


THE ROLE OF CT PERFUSION IN ACUTE STROKE

CT perfusion is an important and rapidly growing diagnostic tool in the evaluation of acute ischemic stroke. It allows for the assessment of blood flow, cerebral blood volume (CBV), and mean transit time (MTT) in the affected area. These parameters are crucial in determining the potential for reperfusion and the likelihood of favorable clinical outcomes.

Table 1: Key Perfusion Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>CBV</td>
<td>Cerebral blood volume is the total amount of blood present in the tissue.</td>
</tr>
<tr>
<td>MTT</td>
<td>Mean transit time is the average time it takes for a bolus of contrast to pass through the brain.</td>
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<tr>
<td>A1</td>
<td>Adjacent perfusion to the ischemic area.</td>
</tr>
<tr>
<td>A2</td>
<td>Adjacent perfusion to the non-ischemic area.</td>
</tr>
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</table>

The role of perfusion imaging in acute stroke is supported by the American Heart Association. Perfusion information complemented the parenchymal data from routine CT or MR and identified the site of vascular occlusion by using a combination of density measures. The chosen slices were obtained at 4-Kbps for 45 seconds using a cine mode while injecting a 50-mL, 400-mg/mL contrast bolus at 4 ml/sec, followed by a 20-ml saline chaser. During the analysis, regions of interest were placed to allow kinetic modeling. ROIs are shown for the anterior cerebral artery, used as the arterial reference territory, the superior sagittal sinus, which serves as a venous reference function, and arterial collateral territory contained in the MCA territories. Extensive low attenuation is seen throughout the right hemisphere.

One-fifth of acute stroke patients actually arrive at the hospital within the approved three-hour window. Simply reading CTs more carefully and treating beyond three hours of the event may improve outcomes. Although it is considered an off-label use of IV desmoteplase, recent data suggest that the technique is safe and effective in patients treated as late as nine hours after symptom onset.

Table 2: Perfusion Study-Step-by-Step

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquire dynamic images</td>
<td>Using IV bolus contrast techniques to provide perfusion parameters.</td>
</tr>
<tr>
<td>Gadolinium contrast (Gd)</td>
<td>Used to enhance tissue contrast.</td>
</tr>
<tr>
<td>Quality control steps</td>
<td>Ensure image quality and data integrity.</td>
</tr>
<tr>
<td>Acquire parameter maps</td>
<td>Select artery, vein curves, apply deconvolution model, create/resolve parameter maps.</td>
</tr>
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Although it is considered an off-label use of contrast in CT and MR, the use of perfusion in evaluating acute ischemic stroke is supported by the American Heart Association. Perfusion information complemented the parenchymal data from routine CT or MR and identified the site of vascular occlusion by using a combination of density measures. The chosen slices were obtained at 4-Kbps for 45 seconds using a cine mode while injecting a 50-mL, 400-mg/mL contrast bolus at 4 ml/sec, followed by a 20-ml saline chaser. During the analysis, regions of interest were placed to allow kinetic modeling. ROIs are shown for the anterior cerebral artery, used as the arterial reference territory, the superior sagittal sinus, which serves as a venous reference function, and arterial collateral territory contained in the MCA territories. Extensive low attenuation is seen throughout the right hemisphere.

The DIAS and Dose Escalation of Thrombolysis for Acute Ischemic Stroke Study (DEADAS) trials have used perfusion-diffusion mismatch as a selection criterion for thrombolytic therapy, showing that these techniques provide additional clinical trial centers.

Recent evidence suggests that the comprehensive CT or MR stroke protocol, including the full tail of the venous curve, can be used to display any of these maps; for example, three different color scales can be chosen to display any of these maps. The various parameter maps are displayed in a color scale that is optimized to suit the particular visualization needs. Color scales can be chosen to display one of these maps. Color scales can be chosen to display one of these maps.

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Perfusion parameter maps are calculated (Figure 4). The goal is to use the parameter maps to reflect the tissue itself, not the bulk delivery of blood to vessels. The deconvolution perfusion software therefore attempts to correct for macrovascular blood delivery, hemodynamic, and volume effects, and other effects. CT perfusion has a clear advantage over MR in that it is performed as a part of the same comprehensive imaging session. Dynamic data sets are generated using rapid bolus administration of IV indium contrast, contrasted with rapid cine mode CT scanning through a limited area of the brain. Over an approximately 45-second scan duration, the dynamic wash-in and wash-out characteristics of the contrast bolus are captured and then used as perfusion parameter maps. An arterial curve is used in a mathematical deconvolution process that allows quantitative perfusion parameter maps to be calculated (Figure 4).

The importance of defining the ischemic area, usually from a combination of Circle of Willis connections and a-pial collateral networks, is emphasized. CT perfusion parameters directly reflect the underlying dynamic physiology of vascular autoregulation. Since blood flow arrives to an ischemic area over a longer path and time, the necessary elevation in blood volume, CBV, can be low (uncompensated), high (compensated), or normal (incompeting). CT is a single-brick layer of the brain, not the absolute stroke and help inform treatment decisions. In Figure 5, the complex regional changes related to reperfusion are seen after IV TPA. This includes a luxury perfusion pattern and signs of a kaku blooming of an area of reduced CBF. The luxury perfusion pattern is seen after IV TPA. This includes a luxury perfusion pattern and signs of a kaku blooming of an area of reduced CBF. CT perfusion assessments can be used to guide treatment decisions and improve patient outcomes.

Collateral flow and autoregulation

Because stroke is a complex, dynamic process, exact thresholds of tissue viability will vary between individuals due to the availability of collateral vessels, area of involvement, white versus gray matter location, pressure gradient imaging protocol, and method of analysis. Neuronal death occurs rapidly in acute stroke—estimates put the figure at about 1.9 million neurons per minute—but the ultimate injury depends on both degree and duration of ischemia and is the ultimate determinant of injury. The key determinant of injury is the extent to which an individual can maintain flow to the ischemic area, usually from a combination of Circle of Willis connections and a-pial collateral networks. CT perfusion parameters directly reflect the underlying dynamic physiology of vascular autoregulation. Since blood flow arrives to an ischemic area over a longer path and time, the necessary elevation in blood volume, CBV, can be low (uncompensated), high (compensated), or normal (incompeting). CT is a single-brick layer of the brain, not the absolute stroke and help inform treatment decisions. In Figure 5, the complex regional changes related to reperfusion are seen after IV TPA. This includes a luxury perfusion pattern and signs of a kaku blooming of an area of reduced CBF. CT perfusion assessments can be used to guide treatment decisions and improve patient outcomes.

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one-fifth of acute stroke patients actually arrive at the hospital within the approved three-hour window. Simply reading CTs more carefully and treating beyond three hours has also been considered. Table 2 has been adjusted to reflect this. Noncontrast CT in an attempt to demonstrate benefit beyond three hours has not shown improved neurologic outcomes.

Perfusion assessment has rapidly become a key method of triage and patient selection for a number of stroke treatment trials, particularly those carried out at time points beyond three hours.

Perfusion techniques in stroke

Fast multislice CT scan protocols can be used with IV bolus contrast techniques to provide parameter maps along with CT angiography for evaluation of clinical stroke centers. These images are generated using rapid bolus administration protocols that allow the perfusion scan to be acquired in a single breath-hold. The deconvolution perfusion software gives an instantaneous parameter map and provides patient-specific information, which enables the educated selection of patients targeted to the most appropriate candidate for a variety of treatment options. Table 1. Key perfusion parameters

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<td>mL/100 g brain/ min</td>
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<tr>
<td>CBV</td>
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</tr>
<tr>
<td>MTT</td>
<td>seconds</td>
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Table 1. Key perfusion parameters

Perfusion parameter maps

Several other parameter maps are generated using the same comprehensive imaging session and the same exam has been used to quickly generate parameter maps due to the extensive information on which to base treatment decisions. In Figure 5, the complex regional changes related to reperfusion are seen after IV TPA. This includes a luxury perfusion pattern and signs of a kypo blood flow in the anterior MCA territory. The CT permeability maps. Preliminary studies suggest that preexisting permeability defects may be linked to hemorrhagic transformation after TPA.

Collateral flow and autoregulation

Because stroke is a dynamic, complex process, exact thresholds of tissue viability will vary. In addition, factors include collateral circulation, vascular territory involved, white versus gray matter location, presence of intracranial stenosis or occlusion, and the interplay between intracranial and intracranial vasculature. Neuronal death occurs rapidly in acute stroke—estimates put the figure at about 1.9 million neurons per minute—but the ultimate injury depends on both degree of ischemia and is the most sensitive and simplest means of detecting abnormal blood delivery. This is the first map we review to show actual stroke, as it gives a worst case scenario estimate of tissue at risk.

Neurovascular coupling—on the other hand, brain attempts to autoregulate perfusion in the face of falling arterial pressures. If collateral supply is sufficient, precarious autoregulation will dilate, leading to a compensatory elevation of cerebral blood flow (CBF) in the ischemic zone. When cerebral blood flow (CBF) decreases, CBV/MTT, this can fully balance overall CBF for some patients, especially those who develop occlusions slowly, over years.

If collaterals are insufficient to support the necessary delivery in blood volume, patients cannot autoregulate and vascular collapse ensues. Low CBF in an area of prolonged MTT therefore predicts impending infarction. Given these variable autoregulations and anterior MCA perfusion, CBV can be low (uncompensated), high (compensated), or normal (indeterminate). CBV is thus a single biomarker of autoregulation. CBV gives an indication of total nutrient delivery, accounting for the net effects of attempted autoregulation.

CT perfusion studies also allow acute triage and evaluation of the effects of intervention. Wintermark and colleagues have shown that an MTT prolongation greater than about 1.4 relative to the opposite hemisphere is sensitive for identification of penumbra, and that absolute CBV reductions below 2 and 1/2 mL/100 g are specific for impending infarction. Perfusion metrics can provide insight into the pathophysiology of acute stroke and help inform decisions in treatment. Figure 5, the complex regional changes related to reperfusion are seen after IV TPA.

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MIGRATION OF CONTRACT TISSUE

Modern isolated contracture is generally well tolerated in perfusion imaging, but potential renal toxicity and allergic reactions can cause morbidity and mortality. Nephrotoxicity has been reported in 3% to 7% of unselected patients receiving IV iodine and renal complication rates as high as 35% have been reported in high-risk, diabetic patients with preexisting renal insufficiency.55,56 Beyond standard hydration, the volume of contrast for combined CTA/CT perfusion exams can be reduced through the use of a saline chaser, a less renal-toxic contrast such as iodixanol for high-risk patients, or acetylcysteine to facilitate clearance.

OPTIMIZING ANATOMIC COVERAGE

Since CT perfusion techniques typically cover only 2 to 4 cm of brain, some strokes are missed simply because they are not included in the slices chosen. A critical aspect of setting up CT perfusion protocols, therefore, is to tailor the exam prescription to the patient’s needs, mainly based on stroke location, TOAST classification, and prior treatment. In noninvasive CT perfusion studies, an average of 4 to 5 mm coverage works well for large anterior circulation strokes, since this sampling rate has been found to be adequate for 1st-order vasculature and, in the posterior circulation territories.

APPLIEDND TRANSPORT

Beyond stroke applications reviewed here, CT perfusion has also been investigated in several other clinical and research settings. Examples include evaluation of collateral flow after subarachnoid hemorrhage (Figure 7), tumor characterization,18 traumatic brain injury,19 and assessment of graft viability.20

SUMMARY

CT perfusion assessment brings an individual, patient-specific, physiologic-based method (not just a time-on-scan parameter) to the selection of candidates who are most likely to benefit from thrombolysis, while simultaneously helping to prevent complications that could be hurt by these potentially risky strategies. Major predictors of CT perfusion integrity include presence of ischemia, high CBV indicates preserved perfusion, low CBF with a large diffusion abnormality indicates neuro-Source data: Stroke 2008;39(8):2174-2181.

REFERENCES

Although such exposure is considered appropriate and reasonable for most stroke patients, there is con-

MIGRATION OF CONTRAST TOXICITY
Modern iodinated contrast is generally well
tolerated in perfusion imaging,16 but poten-
tial renal toxicity and allergic reactions can cause morbidity and mortality.

RADIATION EXPOSURE AND REDUCTION STRATEGIES
Careful attention to technique allows safe ad-
dition of CT perfusion imaging to routine stroke protocols. Scans are typically acquired in cine mode over about 45 seconds at 60 kVp and 100 mA. It should be acknowledged and addressed to insure that this technique is not used for routine CT images but does allow adequate capture of the kinetics of iodinated contrast bolus, and that the raw images from individual time frames are not read for diagnostic purposes. De-

SUMMARY
CT perfusion assessment brings an individual, patient-specific, physiologic-based (not just a time- or anatomy-based)10 to the selection of candidates who are most likely to benefit from thrombolysis, while simultaneously identifying those patients who could be hurt by these potentially risky treatments. A prolonged MTT is the most sensitive parameter for detection of ischemia, high CBV indicates preserved autoregulation, and low CBV indicates uncompensated tissue likely to infarct. Wintzermark and others have shown that CT perfusion metrics can provide pre-
diictive information very similar to that gleaned from diffusion-perfusion mis-

APPLICATIONS BEYOND STROKE
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CT and perfusion computed tomography in hyperacute stroke. AJNR 2000;21(1):141-149.


