



## Discover Generics

Cost-Effective CT & MRI Contrast Agents



FRESENIUS  
KABI

WATCH VIDEO

# AJNR

## Cerebrovascular Disease

Robert L. DeLaPaz

*AJNR Am J Neuroradiol* 2007, 28 (6) 1197-1199

<http://www.ajnr.org/content/28/6/1197>

This information is current as  
of June 18, 2025.

Robert L. DeLaPaz, for  
the Expert Panel on  
Neurologic Imaging

**C**linically, stroke is the sudden onset of focal neurologic symptoms due to ischemia (88%), hemorrhage into the brain (9%) or hemorrhage into the subarachnoid spaces (3%).<sup>1</sup> There are approximately 700,000 new or recurrent strokes per year in the United States, one every 45 seconds, resulting in approximately 160,000 deaths, making stroke the third leading underlying cause of death in the U.S., behind heart disease and cancer, and the leading cause of long-term disability.<sup>1</sup> The estimated direct and indirect cost for stroke in the U.S. in 2006 was \$57.9 billion.<sup>1</sup>

Noninvasive imaging plays an important role in identifying risk factors for stroke. Evaluation of the carotid arteries with invasive catheter arteriography is being replaced by duplex ultrasound (US), CT angiography (CTA), MR angiography (MRA) and time resolved contrast enhanced MRA (CE-MRA), all of which show high diagnostic accuracy for internal carotid artery (ICA) stenoses of 70%–99%.<sup>2–5</sup> US is the most cost-effective screening method, increasingly combined with CE-MRA for complete evaluation. Measurement of reduced cerebral vascular reserve (CVR) or elevated oxygen extraction fraction (OEF) by using nuclear, CT and MR imaging techniques may further define risk but these methods are not yet in wide clinical use (Table 1).

On the basis of ready availability and high sensitivity to acute hemorrhage, non-contrast CT historically has been the preferred modality for initial imaging of acute stroke, but has lacked high sensitivity to acute ischemia and infarction. Resurgence in the use of CT for acute ischemic stroke evaluation has occurred with the increasing clinical availability of CT perfusion (CTP), resulting in high sensitivity to early perfusion deficits, detectable prior to low density abnormalities on non-contrast CT.<sup>6,7</sup> Quantitative CTP measurements of CBF, CBV, MTT and TTP may also discriminate between infarct and salvageable “ischemic penumbra.”<sup>8,9</sup> The wide availability of these techniques plus the ability to quickly identify acute hemorrhage and vascular lesions using CTA, have been suggested as the key advantages of CT over MR imaging for acute stroke evaluation. However, the limited volume coverage of CTP (currently restricted to a 2 or 4 cm slab, the width of the detector array), the greater risks of reaction or fluid overload from iodinated contrast materials, and the lack of a direct measure of cellular viability like diffusion mitigate these advantages over MR imaging<sup>10</sup> (Table 1).

MR imaging diffusion weighted imaging (DWI) demonstrates diffusion “restriction” (reduced apparent diffusion coefficient, ADC), in acute cerebral ischemic injury within minutes of the precipitating ictus. Numerous direct comparisons to non-contrast CT have shown DWI to be much more sensitive to acute ischemia (80%–100% sensitivity compared to 25%–75% sensitivity for CT) with the greatest differences seen in the first 3-hours after symptom onset.<sup>11,12</sup> The addition of blood flow parameters (CBF, CBV, MTT and TTP) obtainable with gadolinium dynamic susceptibility contrast techniques (DSC or perfusion-weighted imaging, PWI) also allows MR imaging to identify the early “ischemic penumbra” as the reduced perfusion zone outside the DWI positive zone, the perfusion-diffusion (PWI-DWI) “mismatch.”<sup>13,14</sup> Combining this with vascular imaging (MRA) has made MR imaging an appealing tool for diagnosis and treatment monitoring of acute ischemic cerebrovascular disease. Enthusiasm for MR imaging in acute stroke evaluation has historically been dampened by the variable and confounding appearance of acute hemorrhage. Recent experience using T2\* (gradient echo) imaging to detect low signal parenchymal hemorrhage and FLAIR scans to detect high signal subarachnoid blood as well as BBB disruption that may predict infarct hemorrhagic transformation have helped renew interest in MR imaging as a first-line modality in patients with acute stroke.<sup>15–18</sup> However, there is currently insufficient widespread clinical experience to recommend MR imaging over CT for routine exclusion of intracranial hemorrhage.<sup>19</sup> It is also important to emphasize the issue of availability of MR imaging in the therapeutic time window and potential contraindications: patients with pacemakers, cerebral aneurysm clips, ocular foreign bodies or cochlear implants and those suffering from claustrophobia, or morbid obesity (320 lbs)<sup>20</sup> (Table 1).

Because most transient ischemic neurologic symptoms actually last for one hour or less and 50% or more show tissue injury on DWI<sup>21,22</sup>, a new definition of TIA has been proposed as “*a brief episode of neurologic dysfunction presumptively caused by focal brain or retinal ischemia, typically lasting less than one hour, without neuroimaging evidence of acute infarction.*”<sup>23,24</sup> This change reflects the growing emphasis on the earliest possible diagnosis and treatment of acute ischemia and the use of MR imaging and CT for definitive diagnosis and exclusion of hemorrhage.<sup>19</sup> The current recommended clinical practice in the U.S. is treatment with intravenous recombinant tissue plasminogen activator (rtPA), within 1 hour and no later than 3 hours after symptom onset, following the exclusion of intracerebral hemorrhage by a non-contrast CT scan.<sup>25–27</sup> However, only 20%–25% of admissions typically arrive at the emergency department within 3 hours of symptom onset and, following appropriate exclusions, successful treatment with rtPA, without symptomatic major hemor-

This article is a summary of the complete version of this topic which is available on the ACR website at [www.acr.org/ac](http://www.acr.org/ac). Practitioners are encouraged to refer to the complete version.

Reprinted with permission of the American College of Radiology.

Address correspondence to Robert L. DeLaPaz, MD, Department of Quality & Safety, American College of Radiology, 1891 Preston White Dr, Reston, VA 20191-4397

**Table 1: Clinical condition—Cerebrovascular disease: Ischemia**

	MRI, brain, with or without contrast	CT, head, with or without contrast	MRA, head and neck, with or without contrast	CTA, head and neck	Arterio- graphy, neck	Arterio- graphy, head and neck	US, carotid, duplex	US, trans cranial, Doppler
Asymptomatic: positive physical exam (cervical bruit) and/or risk factors.	5 <sup>a</sup>	5 <sup>ak</sup>	8 <sup>i</sup>	8 <sup>j</sup>	2	2	8 <sup>h</sup>	3
TIA: carotid territory or vertebrobasilar TIA, initial screening survey	8 <sup>abc</sup>	8 <sup>abcd</sup>	8 <sup>bc</sup>	8 <sup>bc</sup>	3	3	6	3
Less than 3 hours: new focal neurologic defect, fixed or worsening.	8 <sup>abc</sup>	8 <sup>abc</sup>	8 <sup>bc</sup>	8 <sup>bc</sup>	5 <sup>e</sup>	5 <sup>e</sup>	2	2
Three to 24 hours: new focal neurologic defect, fixed or worsening.	8 <sup>bcd</sup>	8 <sup>bcd</sup>	8 <sup>bc</sup>	8 <sup>bc</sup>	6 <sup>e</sup>	6 <sup>e</sup>	2	2
Greater than 24 hours: new focal neurologic defect, fixed or worsening.	8 <sup>bcd</sup>	8 <sup>bcd</sup>	8 <sup>bc</sup>	8 <sup>bc</sup>	6 <sup>e</sup>	6 <sup>e</sup>	2	2

**Note:**—Appropriateness criteria scale from 1 to 9, 1 = least appropriate, 9 = most appropriate; <sup>a</sup>, consider perfusion if stenosis found; <sup>b</sup>, combined vascular and cerebral evaluation should be considered; <sup>c</sup>, MR preferred if treatment not unreasonably delayed; <sup>d</sup>, primarily to rule out hemorrhage; <sup>e</sup>, if intra-arterial therapy is considered; <sup>f</sup>, diffusion especially valuable; <sup>g</sup>, for perfusion according to institutional protocols; <sup>h</sup>, may need to confirm with second non-invasive study; <sup>i</sup>, MRA of neck only, with or without contrast. MRA head = 3 but recommended if neck stenosis or occlusion found; <sup>j</sup>, CTA of neck only. CTA head = 3 but recommended if neck stenosis or occlusion found; <sup>k</sup>, CT head without contrast = 3

**Table 2: Clinical condition—Cerebrovascular disease: Hemorrhage**

	MRI, brain, with or without contrast	CT, head, with or without contrast	CT, head, without and with contrast	MRA, head, with or without contrast	MRA, neck, with or without contrast	CTA, neck	CTA, head	Arterio- graphy, head and neck	Arterio- graphy, neck	US, trans cranial, Doppler
Aneurysm: Risk for unruptured aneurysm. Positive family history	6	3	3	8 <sup>b</sup>	3	2	8 <sup>bc</sup>	1	1	1
SAH: clinically suspected subarachnoid hemorrhage, not yet confirmed	4	9	5	4	2	2 <sup>d</sup>	2	2	2	1
SAH: proven by lumbar puncture or imaging	6	8	5	7	6 <sup>d</sup>	6 <sup>d</sup>	8	8	8 <sup>de</sup>	5 <sup>f</sup>
SAH: proven but negative angiogram, follow-up	8 <sup>ab</sup>	5	4	8 <sup>ab</sup>	5	5	8 <sup>b</sup>	8	5	5 <sup>f</sup>
Hematoma: clinically suspected parenchymal hemorrhage, not yet confirmed	7	8	7	4	3	3	4	3	2	1
Hematoma: proven parenchymal hemorrhage	8 <sup>ab</sup>	8 <sup>ab</sup>	7	8 <sup>ab</sup>	5	5	8 <sup>ab</sup>	7 <sup>g</sup>	7	1

**Note:**—Appropriateness criteria scale from 1 to 9, 1 = least appropriate, 9 = most appropriate; <sup>a</sup>, combined vascular and cerebral evaluation; <sup>b</sup>, MR preferred if treatment not unreasonably delayed should be considered; <sup>c</sup>, noncontrast CT obtained routinely at the same time; <sup>d</sup>, for treatment planning; <sup>e</sup>, as part of cerebral angiography; <sup>f</sup>, for vasospasm; <sup>g</sup>, if suspect AVM

rhage, is limited to 3%–8.5% of ischemic stroke admissions.<sup>25,28</sup> Accordingly, current thrombolysis and clot extraction research trials are focused on expanding this time-to-treatment window with individualized, patient-specific therapy guided by the MR imaging PWI-DWI mismatch as a surrogate biomarker for the salvageable ischemic penumbra<sup>29–32</sup>, one demonstrating successful treatment as late as 9 hours after ictus.<sup>33</sup> Because the diffusion restriction and mismatch zones may also include underperfused but metabolically stable “oligemic” tissue, BOLD-MR imaging, SPECT and PET methods may be more widely used in the future to specifically identify the treatable ischemic penumbra by elevated OEF in low CBF “misery perfusion” regions or by using specific markers of cellular oxidative stress and ischemic injury (Table 1).

As CT is almost universally available and is highly sensitive to acute intracranial hemorrhage, it remains the mainstay in emergent evaluation of suspected epidural, subdural, subarachnoid and parenchymal hemorrhage. Catheter arteriography also remains the definitive diagnostic test for the source of intracranial hemorrhage, especially subarachnoid hemorrhage (SAH), with sensitivity to all cerebral aneurysms greater

than 90%, decreasing to 80% in the setting of acute SAH.<sup>34</sup> However, recent comparisons of CTA to catheter arteriography in SAH patients have shown overall CTA aneurysm detection sensitivities of 85%–95%, declining for smaller aneurysms to approximately 50% for those under 2 mm diameter.<sup>35–37</sup> Treatment of intracranial aneurysms following SAH is increasingly based on CTA alone<sup>38,39</sup> and the evaluation of post-SAH vasospasm and ischemia are increasingly investigated with transcranial Doppler (TCD), CTA and CTP in place of catheter angiography and SPECT.<sup>40,41</sup> Follow-up of clipped or coiled aneurysms for residual filling remains definitive with catheter arteriography but there is a growing interest in less invasive techniques, especially dynamic bolus CE-MRA (eg, TRICKS).<sup>42–44</sup> Intracranial hemorrhage may also be caused by arteriovenous vascular malformations and fistulae which are currently also best assessed by catheter arteriography. Existing time-resolved CE-MRA and multi-section CTA methods do not yet match the combined high spatial and temporal resolution of catheter arteriography for primary diagnosis of arteriovenous malformations but may useful for treatment follow-up<sup>45,46</sup> (Table 2).

## Review Information

This guideline was originally developed in 1996. The last review and update was completed in 2007.

## Appendix

Expert Panel on Neurologic Imaging: Robert L. DeLaPaz, MD, Principal Author, Columbia University Medical Center, New York, NY; David J. Seidenwurm, MD, Panel Chair; Patricia C. Davis, MD, Vice-Chair; James A. Brunberg, MD; Pr. Didier Dormont; David B. Hackney, MD; John E. Jordan, MD; John P. Karis, MD; Suresh Kumar Mukherji, MD; Patrick A. Turski, MD; Franz J. Wippold II, MD; Robert D. Zimmerman, MD; Michael A. Sloan, MD, MS, American Academy of Neurology.

## References

1. Thom T, Haase N, Rosamond W, et al. **Heart disease and stroke statistics—2006 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee.** *Circulation* 2006;113:e85–151
2. Barth A, Arnold M, Mattle HP, et al. **Contrast-enhanced 3-D MRA in decision making for carotid endarterectomy: a 6-year experience.** *Cerebrovasc Dis* 2006;21:393–400
3. Honish C, Sadanand V, Fladeland D, et al. **The reliability of ultrasound measurements of carotid stenosis compared to MRA and DSA.** *Can J Neurol Sci* 2005;32:465–71
4. Koelmenay MJ, Nederkoorn PJ, Reitsma JB, et al. **Systematic review of computed tomographic angiography for assessment of carotid artery disease.** *Stroke* 2004;35:2306–12
5. Wardlaw JM, Chappell FM, Best JJ, et al. **Non-invasive imaging compared with intra-arterial angiography in the diagnosis of symptomatic carotid stenosis: a meta-analysis.** *Lancet* 2006;367:1503–12
6. Coutts SB, Lev MH, Eliasziw M, et al. **ASPECTS on CTA source images versus unenhanced CT: added value in predicting final infarct extent and clinical outcome.** *Stroke* 2004;35:2472–76
7. Smith WS, Roberts HC, Chuang NA, et al. **Safety and feasibility of a CT protocol for acute stroke: combined CT, CT angiography, and CT perfusion imaging in 53 consecutive patients.** *AJNR Am J Neuroradiol* 2003;24:688–90
8. Schaefer PW, Roccatagliata L, Ledezma C, et al. **First-pass quantitative CT perfusion identifies thresholds for salvageable penumbra in acute stroke patients treated with intra-arterial therapy.** *AJNR Am J Neuroradiol* 2006;27:20–25
9. Wintermark M, Flanders AE, Velthuis B, et al. **Perfusion-CT assessment of infarct core and penumbra: receiver operating characteristic curve analysis in 130 patients suspected of acute hemispheric stroke.** *Stroke* 2006;37:979–85
10. Latchaw RE, Yonas H, Hunter GJ, et al. **Guidelines and recommendations for perfusion imaging in cerebral ischemia: A scientific statement for healthcare professionals by the writing group on perfusion imaging, from the Council on Cardiovascular Radiology of the American Heart Association.** *Stroke* 2003;34:1084–104
11. Chalela JA, Kidwell CS, Nentwich LM, et al. **Magnetic resonance imaging and computed tomography in emergency assessment of patients with suspected acute stroke: a prospective comparison.** *Lancet* 2007;369:293–98
12. Mullins ME, Schaefer PW, Sorensen AG, et al. **CT and conventional and diffusion-weighted MR imaging in acute stroke: study in 691 patients at presentation to the emergency department.** *Radiology* 2002;224:353–60
13. Kidwell CS, Alger JR, Saver JL. **Evolving paradigms in neuroimaging of the ischemic penumbra.** *Stroke* 2004;35:2662–65
14. Schaefer PW, Ozsunar Y, He J, et al. **Assessing tissue viability with MR diffusion and perfusion imaging.** *AJNR Am J Neuroradiol* 2003;24:436–43
15. da Rocha AJ, da Silva CJ, Gama HP, et al. **Comparison of magnetic resonance imaging sequences with computed tomography to detect low-grade subarachnoid hemorrhage: Role of fluid-attenuated inversion recovery sequence.** *J Comput Assist Tomogr* 2006;30:295–303
16. Fiebach JB, Schellinger PD, Gass A, et al. **Stroke magnetic resonance imaging is accurate in hyperacute intracerebral hemorrhage: a multicenter study on the validity of stroke imaging.** *Stroke* 2004;35:502–06
17. Kidwell CS, Chalela JA, Saver JL, et al. **Comparison of MRI and CT for detection of acute intracerebral hemorrhage.** *JAMA* 2004;292:1823–30
18. Warach S, Latour LL. **Evidence of reperfusion injury, exacerbated by thrombolytic therapy, in human focal brain ischemia using a novel imaging marker of early blood-brain barrier disruption.** *Stroke* 2004;35:2659–61
19. Adams H, Adams R, Del Zoppo G, et al. **Guidelines for the early management of patients with ischemic stroke: 2005 guidelines update a scientific statement from the Stroke Council of the American Heart Association/American Stroke Association.** *Stroke* 2005;36:916–23
20. Shellock FG, Cruess JV. **MR procedures: biologic effects, safety, and patient care.** *Radiology* 2004;232:635–52
21. Kidwell CS, Alger JR, Di Salle F, et al. **Diffusion MRI in patients with transient ischemic attacks.** *Stroke* 1999;30:1174–80
22. Restrepo L, Jacobs MA, Barker PB, et al. **Assessment of transient ischemic attack with diffusion- and perfusion-weighted imaging.** *AJNR Am J Neuroradiol* 2004;25:1645–52
23. Albers GW, Caplan LR, Easton JD, et al. **Transient ischemic attack—proposal for a new definition.** *N Engl J Med* 2002;347:1713–16
24. Warach S, Kidwell CS. **The redefinition of TIA: the uses and limitations of DWI in acute ischemic cerebrovascular syndromes.** *Neurology* 2004;62:359–60
25. Graham GD. **Tissue plasminogen activator for acute ischemic stroke in clinical practice: a meta-analysis of safety data.** *Stroke* 2003;34:2847–50
26. Hacke W, Donnan G, Fieschi C, et al. **Association of outcome with early stroke treatment: pooled analysis of ATLANTIS, ECASS, and NINDS rt-PA stroke trials.** *Lancet* 2004;363:768–74
27. Wardlaw JM, Zoppo G, Yamaguchi T, et al. **Thrombolysis for acute ischaemic stroke.** *Cochrane Database Syst Rev* 2003;CD000213
28. Reeves MJ, Arora S, Broderick JP, et al. **Acute stroke care in the US: results from 4 pilot prototypes of the Paul Coverdell National Acute Stroke Registry.** *Stroke* 2005;36:1232–40
29. Albers GW, Thijs VN, Wechsler L, et al. **Magnetic resonance imaging profiles predict clinical response to early reperfusion: the diffusion and perfusion imaging evaluation for understanding stroke evolution (DEFUSE) study.** *Ann Neurol* 2006;60:508–17
30. Hjort N, Butcher K, Davis SM, et al. **Magnetic resonance imaging criteria for thrombolysis in acute cerebral infarct.** *Stroke* 2005;36:388–97
31. Köhrmann M, Jüttler E, Fiebach JB, et al. **MRI versus CT-based thrombolysis treatment within and beyond the 3 h time window after stroke onset: a cohort study.** *Lancet Neurol* 2006;5:661–67
32. Rowley HA. **Extending the time window for thrombolysis: evidence from acute stroke trials.** *Neuroimaging Clin N Am* 2005;15:575–87, x
33. Furlan AJ, Eyding D, Albers GW, et al. **Dose Escalation of Desmoteplase for Acute Ischemic Stroke (DEDAS): evidence of safety and efficacy 3 to 9 hours after stroke onset.** *Stroke* 2006;37:1227–31
34. Kassell NF, Boarini DJ, Adams HP, Jr., et al. **Overall management of ruptured aneurysm: comparison of early and late operation.** *Neurosurgery* 1981;9:120–28
35. Dammert S, Krings T, Moller-Hartmann W, et al. **Detection of intracranial aneurysms with multislice CT: comparison with conventional angiography.** *Neuroradiology* 2004;46:427–34
36. Jayaraman MV, Mayo-Smith WW, Tung GA, et al. **Detection of intracranial aneurysms: multi-detector row CT angiography compared with DSA.** *Radiology* 2004;230:510–18
37. Wintermark M, Uske A, Chalaron M, et al. **Multislice computerized tomography angiography in the evaluation of intracranial aneurysms: a comparison with intraarterial digital subtraction angiography.** *J Neurosurg* 2003;98:828–36
38. Dehdashti AR, Rufenacht DA, Delavelle J, et al. **Therapeutic decision and management of aneurysmal subarachnoid haemorrhage based on computed tomographic angiography.** *Br J Neurosurg* 2003;17:46–53
39. Hoh BL, Cheung AC, Rabinov JD, et al. **Results of a prospective protocol of computed tomographic angiography in place of catheter angiography as the only diagnostic and pretreatment planning study for cerebral aneurysms by a combined neurovascular team.** *Neurosurgery* 54:1329–40, 2004; discussion 1340–22
40. Sviri GE, Mesiwala AH, Lewis DH, et al. **Dynamic perfusion computerized tomography in cerebral vasospasm following aneurysmal subarachnoid hemorrhage: a comparison with technetium-99m-labeled ethyl cysteinate dimer-single-photon emission computerized tomography.** *J Neurosurg* 2006;104:404–10
41. Wintermark M, Ko NU, Smith WS, et al. **Vasospasm after subarachnoid hemorrhage: utility of perfusion CT and CT angiography on diagnosis and management.** *AJNR Am J Neuroradiol* 2006;27:26–34
42. Farb RI, Nag S, Scott JN, et al. **Surveillance of intracranial aneurysms treated with detachable coils: a comparison of MRA techniques.** *Neuroradiology* 2005;47:507–15
43. Gaurvit JY, Leclerc X, Caron S, et al. **Intracranial aneurysms treated with Guglielmi detachable coils: imaging follow-up with contrast-enhanced MR angiography.** *Stroke* 2006;37:1033–37
44. Pierot L, Delcourt C, Bouquigny F, et al. **Follow-up of intracranial aneurysms selectively treated with coils: Prospective evaluation of contrast-enhanced MR angiography.** *AJNR Am J Neuroradiol* 2006;27:744–49
45. Gaurvit JY, Oppenheim C, Nataf F, et al. **Three-dimensional dynamic magnetic resonance angiography for the evaluation of radiosurgically treated cerebral arteriovenous malformations.** *Eur Radiol* 2006;16:583–91
46. Matsumoto M, Kodama N, Endo Y, et al. **Dynamic 3D-CT angiography.** *AJNR Am J Neuroradiol* 2007;28:299–304