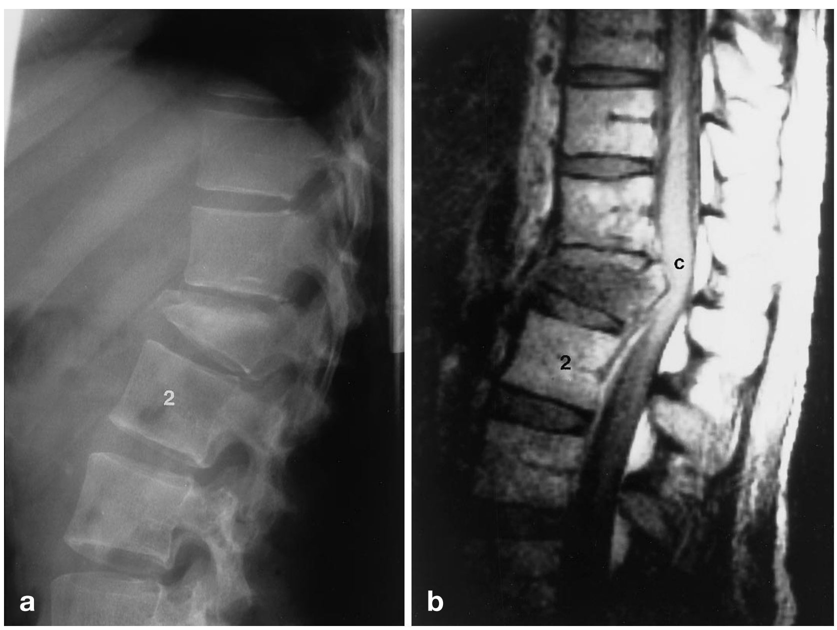
Fig. 5 Sagittal T1-weighted (**a**) and T2-weighted (**b**) MR scans of a post-traumatic epidural hematoma *(arrows)*; status following reduction of C7/T1 fracture dislocation. *7* C7 vertebral body

and ultimately result in thromboembolic strokes, and (b) less commonly, completely occluded, resulting in infarction.

Trauma (blunt trauma, spinal manipulation) is the most common cause of head/neck vascular dissection, though hypertension, migraines, vasculopathy (Marfan's syndrome, fibromuscular dysplasia), certain drugs and pharyngeal infections are also known causes of dissection. Any activity which involves neck motion can cause vascular dissection. Sometimes, no antecedent cause can be linked to a dissection.

Most dissections involve the cervical internal carotid arteries (distal to the bulb region), the cervical vertebral arteries (C2 to the foramen magnum) or the petrous internal carotid region. However, dissections anywhere from the aortic arch to the intracranial vasculature can

Fig. 4 **a** Chance L1 fracture demonstrated on lateral X-ray. **b** Impingement on the conus medullaris *(c)* is only seen on the sagittal T1-weighted MR scan. *2* L2 vertebral body



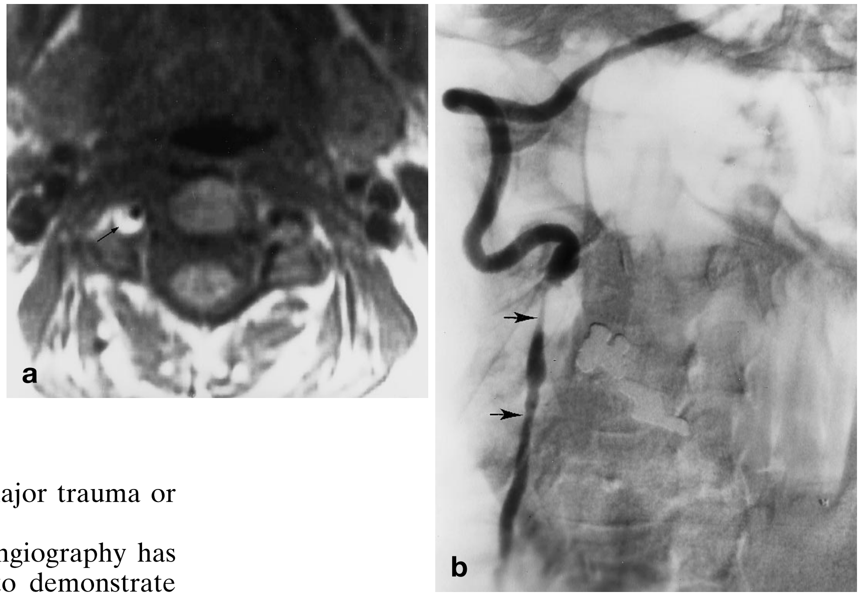


Fig. 6 a, b Post-traumatic right vertebral artery dissection. High signal "crescent" sign representing hematoma in the wall of the RVA is seen *(arrow)* on an axial T1-weighted MR scan (**a**). Dissection *(arrows)* is confirmed at formal angiography (**b**)

be seen, particularly in the setting of major trauma or vasculopathy.

In the past, endovascular cerebral angiography has been the imaging modality of choice to demonstrate (smooth or irregular) luminal narrowing resulting in either a "string" sign or complete occlusion of a vessel in the region of a dissection. As a dissection is often associated with a hematoma in the wall of the involved vessel (which causes the vessel lumen compromise), MR imaging [4, 5] is ideally suited to directly demonstrate the hematoma in the vessel wall in addition to showing the compromised though still patent vascular lumen on an MR angiogram (MRA).

When evaluating for cervical dissection, one should obtain axial T1-weighted scans (with or without fat suppression) through the region of interest in the attempt to show the classic crescentic high-signal hematoma (Fig. 6) in the wall of the vessel. Additional 2D TOF MR angiography through the neck to evaluate vessel morphology both for a dissection and for possible causes of the dissection (e. g. underlying fibromuscular dysplasia) can then be performed.

By first using MR/MRA, more invasive endovascular angiography can be avoided for the evaluation of many patients with suspected dissection. However, as (a) the spatial resolution of MRA remains inferior to that of formal endovascular angiography, (b) associated post-traumatic pseudoaneurysms (Fig. 7) can be difficult to detect with MRA and (c) some patients still cannot cooperate for MRA, occasional patients may still require conventional endovascular angiography to rule out dissection.

Fig. 7 Post-traumatic left internal carotid (LIC) dissection with associated pseudoaneurysm *(arrows)* just below the skull base as demonstrated on 2D TOF MR angiography (**a**) and formal endovascular angiography (**b**)

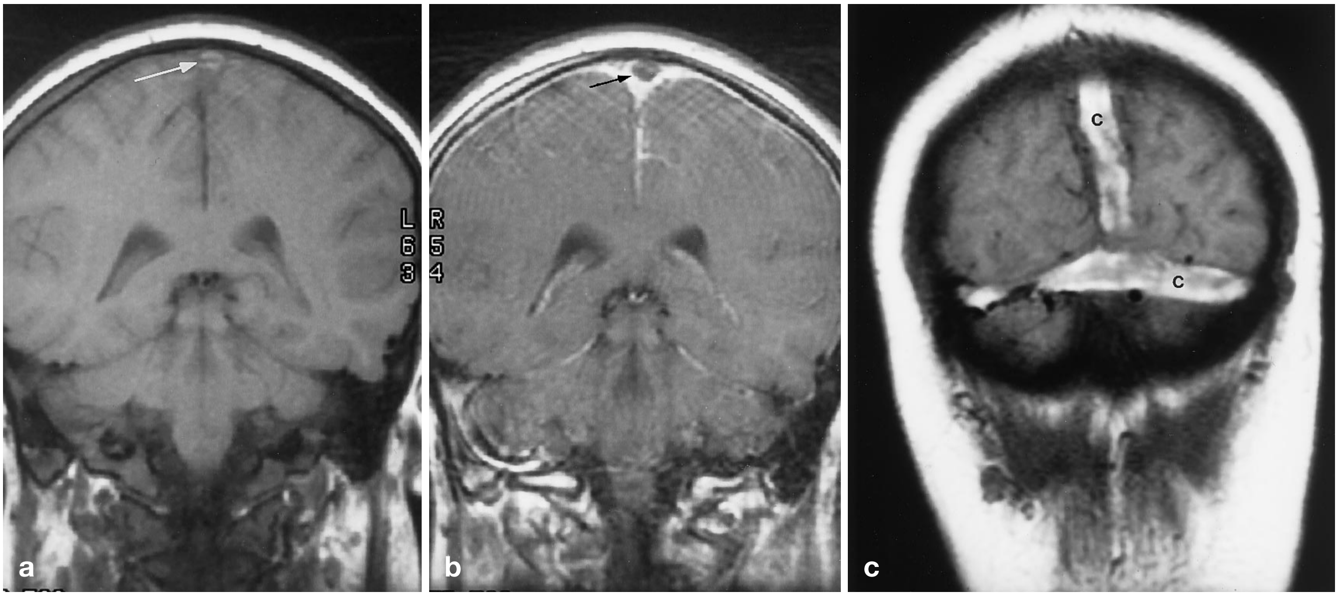


Fig. 8 Acute superior sagittal sinus thrombosis *(arrows)* demonstrating the "delta" sign on non-contrast coronal T1-weighted MR (**a**) and the "empty delta" sign on contrast-enhanced coronal T1-weighted MR (**b**). In another patient, subacute superior sagittal and transverse dural venous sinus thrombosis with sinus clot *(c)* demonstrating increased signal on non-contrast coronal T1-weighted MR imaging (**c**)

Dural venous sinus thrombosis

Major dural venous thrombosis refers to veno-occlusive changes of the superior sagittal sinus, transverse sinus, sigmoid sinus and/or the deeper venous system (internal cerebral veins, vein of Galen, straight sinus). When these structures thrombose, smaller cortical or deep venous vessels can no longer drain the brain in a normal manner, which leads to venous congestion and ultimately venous infarctions, which can be fatal. As presenting symptoms in these patients can be non-specific (headache, visual changes), clinical suspicion needs to be high. Risk factors commonly associated with venous thromboses include: dehydration (particularly in infants), pregnancy/puerperium, oral contraceptives, infection (both local invasion from the paranasal sinuses and the mastoids in addition to disseminated infection), tumor (local invasion), coagulopathies (including the lupus anticoagulant) and trauma.

As with CT, dural venous thromboses can be suspected on non-contrast-enhanced MR imaging ("delta" sign) and on contrast-enhanced MR ("empty delta" sign), but often will need confirmation with MR venography, which has replaced endovascular arteriography and venous digital subtraction angiography [5].

Axial and coronal non-contrast and contrast-enhanced T1-weighted scans and axial T2-weighted scans can be performed in patients with suspected dural venous thrombosis to evaluate for subacute thrombus in a venous sinus and to identify "delta signs" (Fig. 8), and also to search for associated venous infarctions (which are often hemorrhagic). However, as flow artifacts can limit evaluation for thromboses on spin-echo scans, formal phase-contrast MR venography to best delineate flow within the dural venous sinuses (Fig. 9) is usually also necessary.

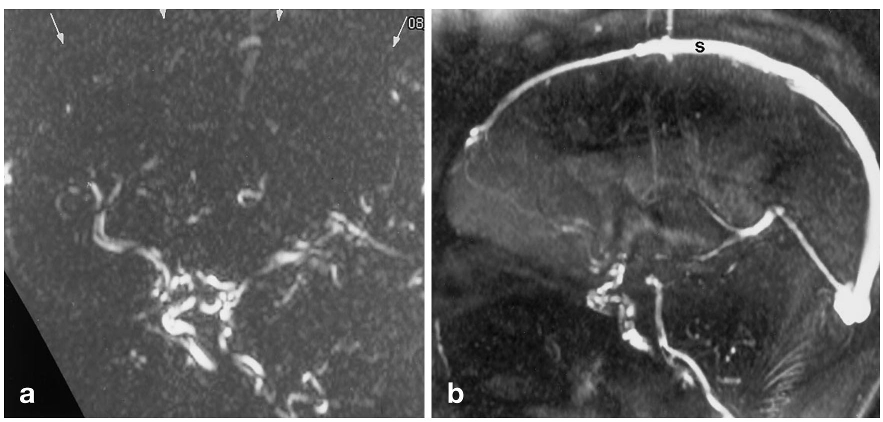


Fig. 9 Acute superior sagittal sinus thrombosis *(arrows)* demonstrating absence of flow on midline sagittal phase contrast MR venography (**a**). A normal midline sagittal phase contrast MR venogram (**b**) is shown for comparison. *s* Superior sagittal sinus

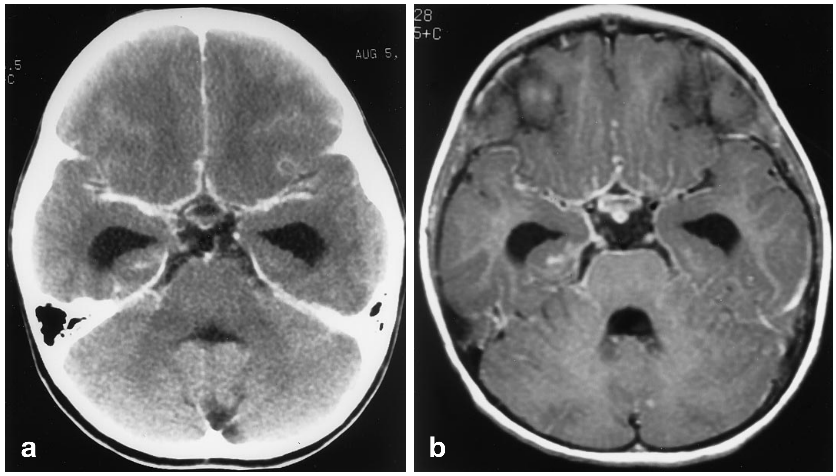


Fig. 10 a, b Tuberculous meningitis. Contrast-enhanced CT (**a**) and contrast-enhanced T1-weighted MR (**b**) demonstrate enhancement of basal cisterns and hydrocephalus. While the enhancement is easier to see on MR, in the emergency setting the MR did not change patient management

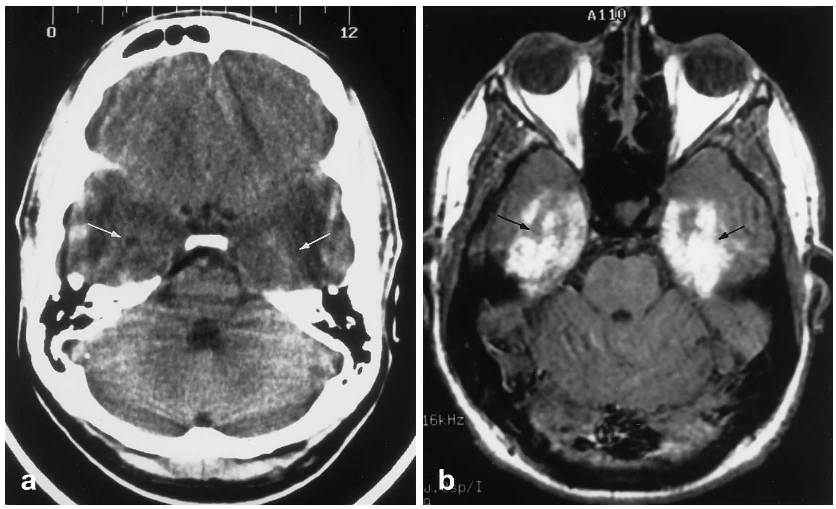


Fig. 11 Temporal lobe herpes simplex encephalitis *(arrows)* might be suspected on the CT scan (**a**), but is dramatically demonstrated (hemorrhagic) on the non-contrast T1-weighted MR scan (**b**)

As with arterial dissections, venous thromboses and their response to therapy can be followed with serial MR venograms, obviating the need for more invasive endovascular angiography.

Meningoencephalitis

The need for emergency MR evaluation of suspected meningitis or encephalitis of any infectious etiology is controversial, as one could argue that regardless of the imaging findings, suspected meningoencephalitis should be treated urgently based on clinical and cerebrospinal fluid findings with cross-sectional imaging (usually CT) being performed urgently solely to rule out changes suggestive of increasing intracranial pressure, which would contra-indicate lumbar puncture (Fig. 10).

MR imaging is best to define the extent of an infection or to follow the course of an infection [6]. In some cases, however, clinical and cerebrospinal fluid findings may be non-specific and, as the risks of some of the drugs used to treat CNS infections are not insignificant, emergency MR imaging to help "sway" a clinician either towards or away from a diagnosis of meningoencephalitis may be necessary (Fig. 11).

Vasculitis

The need for emergency MR imaging to confirm or rule out suspected CNS vasculitis or to assess for the appearance of new cerebral lesions in a patient with known vasculitis who is clinically deteriorating is not clear.

Non-infectious vasculitides, including collagen vascular disease (e. g. SLE), polyarteritis nodosa, temporal arteritis, Takayasu arteritis, Wegener's granulomatosis, cocaine use, sarcoidosis, primary CNS angiitis and others, can often be diagnosed on the basis of clinical and laboratory findings. Some vasculitides have a predisposition to primarily involve the CNS, and therefore MR (and sometimes formal endovascular angiography) is crucial for making the diagnosis. However, in this patient population, MR imaging on an emergency basis is probably not necessary, as acute CNS-related symptoms

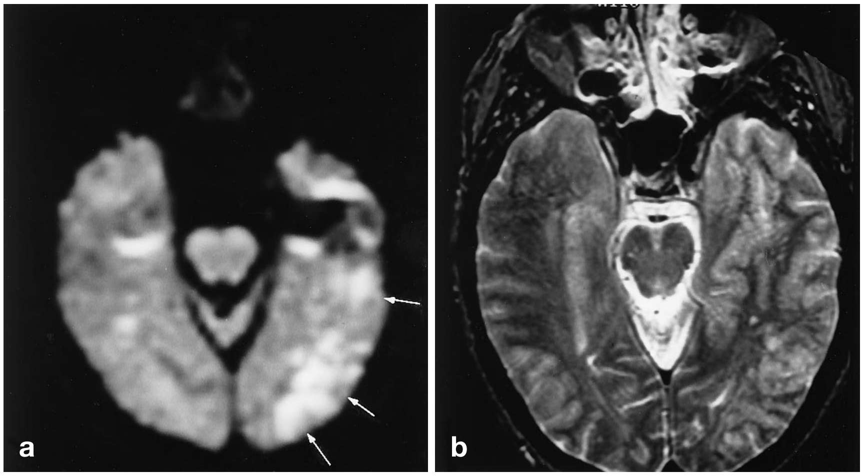


Fig. 12 Acute (less than 6 h) ischemic changes *(arrows)* in the left temporo-parietal region, well seen on diffusion imaging (**a**), but poorly seen on T2-weighted (2500/80) imaging (**b**)

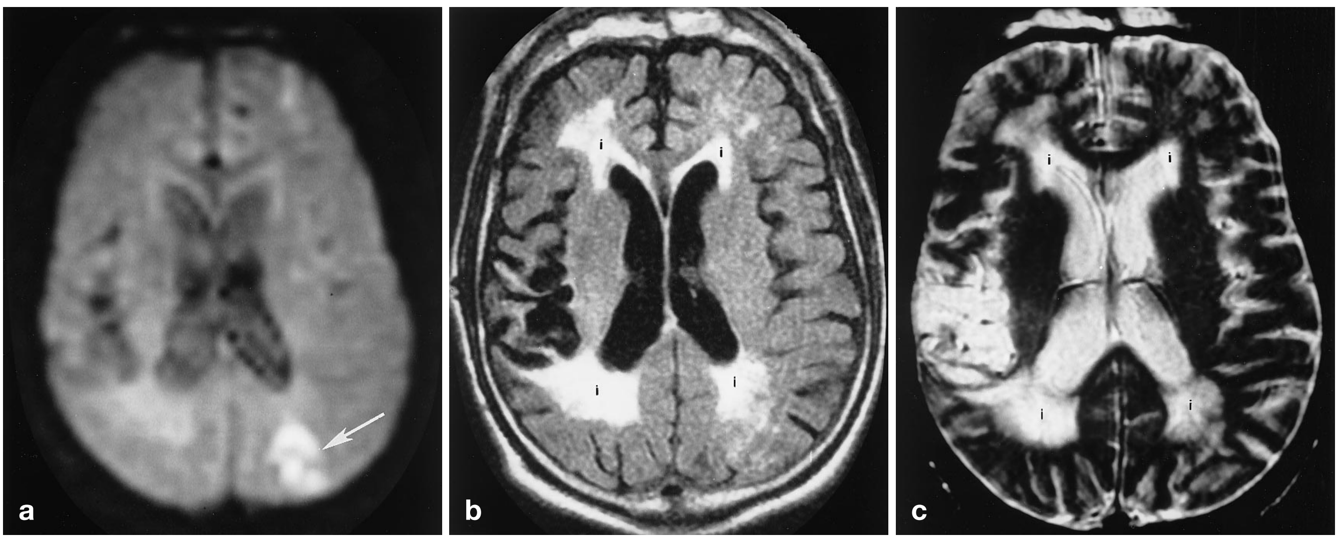
can be adequately evaluated with CT (ruling out acute hemorrhage or mass effect) and MR can then be performed on a more routine basis to evaluate definitively for vasculitis-related ischemic changes [7]. In some cases of vasculitis, however, the argument can be made that therapeutic regimens may be changed immediately in a deteriorating patient if new lesions can be demonstrated on MR imaging.

Cerebral ischemia

At the end of the 1990s, emergency MR imaging for the evaluation of acute cerebral ischemia is a rapidly evolving field. While hemorrhage associated with cerebral ischemia and non-vascular causes of stroke symptoms (such as mass effect and/or edema associated with infection and neoplasm) can usually be comfortably ruled out with CT in the acute setting, diffusion and perfusion MR are much more sensitive techniques for detecting the earliest changes of cerebral ischemia.

Diffusion-weighted (DW) MR imaging has already proven to be valuable in the emergency room setting for the evaluation of suspected cerebral infarction. DW MR imaging allows characterization of tissues according to rates of microscopic diffusional motion of water [8] and is therefore substantially more sensitive than CT or even conventional spin-echo MR imaging for the detection of cerebral infarction in its earliest phase (i.e., within the first few hours after stroke onset). On DW images, areas of hyperacute infarction are seen as regions of hyperintense signal (Figs. 12a, 13a, 14a, 15a) due to restricted water diffusion within these regions, in contrast to the intermediate signal intensity of normal brain tissue [8]. At the same point in time, little or no signal abnormality will be seen on T2-weighted images or fluid-attenuated inversion recovery

Fig. 13 Acute (less than 24 h) ischemic changes *(arrows)* in the left parieto-occipital region *(arrow)* easily identified on diffusion imaging (**a**), poorly seen on FLAIR imaging (**b**) and not seen on T2-weighted imaging (**c**). Also note the chronic ischemic changes *(i)* on the FLAIR and T2-weighted scans which are poorly seen on the diffusion imaging



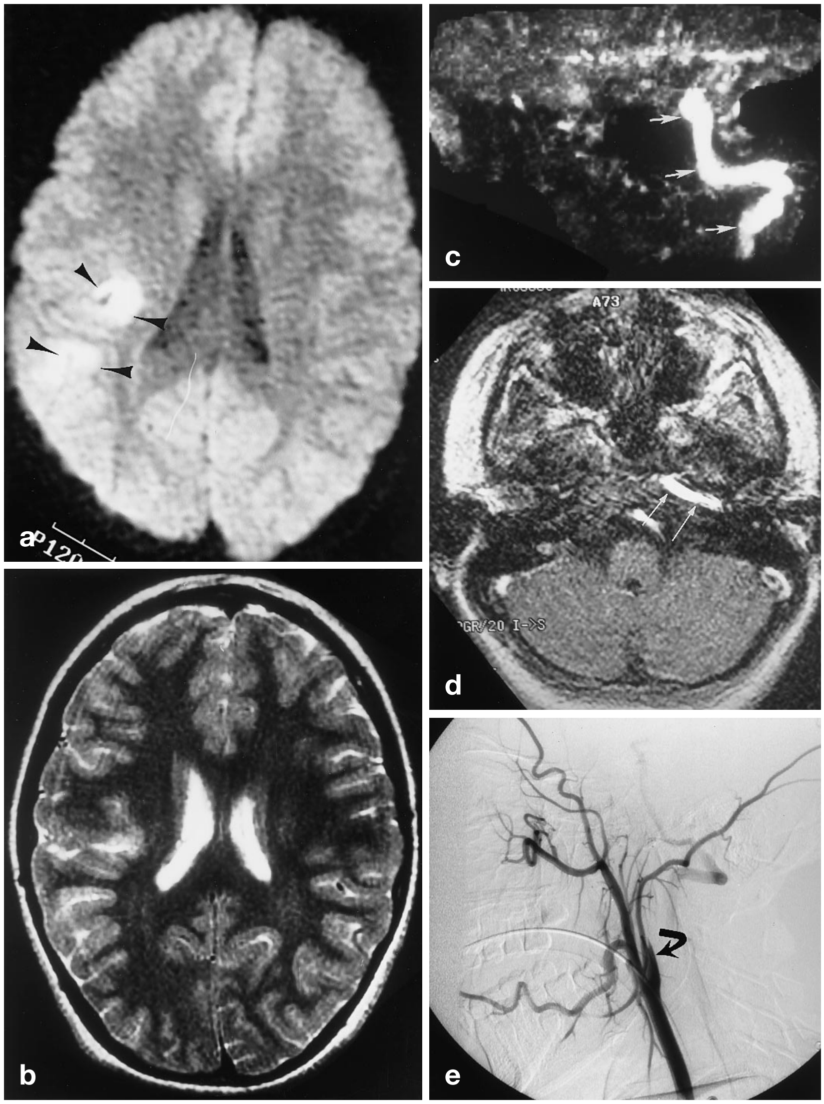


Fig. 14 a–e An 11-year-old patient with acute onset of left hemiparesis. Diffusion MR (**a**) obtained several hours after presentation demonstrates gyriform abnormality in the posterior right frontal region *(arrowheads)*. This region appears essentially normal on the T2-weighted study (**b**). Motion-degraded MR angiography including a reformatted image (**c**) and a skull base “source” image (**d**) demonstrates absence of the right internal carotid artery (*arrows,* normal left internal carotid artery). Formal endovascular angiography (**e**) confirmed complete occlusion of the right internal carotid artery due to a dissection *(curved arrow)*

(FLAIR) images (Figs. 12 b, 13 b, c, 14 b, 15 b). One further advantage of DW imaging is its ability to discriminate hyperacute and acute areas of infarction from older infarctions, which appear isointense or only slightly hyperintense to normal brain tissue on DW images (Fig. 13).

Perfusion-weighted (PW) MR imaging allows for evaluation of cerebral blood flow to the brain based on signal changes reflecting either blood oxygenation levels or the amount of intravascular contrast agent delivered to a portion of the brain [9]. If a perfusion deficit on MR imaging is more extensive than a corresponding diffusion abnormality, the area of perfusion abnormality without diffusion abnormality may represent the “ischemic penumbra” of brain “at risk” for additional injury in the acute period. Identification of such a penumbra may eventually prove to be an indication for aggressive therapy.

Finally, in the setting of acute ischemia, emergency MR angiography may sometimes be able to define the etiology of a patient’s symptoms, such as a vascular dissection (Fig. 14) or an embolus (Fig. 15).

As early interventions aimed at reversing or minimizing the effects of acute cerebral ischemia continue to become more widely available, such sensitive imaging techniques as DW and PW MR imaging, as well as MRA, will play an increasingly important role in the emergency evaluation of the stroke patient.

The future

In the future, additional roles for emergency MR evaluation may include evaluating for intracranial aneurysms and further evaluation of acute cerebral ischemia.

In the setting of acute subarachnoid hemorrhage, ruling out aneurysms with high-resolution MR angiography may become feasible. Currently however, the spatial resolution, the time required to acquire MR angiographic images, and the patient cooperation that is ne-

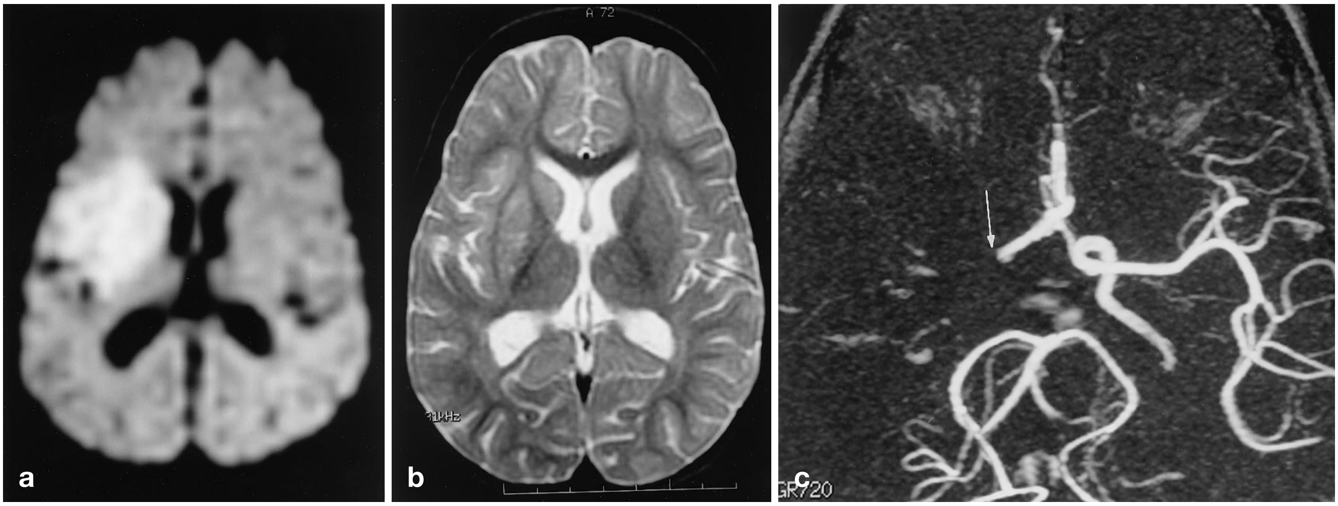


Fig. 15 a–c A 30-year-old patient 3 days after repair of an ASD with acute onset of left hemiparesis. **a** Diffusion MR obtained several hours after presentation demonstrates abnormality in the anterior right middle cerebral artery territory. **b** This region is only minimally abnormal on the T2-weighted study. **c** MR angiography including a reformatted image demonstrates occlusion of the right middle cerebral artery at its origin *(arrow)* due to a subsequently demonstrated embolus

cessary to perform MR angiography do not permit reliable ruling out of intracranial aneurysms, particularly those distant from the circle of Willis region. Similarly, small intracranial arteriovenous malformations and fistulas (additional though less common causes of subarachnoid hemorrhage) will currently be missed on MR angiography.

Assessing for salvageable brain in the setting of acute stroke with MR spectroscopy (in addition to diffusion and/or perfusion MR imaging) to further determine whether a patient is a candidate for aggressive therapy may eventually become the standard. Currently, however, such spectroscopy, like functional imaging, remains non-existent or at best experimental at most imaging facilities.

In summary, as with essentially everything in medicine, the patient's clinical condition determines whether any procedure/intervention is warranted and whether that study should be performed on an emergent basis. If one performs MR imaging and one's patient referral pattern warrants it, such service should probably be available 24 h/day for those times when true emergency MR imaging is indicated.

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Commentary Robert A. Novelline

Quint and colleagues review the current indications for emergency MR examinations of the central nervous system (CNS). The authors state that "while MR is clearly the imaging modality of choice for evaluation of almost all non-traumatic CNS pathology, when MR should be performed on an *emergency* basis is not as clear". However, they conclude that MR imaging has "few, but important indications for use in the acute setting". Their case materials include excellent examples of patients with acute non-traumatic spinal cord compression, traumatic spinal cord compression, vascular dissection, dural venous sinus thrombosis, meningoencephalitis, cerebral vasculitis and cerebral ischemia which were diagnosed on an emergency basis with MR imaging. The authors further propose that future, additional roles for emergency MR evaluation may include the detection of suspected intracranial aneurysms in patients presenting subarachnoid hemorrhage and the assessment of salvageable brain in acute stroke with MR spectroscopy.

In recent years several other reports have identified acute non-CNS medical and surgical conditions which are best evaluated by emergency MR examinations [1]. Many involve the musculoskeletal system [2–6]. Feldman et al. [7] reported on the role of emergency MR in the detection of occult fractures. In a series of 30 patients, MR imaging allowed identification of acute fractures in an emergency room setting, as well as subtle subacute or chronic fractures in the context of strong clinical suspicion despite negative or inconclusive radiographs or other subsequently indecisive imaging studies. And magnetic resonance imaging may prove more cost effective than traditional techniques. Rubin et al. [8] compared the cost effectiveness of MR imaging compared to radionuclide bone scanning in the evaluation of patients with clinically suspected hip fractures and negative or equivocal plain films. In their series the time to surgery was longer in patients undergoing bone scanning and consequently early MR imaging proved more cost effective. Many aortic emergency conditions such as suspected aortic dissection [9, 10] and suspected aortic trauma [11] can be accurately diagnosed by MR imaging, which may be the best procedure in patients with renal failure or a history of prior serious reaction to intravenous contrast medium. MR imaging has also proven beneficial in a variety of thoracic and abdominal emergency conditions.

What is obvious to the radiologist in emergency imaging practice is that, as the indications for emergency MR examinations become increasingly recognized, so does the need for: (1) an MR scanner that is installed conveniently close to the emergency department and (2) a full-time emergency MR support staff. A low-field magnet would probably not be the best choice to fill this need as so many currently recognized indications for emergency MR imaging involve the central nervous system, which is best evaluated with high-field units. Consequently, the planning of future emergency radiology divisions or units should include consideration of an on-site or closely available MR scanner. Also, the plans for staffing should include an in-house or on-call MR technologist 24 h per day, 7 days per week. This staffing need further emphasizes the benefits of cross-training of off-hours radiology technologists who are trained to do not only radiography, but also CT, ultrasound or MR imaging.

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