Brain perfusion CT is a useful instrument for the study and analysis of a variety of pathological conditions. It is particularly helpful for investigating ischemic stroke, one of the prime causes of disability in industrialized countries.

Thrombolytic therapy can restore normal blood flow in obstructed vessels following stroke, but treatment must be administered rapidly after onset of symptoms. Efforts have therefore been made to select and study which patients may benefit from this approach. A patient with suspected ischemic stroke first undergoes a basal unenhanced brain CT to evaluate the possible presence of hemorrhagic stroke, the main contraindication for thrombolytic therapy. Alternative techniques, such as perfusion MRI, xenon CT, PET, and SPECT, have also been investigated as possible means of detecting perfusion deficits. All appear favorable, but their costs prevent all but a few specialist centers from offering these services.

Perfusion CT, by comparison, is a low-cost, relatively easy, and noninvasive technique, requiring only a CT scanner and a dedicated software package. Further clinical studies are needed, however, before perfusion CT can be adopted for stroke management. Critics of the technique have noted that anatomic coverage is limited to a transverse plane passing through the basal ganglia. Analysis of derived perfusion maps is thus restricted to a discrete cerebral territory. Operator dependence and the absence of standardized protocols also cause concern.

Assessment of stroke and cerebrovascular reserve and grading of glial neoplasms are currently regarded as acceptable applications for perfusion CT. We are studying the viability of the technique in acute ischemic stroke and glial neoplasm grading, using the Advantage 4.0 workstation from GE Healthcare.

Ischemic lesions are commonly seen on CT perfusion maps as areas with reduced cerebral blood flow (CBF), reduced cerebral blood volume (CBV), and increased mean transit time (MTT) (Figure 1). Intracranial neoplasms demonstrate a range of perfusion patterns according to histology, malignancy, and the presence of necrosis. A dedicated tumor protocol, included in the software, acquires data about a parameter known as the "permeability surface," which describes the amount of injected contrast escaping from the abnormal vessels of a neoplasm (Figure 2).

Brain perfusion CT is based on the central volume principle: $\text{CBF} = \frac{\text{CBV}}{\text{MTT}}$. We first use 200 images acquired in cine mode to track the transit of an iodinated contrast bolus through the cerebral vasculature. Dedicated software calculates the transient attenuation increase that the bolus produces during its passage. The next step involves selection of two regions of interest (ROI) in a cerebral artery and in a vein, which is necessary for the generation of time-concentration curves. The operator then obtains perfusion maps using a complex mathematical algorithm known as the deconvolution method.

Perfusion CT is technically easy to perform (Table 1). Postprocessing on a dedicated workstation is generally quick and follows standardized protocols. Several technical aspects can, however, affect data evaluation and the final report.

**MAJOR CHALLENGES**

Pitfalls associated with cerebral perfusion CT can be divided into two major groups (Table 2). Technical pitfalls include scanning mode, slice thickness, anatomic coverage, gantry tilt, kV choice, infusion rate, and prep delays. Problems related to data manipulation include motion correction, choice of vessel to begin analysis, temporal sampling interval, and evaluation of the artery time/intensity curve morphology.

Continuous (cine) scan mode with an interscan interval lesser than or equal to one second, as opposed to discontinuous (nonspiral) CT scanning, is required to increase temporal resolution and overall accuracy of perfusion maps. The reduced acquisition time limits the total dose absorbed by
the patient. Most CT scanners obtain 200 images for a 4 x 5-mm slice thickness protocol and 198 images for 2 x 10-mm slice protocol without table motion.²

Slice location can be selected at the time of examination. A transverse plane passing through the basal ganglia may be used to analyze the principal vascular territories supplied by the anterior cerebral artery, middle cerebral artery, and posterior cerebral artery. The transverse plane can be composed of two 10-mm-thick slices or four 5-mm thick slices. The optimum arteries/veins for ROI selection should be large vessels with courses almost perpendicular to the transverse plane. The anterior cerebral artery and superior sagittal sinus vein are usually prime candidates.

Venous outflow function is important in correcting for volume averaging effects.° Partial volume effects can be minimized on perfusion maps through use of 5-mm-thick rather than 10-mm-thick slices, despite the lower signal-to-noise ratio (Figure 3).

One of the most significant weaknesses of cerebral perfusion CT is its limited anatomic coverage. Maps are based on data from either four 5-mm-thick or two 10-mm-thick slices. Neither of these options covers the entire cerebral parenchyma, which increases the risk of overlooking ischemic lesions in other territories.

Use of a second bolus or the "toggling-table" technique partially overcomes this limitation.³ The first method requires a repeat scan at the second location, using a second bolus of contrast material. Patient radiation dose is inevitably doubled. The toggling table technique appears promising, although further investigation is needed to compare its sensitivity and specificity with those of other techniques such as MRI.³ The toggling table makes it possible to scan a patient at two different positions with a single bolus of contrast agent, producing perfusion maps relative to a larger anatomic area.

Gantry tilt should be the same as that used for the basal CT examination. Choice of 80 kV instead of 120 kV will increase contrast enhancement and reduce patient radiation dose (Figure 4).⁴ The latest deconvolution software allows operators to use contrast injection rates of about 4 mL/sec instead of 20 mL/sec. This lower rate is more tolerable for patients and avoids the use of large-bore cannulas such as 14-gauge catheters. Large catheters may be difficult (or impossible) to place in patients with no antecubital veins, and they involve a higher risk of contrast leakage into soft tissues.³

A prep delay of no more than five seconds avoids the loss of useful data from the first part of the time-attenuation curve and limits total radiation dose. Software can partially correct patient movement, but corrected perfusion maps may not always reflect the true hemodynamic situation, and ischemic lesions may be overlooked as a result (Figure 5).

Choice of input artery (anterior cerebral artery, or right/left middle cerebral artery) affects the values of CBF, CBV, and MTT, and hence the perfusion map. No universally approved strategy exists for selecting the arterial input ROI. Perfusion maps derived from patients with hemilateral stroke, however, are usually more accurate when affected and unaffected arteries are compared (Figure 6).

A smaller arterial input ROI (about 5 to 7 mm²) should be used to reduce volume averaging effects.¹²

Increasing temporal sampling intervals can cause significant overestimation of CBF, CBV, and MTT, although a sampling interval greater than one second does not affect the accuracy of perfusion maps. Increasing the temporal interval reduces the radiation dose patients receive and may permit increased spatial coverage.⁶

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References
TABLE 1. TYPICAL CEREBRAL PERFUSION CT PROTOCOL FOR FOUR-SLICE CT SCANNER*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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<tbody>
<tr>
<td>Mode Cine</td>
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<tr>
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<tr>
<td>Infusion rate</td>
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</tbody>
</table>

*Parameters are merely indicative and will change according to chosen scanner and/or protocol.

TABLE 2. POSSIBLE PITFALLS

- Technical
  - Scanning mode
  - Slice thickness
  - Anatomic coverage
  - Gantry tilt
  - kV choice
  - Infusion rate
  - Prep delay
  - Data manipulation
  - Automated motion correction
  - Selection of input artery to begin analysis
  - Temporal sampling interval

Disclosures:

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