RadioGraphics

CT Protocol for Acute Stroke: Tips and Tricks for General Radiologists[1]

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LEARNING OBJECTIVES

After reading this article and taking the test, the reader will be able to:

- List the key technical points of a complete multidetector CT examination for hyperacute stroke and determine an appropriate CT protocol.
- Describe the main imaging findings of acute ischemic stroke at nonenhanced CT, perfusion CT, and CT angiography.
- Discuss the significance of the penumbra for therapy planning and prognosis in patients with acute stroke.

TEACHING POINTS

See last page

Acute stroke services have been installed in most hospitals in the industrialized world, and dealing with hyperacute stroke has become one of the most frequently performed tasks of the on-call radiologist. Imaging plays a key role in current guidelines for thrombolysis, and knowledge of classic early ischemic signs or depiction of hemorrhage at nonenhanced computed tomography (CT) is necessary (although not sufficient) for a satisfactory imaging study. A modern CT examination must also include perfusion CT and CT angiography. Perfusion CT delineates the ischemic tissue (penumbra) by showing increased mean transit time with decreased cerebral blood flow (CBF) and normal or increased cerebral blood volume (CBV), whereas infarcted tissue manifests with markedly decreased CBF and decreased CBV. CT angiography can depict the occlusion site, help grade collateral blood flow, and help characterize carotid atherosclerotic disease. A complete CT study (nonenhanced CT, perfusion CT, and CT angiography) may be performed and analyzed rapidly and easily by general radiologists using a simple standardized protocol and may even facilitate diagnosis by less experienced radiologists in affected patients.

Abbreviations: ACA = anterior cerebral artery, CBF = cerebral blood flow, CBV = cerebral blood volume, MCA = middle cerebral artery, MIP = maximum-intensity-projection, MTT = mean transit time, ROI = region of interest

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Introduction

Stroke is the third leading cause of death in the United States, with approximately 550,000 cases and 150,000 deaths per year, and is also a major cause of disability in adults (1). Stroke is a syndrome caused by disruption of the blood flow to part of the brain due to either *(a)* occlusion of a blood vessel (ischemic stroke, seen in approximately 80% of cases); or *(b)* rupture of a blood vessel, resulting in injury to cells and causing sudden loss of focal brain functions.

The only therapy for acute stroke currently approved by the U.S. Food and Drug Administration and the European Union is intravenous thrombolysis with a recombinant tissue-type plasminogen activator called alteplase (2). However, the benefit of intravenous thrombolysis decreases steadily over time from symptom onset (3), so that the time window for intervention can be as narrow as 3 hours. Thus, patients must be selected accurately and in a timely manner, since many patients with conditions other than brain ischemia may present with similar clinical findings (4). Imaging plays a key role by helping exclude hemorrhage or other mimicking lesions (5).

The use of computed tomography (CT) for stroke evaluation has progressively increased, since magnetic resonance (MR) imaging is less widely available than CT outside major stroke centers and is much more limited by patient contraindications or intolerance (6). In addition, CT is fast and is easily performed in severely ill patients who are dependent on support and monitoring devices (Table 1). In recent years, the amount of information provided by the radiologist has increased owing to the use of additional CT techniques such as perfusion CT and CT angiography. Multimodal CT evaluation that combines nonenhanced CT, perfusion CT, and CT angiography has been shown to improve detection of acute infarction (7,8); permit assessment of the site of vascular occlusion, the infarct core, and salvageable brain tissue; and help assess the degree of collateral circulation (9). This multimodal approach requires only 10–15 minutes more than nonenhanced CT alone (10).

These imaging techniques have been devel- oped in major tertiary centers under the tutelage of specialized neuroradiologists. However, perfusion CT and CT angiography have been incorporated into daily clinical practice in stroke units around the world, and it is important that the resultant images be correctly interpreted by the on-call general radiologist. Even when this extra work and responsibility could be perceived as a heavy load, our experience confirms that perfusion CT and CT angiography may be the allies of a relatively inexperienced radiologist, since the findings are frequently easier to interpret than subtle signs at nonenhanced CT. In this article, we review the technical and practical aspects of a multimodal CT protocol for acute stroke, with a focus on data acquisition, postprocessing, and analysis as performed by the general radiologist in the emergency setting.

Teaching Point

Before the Arrival of the Patient

The entire stroke team must keep in mind that "time is brain" and that everything should be prepared for when the patient arrives. The activation of the stroke code leads to stopping work at the emergency department CT scanner. The power injector must be loaded with 125 mL of nonionic contrast material (300 mg of iodine per milliliter) and 50 mL of saline solution. In addition, the emergency department nurse has to gain adequate peripheral venous access with an 18–20-gauge needle to support the 4 mL/sec injection rate needed for perfusion CT. Any metallic hardware, including dental and hair prostheses, should be removed from the patient.

CT Protocol

The complete CT protocol, which includes nonenhanced CT, perfusion CT, and CT angiography, can be performed as a single examination with separate contrast material boluses. The examination is frequently completed and analyzed within 15 minutes in a real clinical setting using new-generation multidetector CT scanners. In addition, correlation of all the imaging findings with the vascular anatomy and clinical findings is crucial, since the latter two elements are linked and are necessary to fulfill all the requirements for hyperacute stroke imaging (11,12). Nevertheless, we usually proceed with perfusion CT and CT angiography only if hemorrhage has been ruled out with nonenhanced CT. Even if there are other contraindications for thrombolysis, CT angiography and perfusion CT are still frequently performed (they are optional but not mandatory and are always performed only after consulting with the neurologist) to achieve a more precise diagnosis. Such a diagnosis is normally helpful in case management—especially at expert centers, where intraarterial treatment may be considered within 3–6 hours after the stroke event.

Table 1
MR Imaging versus CT for Acute Stroke

MR Imaging	Computed Tomography
Less widely available than CT outside of major stroke centers	Widespread access
Contraindications (eg, electronic implants, patient intolerance, medical instability)	Greater acquisition speed
Gradient-echo imaging superior to CT for the detection of acute hemorrhage	Highly sensitive for the exclusion or confirmation of hemorrhage
Diffusion-weighted imaging more sensitive than nonenhanced CT for the early detection of acute ischemia	Findings at CBV–perfusion CT and CT angiography–source imaging correlate with lesion size and ischemic lesion volumes at diffusion-weighted imaging
Much more sensitive than nonenhanced CT for the detection of acute stroke	Multimodal CT survey (nonenhanced CT, perfusion CT, CT angiography) may be as sensitive as MR imaging
Comparison of findings at diffusion-weighted imaging and perfusion-weighted imaging represents the key fact of mismatch theory models	Mismatch can be determined with CBV (infarct core)–CBF (penumbra) maps
No radiation dose	Higher radiation dose

Note.—CBF = cerebral blood flow, CBV = cerebral blood volume.

Table 2
CT Technical Protocol for Acute Stroke

	Imaging Technique		
Parameter	Nonenhanced CT	Perfusion CT	CT Angiography
Mode	Axial scanning	Cine imaging	Helical scanning
Gantry angle (°)	Orbital view	Orbital view	0
Section thickness (mm)	5	5*	0.625
Pitch	. . .	. . .	0.531:1
Kilovolt peak (kVp)	120	80	120
Milliamperage (mA)	250	150	Automatic (200–400) with noise index of 12
Rotation time (sec)	0.8	1	0.4
Contrast material			
Volume (mL)	. . .	50	60
Injection rate (mL/sec)	. . .	4	3.5
Saline flush (mL)	. . .	. . .	30†
Delay (sec)	. . .	5	Bolus tracking on ascending aorta
Attenuation values (bolus tracking) (HU)	. . .	. . .	70
Acquisition time (sec)	. . .	45	~10

*Per eight sections.
†Injection rate = 3.5 mL/sec.

The protocol we use with our 32-detector CT scanner is shown in Table 2. Other similar protocols can be used with different CT equipment (13–15). Table 3 shows the three main questions that need to be answered with CT protocol in patients with acute stroke and the specific procedures that will help answer each question.

Table 3
Questions To Be Answered with CT Protocol

Question	Imaging Technique
Is the stroke ischemic or hemorrhagic?	Nonenhanced CT
Is there a flow obstruction in a major vessel?	CT angiography
Which tissue is already infarcted and which is still salvageable?	Perfusion CT and CT angiography

Nonenhanced CT

Nonenhanced scanning must be performed as soon as possible after the stroke code has been activated (16). CT is highly sensitive for the depiction of hemorrhagic lesions (17), and the key role of nonenhanced CT is the detection of hemorrhage or other possible mimics of stroke (eg, neoplasm, arteriovenous malformation) that could be the cause of the neurologic deficit. The second role of nonenhanced CT is the detection of ischemic signs of established infarction. The main CT finding is a cortical-subcortical hypoattenuating area within a vascular territory (Fig 1). Careful attention to the extent of the hypoattenuating area is crucial: The presence of hypoattenuation affecting more than one-third of the MCA territory is a contraindication for revascularization because it has been demonstrated that hemorrhagic complications are associated with larger established infarcted lesions before treatment (18). It is, however, well-known that nonenhanced CT has a relatively low sensitivity in the first 24 hours, especially within the limited (3–6-hour) time window for thrombolytic treatment. Nevertheless, the capacity for lesion depiction is markedly improved by using a narrow window width and adequate center level settings (5,19). As a general guideline, the images may first be analyzed with a standard window width and level setting of approximately 40/20 HU, with a second narrower setting of 20/32 HU used to demonstrate subtle abnormalities that suggest ischemia (19).

Teaching Point

In a review by Wardlaw and Mielke (20), a higher sensitivity (61%) was observed for depiction of subtle early signs of infarction and ischemia, including *(a)* subtle hypoattenuation, *(b)* obscuration and loss of gray matter–white matter differentiation in the basal ganglia, *(c)* cortical sulcal effacement, *(d)* loss of the insular ribbon, and *(e)* hyperattenuation of a large vessel ("hyperattenuating MCA sign" or "dot sign" in an M2 branch) (Fig 2). These signs are associated with a worse prognosis and poorer functional outcome (20) but are not contraindications for treatment. However, they may be confusing, especially for the nonspecialized radiologist with erroneous interpretations in up to 20% of cases (21). The MCA hyperattenuation is produced by an interarterial thrombus but is seen in only about 30% of cases (15) and may be erroneously interpreted in patients with increased hematocrit, wall calcifications, polycythemia, or arterial dolichoectasia. In addition, these signs, like sulcal effacement, are not useful for distinguishing between ischemic penumbra and core infarction. Several methods, like ASPECTS (Alberta Stroke Program Early CT Score) (22), have been developed to standardize the analysis of early ischemic signs with excellent interobserver reliability, but in our experience they are too time consuming for the on-call radiologist to perform in daily clinical practice.

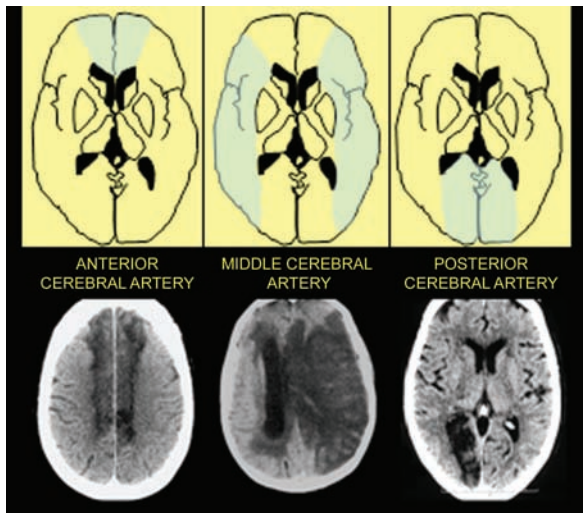


Figure 1. Drawings (top) illustrate the territories (blue) of the ACA, middle cerebral artery (MCA) , and posterior cerebral artery. CT scans (bottom) show established infarctions of these arteries.

Perfusion CT

Perfusion CT is performed by monitoring only the first pass of an iodinated contrast agent bolus through the cerebral circulation (23). It involves continuous cine imaging for 45 seconds over the same slab of tissue (1–32 sections) during the dynamic administration of a small (50-mL), high-flow contrast material bolus (injection rate, 4–5 mL/sec). We usually administer intravenous contrast material prior to testing renal function to reduce delays in treatment and because it has been demonstrated that contrast material–induced nephropathy is a rare complication in acute stroke patients who undergo multimodal contrast-enhanced CT (24). The radiation dose is reduced by using lower milliamperage and ki-

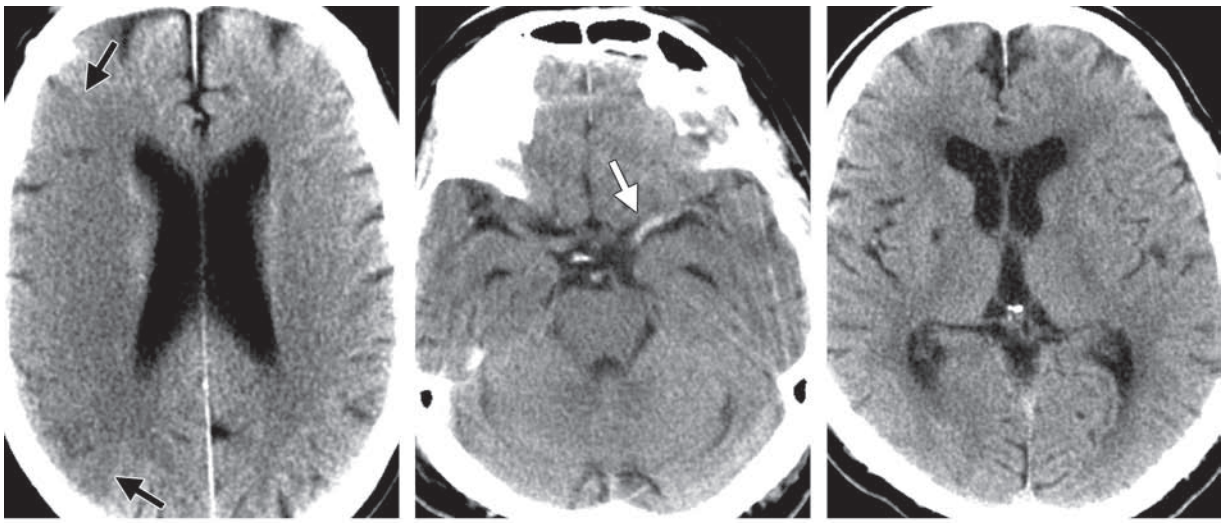


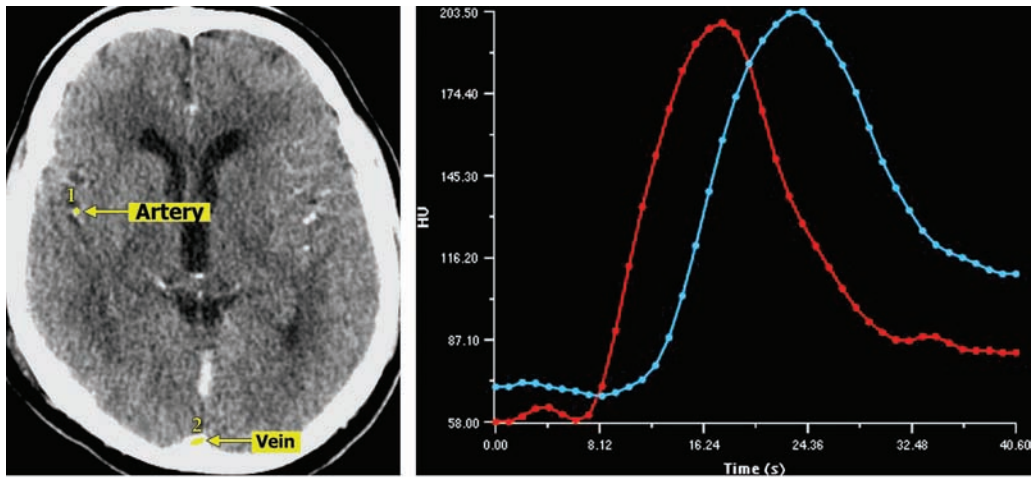
Figure 2. Early ischemic CT signs. CT scans show subtle hypoattenuation and sulcal effacement in the right MCA territory (arrows in **a**), a hyperattenuating left MCA (arrow in **b**), and obscuration and loss of gray matter–white matter differentiation of the left basal ganglia and sulcal effacement in the left MCA territory **(c)**.

lovoltage. Motion artifact is the main challenge in many acute stroke patients, since sedation is frequently not possible, but immobilization of the patient's head can limit motion. It is useful to see all the images as a movie to help detect possible motion artifact prior to selecting the region of interest (ROI) vessels, because if these artifacts are significant, they can completely invalidate the study. In addition, we always use the automatic registration program included as the first element of such software; this program is able to correct small motions (repeating the registration process may be useful in more difficult cases).

The contrast agent passes through the brain tissue, causing a transient hyperattenuation that is directly proportional to the amount of contrast material in the vessels and blood in that region. This principle is used to generate time-attenuation curves for an arterial ROI, a venous ROI, and each pixel. Despite there being new, accurate automatic options in the available software to generate all the maps, it is still frequently better to use a semiautomatic option, which consists of first manually tracing a large ROI around the vessel and then letting the software automatically select an accurate ROI. The arterial ROI is optimally selected in one unaffected vessel that is perpendicular to the acquisition plane, either one of the anterior cerebral arteries (ACAs) or the contralateral MCA. In emergency settings, we prefer to select an ACA as the default arterial input function for simplicity because it has been shown to be adequate (25). The venous ROI is placed over the superior sagittal sinus or torcular Herophili (adequate window width must be used so as not to include skull bone within the venous ROI). The venous ROI is necessary to correct the data for partial volume averaging effects and thereby help achieve accurate quantification of perfusion parameters (Fig 3) (23). The generated graphic must be studied to detect possible poor timing of the contrast material bolus (the curve must have included an initial plane before rising and a decline before the end of the acquisition) and to distinguish good arterial input function or venous outflow function (the venous curve must be higher than and represent a 1–2-second delay after the arterial curve).

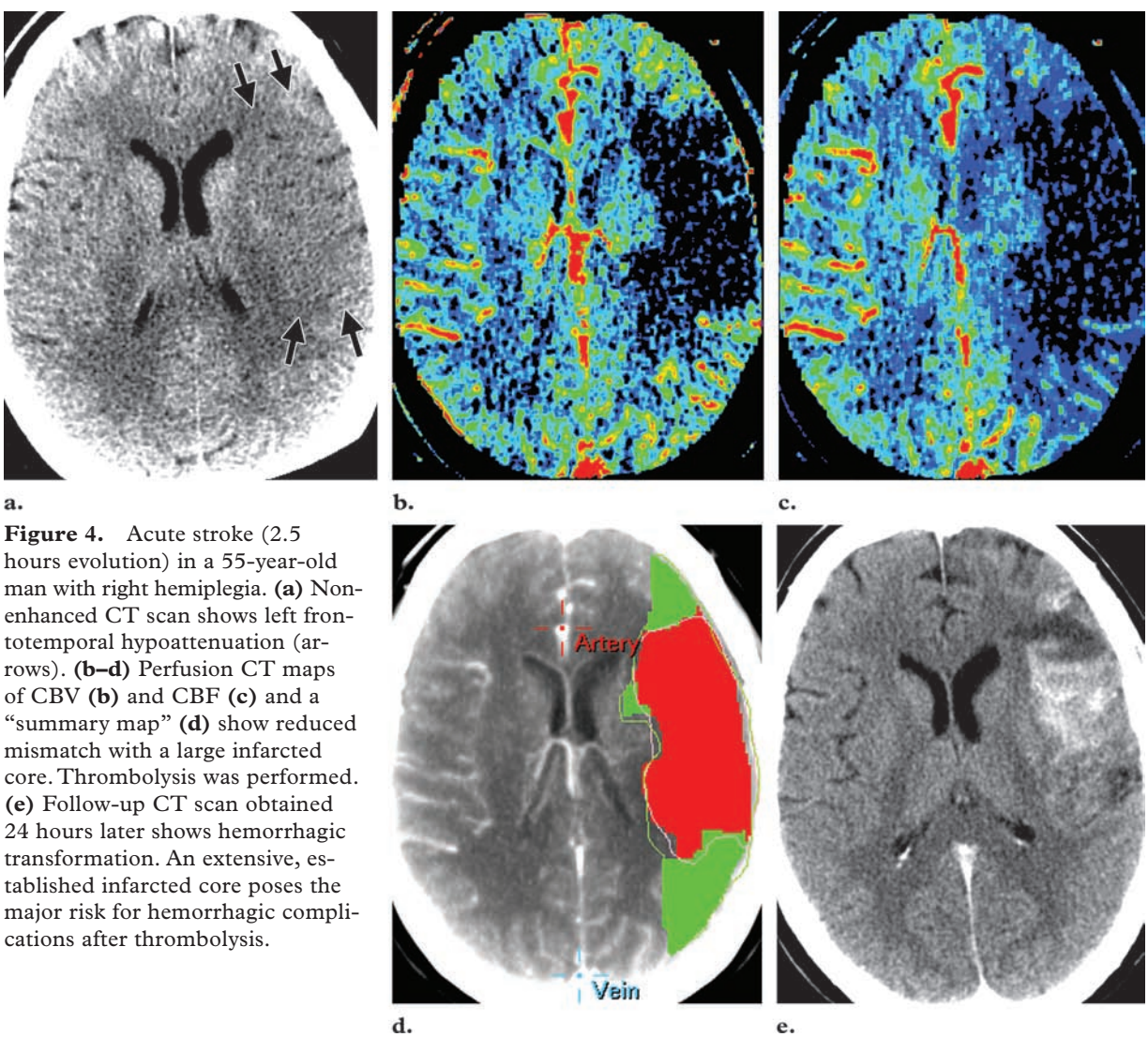
Color-coded perfusion maps showing CBV, mean transit time (MTT), and CBF are obtained (15,23,26). The quantification of these parameters is based on the equation CBF = CBV/MTT. MTT is calculated by performing a mathematical technique called deconvolution on the regional time-attenuation curve of each pixel with respect to the arterial curve (arterial input function) (27,28). CBV is calculated by dividing the area under the curve in a parenchymal pixel by the area under the curve in an arterial pixel. The accuracy of perfusion CT has been validated with other standard perfusion techniques such as positron emission tomography and stable xenon CT (29).

In our experience, quick visual assessment of the perfusion maps is better than more accurate measurements in the emergency setting. The map showing MTT should be analyzed first because it shows the most prominent regional abnormalities (24) and facilitates depiction of the ischemic area



a. b.

Figure 3. Perfusion CT software. **(a)** CT scan with superimposed labels illustrates semiautomatic selection of arterial (ACA or contralateral MCA) and venous ROIs. **(b)** Graph illustrates time-attenuation curves for arterial (red) and venous (blue) ROIs.



a. b. c.

d. e.

Figure 4. Acute stroke (2.5 hours evolution) in a 55-year-old man with right hemiplegia. **(a)** Nonenhanced CT scan shows left frontotemporal hypoattenuation (arrows). **(b–d)** Perfusion CT maps of CBV **(b)** and CBF **(c)** and a "summary map" **(d)** show reduced mismatch with a large infarcted core. Thrombolysis was performed. **(e)** Follow-up CT scan obtained 24 hours later shows hemorrhagic transformation. An extensive, established infarcted core poses the major risk for hemorrhagic complications after thrombolysis.

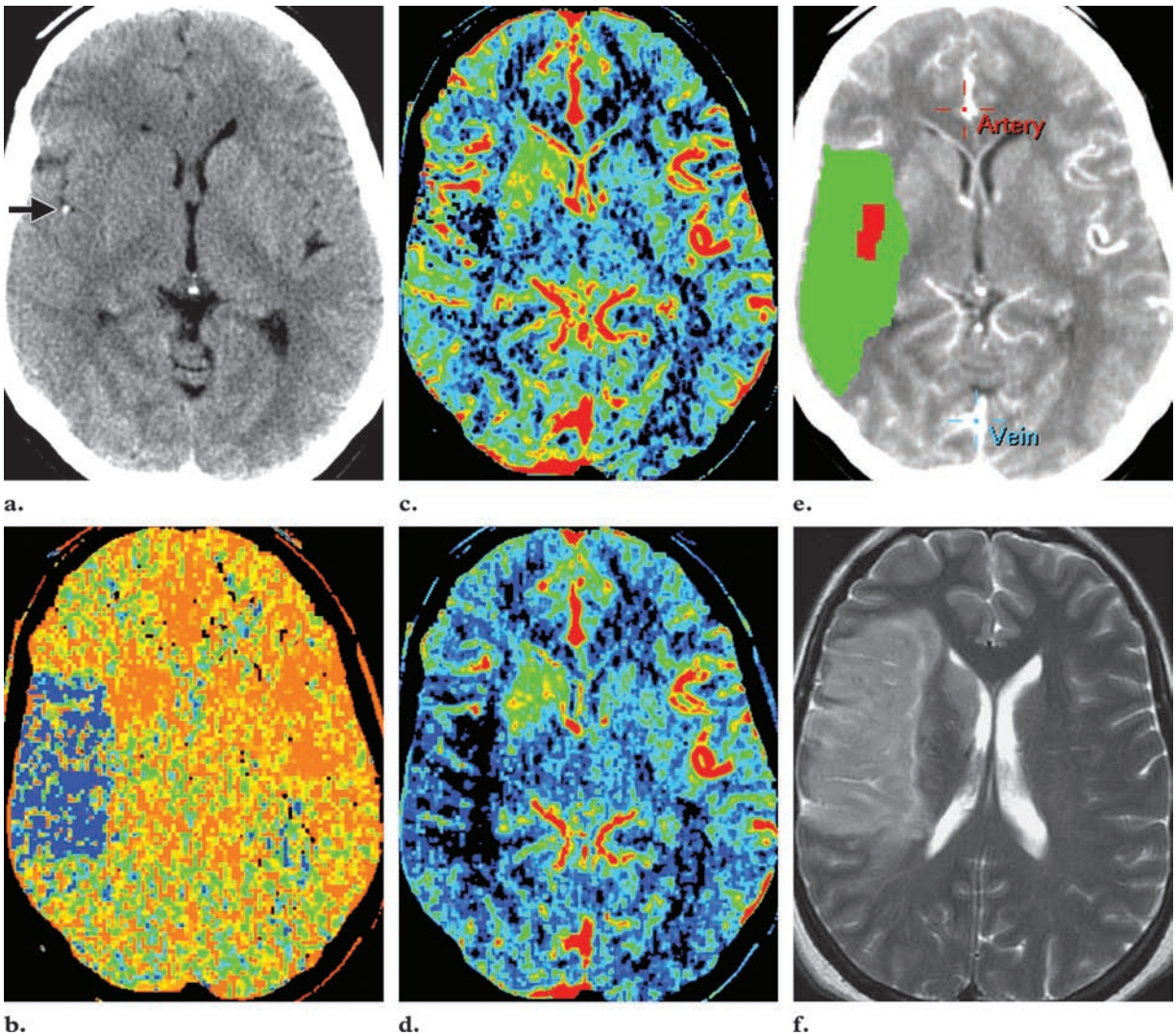


Figure 5. Acute stroke (6 hours evolution) in a 46-year-old woman with left hemiplegia. **(a)** Nonenhanced CT scan shows the dot sign (arrow) in the right MCA, loss of right-sided gray matter–white matter differentiation, and obscuration of the basal ganglia. **(b–e)** Perfusion CT maps of MTT **(b)**, CBV **(c)**, and CBF **(d)** and a summary map **(e)** show altered MTT and CBF in the right frontotemporal area, suggestive of ischemia, and a reduced subcortical area with decreased CBV, suggestive of an infarcted core. Note the area of increased CBF and CBV in the right caudate and lenticular nucleus, representing the first stage of brain ischemia (compensatory supply with cerebrovascular reserve). **(f)** Follow-up axial T2-weighted MR image shows a hyperintense right frontoparietal area and caudate nucleus related to final infarction in the ischemic area (both decreased and increased flow areas at perfusion CT), which resulted because no treatment was performed.

(increased MTT) and the search for a correlation with suspect clinical and imaging findings. Subsequently, we analyze the CBF and CBV maps, which are more specific for distinguishing ischemia from infarction (Figs 4, 5) (30–33). It may be useful to outline the areas with altered CBF and CBV, superimpose both areas, and calculate the percentage of mismatch (CBV area ÷ CBF area).

The main challenge of perfusion CT used to be limited coverage (2–4 cm per scan), but newer 256-section scanners can provide whole-brain coverage, and in the next few years this coverage will be widely available. Our main strategy is to study a single 4-cm slab at the level of the basal ganglia because it contains representative territories of the ACA, MCA, and posterior cerebral artery and is the best option for evaluating suspected MCA stroke. However, we can also set the region of perfusion in another territory—even in the infratentorial region, although many more artifacts might be observed—based on the nonenhanced CT findings or clinical findings.

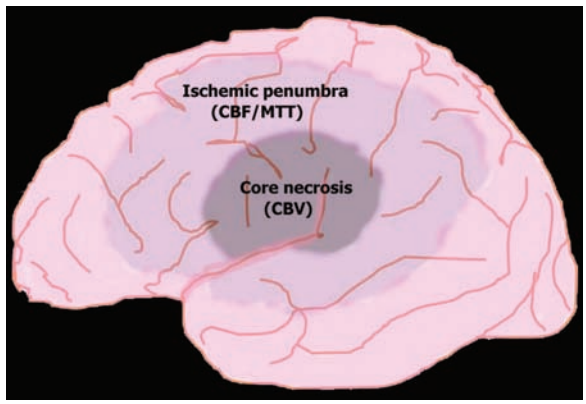


Figure 6. Drawing illustrates the pathophysiologic features of acute stroke: a core of irreversibly infarcted tissue related to decreased CBV surrounded by a peripheral region of ischemic but salvageable tissue (penumbra) with decreased CBF, increased MTT, and normal CBV.

Table 4
Perfusion CT Analysis of Hyperacute Ischemic Stroke

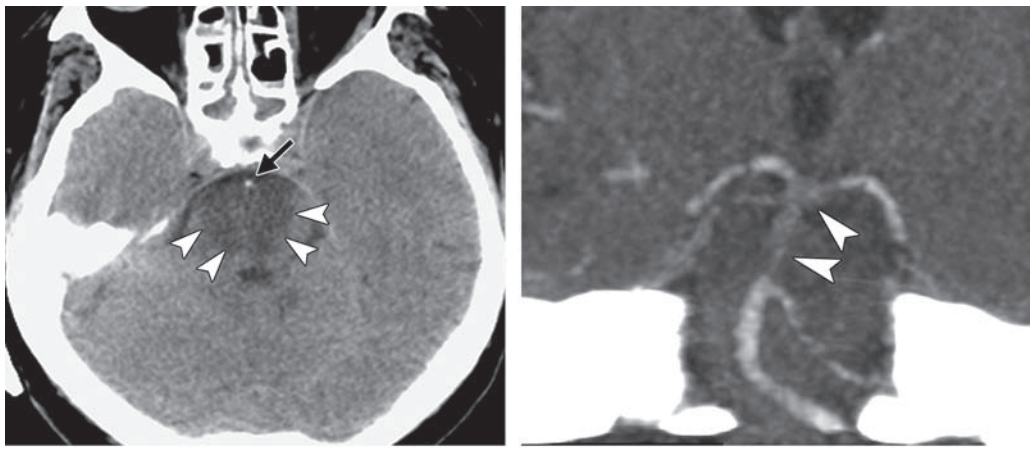
	Analytic Tool			
Entity	MTT	CBF	CBV	Nonenhanced CT
Penumbra	Elevated (>145%)	Decreased	Normal or mildly increased	Normal findings or brain swelling
Infarct core	Elevated	Markedly decreased	Markedly decreased (<2.0 mL × 100 g^{-1})	Hypoattenuating parenchyma

Source.—Reference 8.

In acute stroke, there is a central, irreversibly infarcted tissue core surrounded by a peripheral region of stunned cells called the penumbra that receives a collateral blood supply from uninjured arterial and leptomeningeal territories (Fig 6). The cells in the penumbra are potentially salvageable with early recanalization (5). Recent studies have demonstrated that intravenous thrombolytic therapy may benefit patients beyond the first 3 hours of evolution if the patients are carefully selected based on findings of perfusion mismatch (4).

Perfusion CT can help distinguish the penumbra from infarcted tissue in acute stroke patients. Several studies have shown that the CBV map depicts the lesions seen at diffusion MR imaging, helping predict the infarcted brain tissue that is not salvageable despite reperfusion (30,31). In addition, the CBF map depicts the altered area seen at perfusion MR imaging, which is related to the ischemic area. Thus, the ischemic tissue (penumbra) shows increased MTT with decreased CBF and normal or mildly increased CBV (secondary to autoregulatory mechanisms in the early stage of ischemia), whereas infarcted tissue shows markedly decreased CBF and increased MTT with markedly decreased CBV (Table 4) (8,30,31). Hence, the salvageable brain tissue is equivalent to CBF – CBV (Figs 4, 5). Some authors have reported a threshold for core infarction when CBV is less than 2 L/min and for ischemic tissue when MTT is over 145% (8). On the basis of these quantitative thresholds, delineation of infarction and penumbra may be achieved and presented on summary maps, on which the infarcted core is shown in red and the penumbra in green (15). These summary maps easily and rapidly provide information to the clinician and can be automatically generated with some software programs; to our knowledge, however, there have been no reports analyzing the usefulness and reliability of these maps in the daily clinical setting.

Nevertheless, a patient is selected for thrombolysis on the basis of clinical findings (persisting and disabling deficit), a 3-hour interval from the onset of symptoms, exclusion of many other clinical criteria, and the absence of hemorrhage at nonenhanced CT. Up-to-date perfusion CT findings are still not included in the standardized criteria for patient selection for thrombolysis (34,35). Thus, if the perfusion CT findings are normal or show a small or absent penumbra (ie, no mismatch), thrombolysis is still usually performed. (It may be possible that small but clinically significant ischemic foci may be below the spatial or contrast resolution of a "normal" perfusion CT scan.) In addition, several reports and our own experience demonstrate that diffusion-weighted imaging lesions and CBV lesions are not always irreversible (5,30,34). On the other hand, many trials now being performed at expert



a. b.

Figure 7. Acute stroke in a 43-year-old woman who had lost consciousness. Findings at initial nonenhanced CT were normal, and CT angiography was not performed. **(a)** Follow-up nonenhanced CT scan (36 hours evolution) shows a hypoattenuating midbrain (arrowheads) and a hyperattenuating basilar artery (arrow). **(b)** CT angiogram helps confirm a filling defect of the basilar artery (arrowheads) related to pons infarction and basilar artery obstruction.

centers are based on the selection of patients according to the presence or absence of "viable ischemic brain tissue" as defined with perfusion (MR imaging or CT) mismatch.

CT Angiography

Teaching Point

The main role of CT angiography is to reveal the status of large cervical and intracranial arteries and thereby help define the occlusion site, depict arterial dissection, grade collateral blood flow, and characterize atherosclerotic disease. This information helps accurately predict the extent and location of the final infarction and is very useful in providing guidance for the interventional neuroradiologist prior to intraarterial thrombolysis if available. Intraarterial thrombolysis has been associated with higher recanalization rates for occlusions of the internal carotid artery, MCA stem, and basilar artery (34,35). Thus, CT angiography is useful in detecting these occlusions and differentiating them from more distal (M2 or M3) occlusions for intravenous, intraarterial, or mixed (intravenous-intraarterial) treatment planning. In addition, CT angiography is especially important for the detection of thrombosis of the vertebrobasilar system (36), since this entity is very difficult to detect at nonenhanced CT and the brainstem is frequently not included in the perfusion coverage. In our experience, the main pitfalls have been caused by basilar artery occlusions that are missed because nonenhanced CT and perfusion CT are performed but not CT angiography (Fig 7).

CT angiography is a thin-section volumetric CT examination performed with a time-optimized bolus of nonionic contrast medium (300–400 mg of iodine per milliliter) to enhance the carotid and vertebral arteries and the circle of Willis. The examination includes the region from the aortic arch to the vertex, with a minimum section thickness and reduced pitch (Table 2) (15).

The evaluation of the main intracranial arteries requires approximately 5 minutes and is performed with multiplanar maximum-intensity-projection (MIP) reformatting (thickness ~ 20 mm) on a three-dimensional workstation for rapid identification of occlusion or stenosis of the carotid artery or MCA. At our center, the basic analysis is standardized with five predefined MIP reformatted images (two axial, one midline sagittal, and two coronal) of the circle of Willis and rapid review of the axial images of the vessels from the aorta to the vertex. Additional views can be obtained to detect occlusions in minor vessels like CM2-CM3 branches (Figs 8, 9).

At nonenhanced CT, a hyperattenuating carotid artery or MCA represents an intravascular acute blood clot, but this finding may be difficult to interpret. CT angiography can help detect the presence of a filling defect in the vessel caused by true arterial thrombosis with a sensitivity of 89% compared with conventional angiography (37). On the other hand, minor thromboses are frequently missed in the daily clinical setting if no correlation is performed with perfusion and clinical findings and if the search does not encompass the involved vessel. Moreover, the extent of arterial leptomeningeal collateral vessels beyond the occlusion must be analyzed because patients with better pial collateral formation appear to have a better prognosis (38,39). The branches of the contributing vessels can be evaluated based on a simplified version of the classic angiographic grading scale for collateral

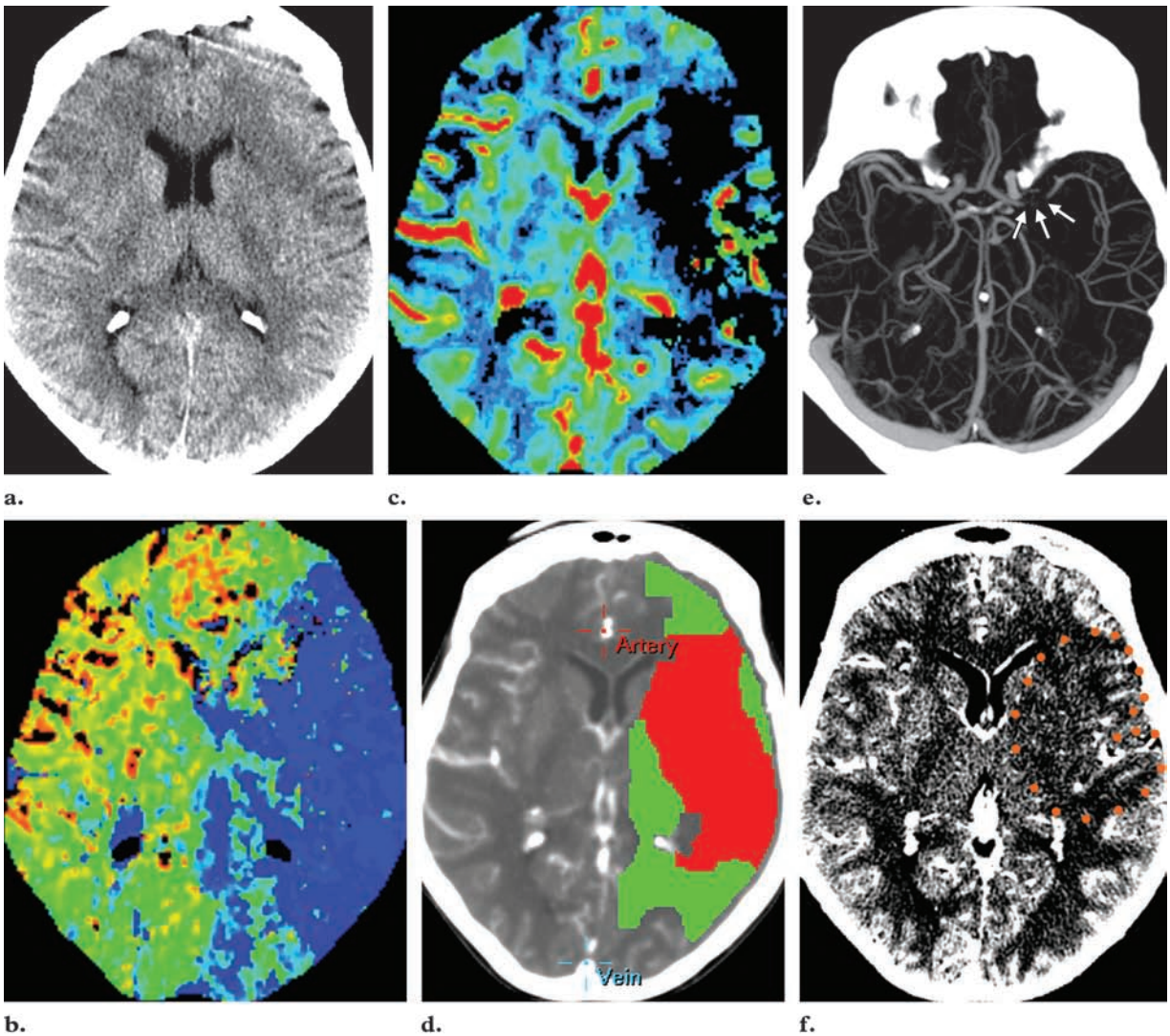
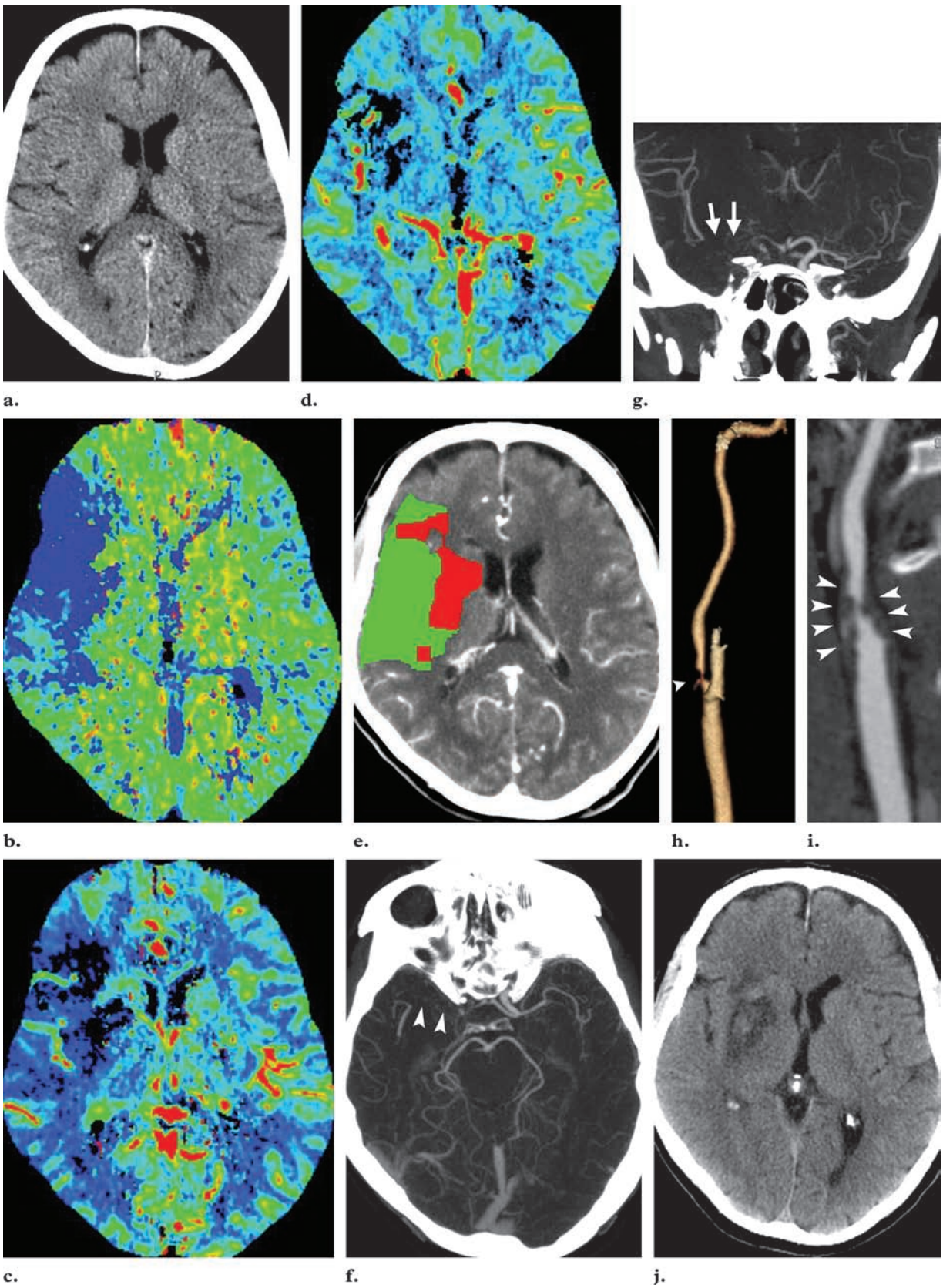


Figure 8. Acute stroke (1.5 hours evolution) in a 57-year-old woman with right hemiplegia. **(a)** Nonenhanced CT scan shows loss of the insular ribbon in the left MCA and hypoattenuation of the left lenticular nucleus. **(b–d)** Perfusion CT maps of MTT **(b)** and CBV **(c)** and a summary map **(d)** show extensive infarction with reduced mismatch. **(e)** Axial MIP reformatted CT angiographic image shows left MCA obstruction (arrows). **(f)** CT angiographic–source image shows an area of hypoattenuation, thereby helping confirm core infarction (orange dots). **(g)** Axial diffusion-weighted MR image obtained 24 hours later shows a hyperintense lesion representing established infarction. The lesion appears very similar to the area seen at CT angiography–source imaging.

Figure 9. Acute stroke (2 hours evolution) in a 46-year-old man with left hemiparesis. **(a)** Nonenhanced CT scan shows slight hypoattenuation of the right basal ganglia. **(b–e)** Perfusion CT maps of MTT **(b)**, CBF **(c)**, and CBV **(d)** and a summary map **(e)** show 70% mismatch in the right frontotemporal region and basal ganglia. **(f, g)** Axial **(f)** and coronal **(g)** MIP reformatted CT angiographic images show obstruction of the right MCA (arrowheads in **f**) and right carotid artery (arrows in **g**). **(h, i)** Volume-rendered **(h)** and curved **(i)** reformatted images show significant stenosis of the right internal carotid artery (arrowheads). Thrombolysis was performed. **(j)** Follow-up nonenhanced CT scan obtained 24 hours later shows established infarction in the right basal ganglia only, related to the area observed on the CBV map (cf **d**).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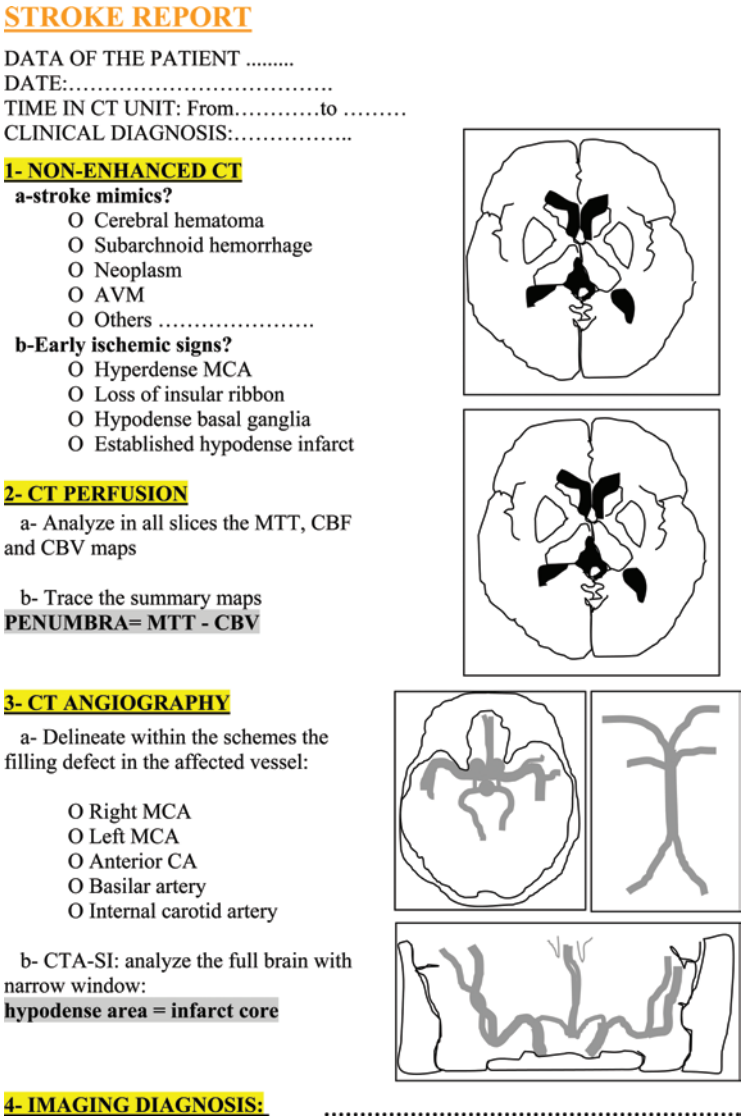

Figure 10. Chart illustrates a stroke report. *AVM* = arteriovenous malformation, *CA* = carotid artery, *CTA-SI* = CT angiography–source imaging.

circulation: 0 = no visible collateral vessels to the ischemic site, 1 = visible collateral vessels to the periphery of the ischemic site, 2 = complete irrigation of the ischemic bed by collateral flow, and 3 = normal antegrade flow (39). In addition, curved reformatted images of the carotid and vertebral arteries are obtained for better evaluation of the presence and morphologic features (calcification, irregular surface, ulceration) of heterogeneous plaques and quantification of the degree of stenosis (40). Shaded-surface-display views may be especially useful for the evaluation of arteries with complex morphologic features.

A second step includes a whole-brain analysis of the source images with a narrow window (CT angiography–source imaging). This technique provides a whole-brain "perfused blood volume map," since the contrast agent fills the brain microvasculature in normal perfused tissue (7,41,42) but not the microvasculature of infarcted brain regions, which are depicted as hypoattenuating parenchyma. Various window width and center level settings must be used for optimal detection of ischemic hypoattenuation (approximately 25/35 HU, but important differences can be observed with different CT scanners and patients because of variations in the time of arrival of the contrast material bolus and in acquisition parameters). CT angiography–source imaging is more sensitive than nonenhanced CT in the detection of early irreversible ischemia and more accurate in predicting final infarct volume (41), with good correlation with the hyperintense lesions seen at diffusion-weighted imaging (7,42,43) and the low-CBV areas seen at perfusion CT. CT angiography–source imaging

Table 5
Simple Standardized CT Protocol for Acute Ischemic Stroke

Imaging Technique	Caveats and Suggestions
Nonenhanced CT	Absence of hemorrhage or tumor represents the key fact of the entire study
	Subtle hypoattenuating areas are not very important (perfusion CT will help)
	Hyperattenuating MCA may be an erroneous sign (CT angiography should be performed)
	Hypoattenuation indicates infarcted tissue (involvement of more than one-third of MCA territory impedes thrombolysis)
	Take time to analyze images, double-check ventricles and basal cisterns for possible subarachnoid hemorrhage
Perfusion CT	Limited anatomic coverage (lesion outside selected coverage [eg, lacunar infarct] may be missed)
	Patient motion can impede this technique (sedation needed but frequently not possible)
	Review cine images to detect movement; use registration program
	Software: *(a)* watch for erroneous selection of the artery, with inclusion of parenchyma or skull base in the ROI; *(b)* an ACA or the contralateral MCA is a better arterial input function option
	Look at MTT map first because it is easier to analyze
	Subsequently delineate the altered areas on the CBV map (infarct core) and on the CBF map (ischemic area) to obtain a mismatch map (penumbra [salvageable tissue] = CBF − CBV)
	Summary maps are very useful, but double-check for possible artifacts
CT Angiography	Use basic predefined MIP reformatted images for rapid and easy analysis
	Look carefully for basilar artery obstruction (may be missed at nonenhanced CT or perfusion CT)
	Look for possible extracranial carotid artery obstruction
	Source images must be analyzed with a narrow window for full-brain CBV-like information (hypoattenuation indicates infarcted tissue)
	Analyze distal collateral blood flow to the ischemic area observed at perfusion CT
	Integrate all imaging and clinical findings

provides accurate complementary whole-brain information for the perfusion CT maps and can sometimes obviate a separate perfusion CT study.

According to current guidelines, head CT or MR imaging should be performed and intravenous thrombolysis initiated within 60 minutes after the patient arrives at the hospital (35). Thus, the complete CT protocol can be performed routinely because some reports, as well as our experience, show that CT angiographic and perfusion CT maps may be analyzed in approximately 10–15 minutes (5) with good interobserver agreement (44). Finally, the information obtained must be rapidly provided to the neurologist in an easy-to-interpret visual report. At our institution, the key findings obtained at nonenhanced CT are evaluated before the patient leaves the CT scanner. Subsequently, perfusion CT and CT angiographic findings are evaluated and included in a standardized stroke report (Fig 10) to summarize the main findings and facilitate analysis and the communication of the key findings to all on-call radiologists and residents (38).

Conclusions

The on-call radiologist has a key role in the management of acute stroke. A complete CT study (nonenhanced CT, perfusion CT, and CT angiography) may be performed and analyzed rapidly and easily by general radiologists using a simple standardized protocol (Table 5). Hemorrhages should be ruled out at nonenhanced CT, but time should not be lost in puzzling over subtle early ischemic signs. Perfusion CT can delineate the salvageable brain tissue (mismatch), and CT angiography helps detect vessel occlusion and collateral flow.

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CT Protocol for Acute Stroke: Tips and Tricks for General Radiologists

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Page 1674
Perfusion CT and CT angiography have been incorporated into daily clinical practice in stroke units around the world, and it is important that the resultant images be correctly interpreted by the on-call general radiologist.

Page 1676
The key role of nonenhanced CT is the detection of hemorrhage or other possible mimics of stroke (eg, neoplasm, arteriovenous malformation) that could be the cause of the neurologic deficit.

Page 1680
In acute stroke, there is a central, irreversibly infarcted tissue core surrounded by a peripheral region of stunned cells called the penumbra that receives a collateral blood supply from uninjured arterial and leptomeningeal territories. The cells in the penumbra are potentially salvageable with early recanalization.

Page 1680
The ischemic tissue (penumbra) shows increased MTT with decreased CBF and normal or mildly increased CBV (secondary to autoregulatory mechanisms in the early stage of ischemia), whereas infarcted tissue shows markedly decreased CBF and increased MTT with markedly decreased CBV. Hence, the salvageable brain tissue is equivalent to CBF [minus] CBV.

Page 1681
The main role of CT angiography is to reveal the status of large cervical and intracranial arteries and thereby help define the occlusion site, depict arterial dissection, grade collateral blood flow, and characterize atherosclerotic disease.