Utility of Perfusion-Weighted CT Imaging in Acute Middle Cerebral Artery Stroke Treated With Intra-Arterial Thrombolysis

Prediction of Final Infarct Volume and Clinical Outcome

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Background and Purpose—The goal of this study was to evaluate the utility of perfusion-weighted CT (PWCT) in predicting final infarct volume and clinical outcome in patients with acute middle cerebral artery (MCA) stroke.

Methods—Twenty-two consecutive patients with MCA stem occlusion who underwent intra-arterial thrombolysis within 6 hours of stroke onset had noncontrast CT and CT angiography with whole-brain PWCT imaging before treatment. Infarct volumes were computed from the initial PWCT and follow-up scans; clinical outcome was measured with the modified Rankin scale.

Results—Initial PWCT lesion volumes correlated significantly with final infarct volume ($P=0.0002$) and clinical outcome ($P=0.01$). For the 10 patients with complete recanalization, the relationship between initial and final lesion volume was especially strong ($R^2=0.94$, $P<0.0001$, slope of regression line $=0.92$). For those without complete recanalization, there was progression of lesion volume on follow-up imaging ($R^2=0.50$, $P=0.01$, slope of regression line $=1.61$). All patients with either initial PWCT lesion volumes $>100$ mL or no recanalization had poor outcomes (Rankin scores, 4 to 6). Mean admission NIH Stroke Scale scores and mean lesion volumes in the poor outcome group were significantly different compared with the good or fair outcome (Rankin scores, 0 to 3) group (21±4 versus 17±5, $P=0.05$, and 106±79 versus 29±37 mL, $P=0.01$). Patients with initial volumes $<100$ mL and partial or complete recanalization all had good (Rankin scores, 0 to 2) or fair (Rankin score, 3) outcomes.

Conclusions—Lesion volumes on admission PWCT images approximate final infarct volume for patients with early complete recanalization of MCA stem occlusion. For those without complete recanalization, there is subsequent enlargement of lesion volume on follow-up. Initial PWCT lesion volumes also have predictive value; volumes $>100$ mL are associated with a poor clinical outcome. In these highly selected patients, initial PWCT lesion volume was a stronger predictor of clinical outcome than was initial NIH Stroke Scale score. (Stroke. 2001;32:2021-2028.)

Key Words: cerebral ischemia ■ stroke ■ thrombolysis ■ tomography, perfusion-weighted

Patient selection for intravenous or intra-arterial thrombolytic therapy involves weighing the risk of intracranial hemorrhage against the potential benefits of treatment. Decisions on acute stroke treatment could be facilitated by the use of imaging techniques that better predict clinical outcome and final infarct volume in response to successful revascularization. Increasingly, measures of cerebral perfusion have been advocated for predicting prognosis and guiding therapy. Dynamic contrast-enhanced CT imaging techniques, compared with more established MR techniques, are relatively newer methods of evaluating perfusion parameters such as cerebral blood volume (CBV) and cerebral blood flow (CBF). Because noncontrast CT (NCCT) imaging is routinely the first radiological test performed in the emergency assessment of acute stroke patients, the additional data

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Stroke is available at http://www.strokeaha.org
supplied by CT angiographic (CTA) and perfusion-weighted CT (PWCT) imaging can be obtained rapidly and at relatively low cost. This additional contrast imaging is associated with minimal delays in treatment.7,12,13 We have used an imaging protocol for the evaluation of potential thrombolysis candidates with 3 components: a noncontrast head CT followed immediately by CTA with multislice whole-brain perfused blood volume (PWCT) acquisition. In this protocol, only a single helical CT scan acquisition, obtained during the dynamic administration of a single bolus of nonionic contrast, is required to simultaneously acquire both the CTA and the PWCT portions of the study, as described previously by Hunter et al.7

The clinical value of CTA imaging of circle of Willis occlusions or stenoses in acute stroke patients has been described previously.7,13–16 In this study, we report that simultaneously acquired PWCT images help to predict final infarct volume and clinical outcome in patients presenting with angiographically proven acute middle cerebral artery (MCA) embolic stroke.

Subjects and Methods
We reviewed the clinical and imaging findings of 22 consecutive patients (10 women, 12 men; mean age, 73 ±11 years) who presented within 6 hours of onset of signs and symptoms suggesting proximal MCA occlusion (10 patients presented at <3 hours, 12 patients presented at 3 to 6 hours). NIH Stroke Scale (NIHSS) scores were recorded at the time of admission to the emergency department.17 All patients were referred by the neurology stroke service for noncontrast head CT scanning (NCCT), followed immediately by CTA of the circle of Willis and skull base vessels with concurrent CTBV imaging (PWCT) performed according to the method of Hunter et al. All eligible patients underwent intra-arterial thrombolytic treatment per clinical protocol. Only patients with angiographically proven MCA occlusions were included in this analysis.

Scanning protocol was as follows. Standard NCCT scanning was performed in a headholder with a High Speed Advantage helical CT scanner (GE Medical Systems) in the emergency room. The nonhelical NCCT scanning technique was as follows: 120 kV, 170 mA, 2-second scan time, and 5-mm slice thickness. Coverage was from skull base to vertex of contiguous axial slices parallel to the planum sphenoidale.

NCCT scanning was followed immediately by helical scanning that used the following parameters: 3-mm helical beam collimation with a 3-mm/s table speed (pitch of 1), 220-mm scan field of view, coverage from skull base to vertex, 120 kV, maximal mA (usually mA = 220), 90 to 120 cm3 nonionic contrast (Omnipaque 300, Nycomed Inc/Nycomed AS) at 3-mL/s injection rate via an 18-gauge intravenous line by power injector (Medrad), and a 25-second preparation delay between the onset of contrast infusion and the start of scanning. Helical scans were obtained with the same coverage and orientation as the noncontrast scans. This protocol was designed to provide simultaneous high-resolution vascular images of the intracranial circulation and, without additional scanning sequences or contrast administration, whole-brain 3-mm-thick axial perfused blood volume–weighted (PWCT) images.

After the completion of scanning, a neuroradiologist reconstructed the source images into standardized axial “collapsed” maximum intensity projection (MIP) views of the circle of Willis in real time during the patient encounter. Before the initiation of thrombolytic therapy, the NCCT and PWCT source images and reconstructions were interpreted by the treating neuroradiologist(s), acute stroke neurologist(s), and neurointerventionalist(s). NCCT images were evaluated for evidence of dense vessel sign, focal parenchymal low attenuation, hemorrhage, and sulcal effacement. CTA axial source images and circle of Willis MIP reconstructions were evaluated for the presence of a primary or secondary circle of Willis or skull base vessel occlusion. The 3-mm-thick postcontrast PWCT axial source images, obtained through the entire brain, were also evaluated for the presence of regions of relatively diminished contrast enhancement (ie, parenchymal blood pool deficits).

Intra-arterial urokinase infusion and mechanical clot manipulation were performed by a team of experienced interventional neuroradiologists using established techniques.18 Pretreatment and posttreatment arteriographic images of the involved MCA branches were obtained, and the elapsed time between stroke onset and recanalization or procedure termination was recorded. The arteriographic images and clinical records were retrospectively reviewed by a neuroradiologist and neurologist, who classified the success of recanalization as complete recanalization (M1 and M2 branches widely patent post thrombolysis, n = 10), partial recanalization (M1 and ≥1 but not all M2 branches patent, n = 8), or no recanalization (persistent proximal MCA occlusion, n = 4).

Follow-up NCCT imaging was available for 21 patients; T2-weighted MR imaging was used as an end point in 1 patient for whom follow-up NCCT was unavailable. Clinical outcome was measured by use of the modified Rankin score trichotomized into good (0 to 2), fair (3), and poor (4 to 6) outcomes.17,19 Follow-up Rankin scores were obtained by direct patient interviews as part of an Institutional Review Board–approved data collection process. In no case did a secondary clinical ischemic event occur between the time of thrombolysis and follow-up imaging or Rankin score determination.

Image analysis was performed by 3 readers experienced in the interpretation of stroke CT (1 stroke neuroradiologist and 2 stroke neurologists) who were blinded to patient identifiers, precise clinical histories, lateralization of symptoms, and clinical outcome scores but were aware of the suspicion for acute MCA stroke. All imaging studies were rated independently in a random order during multiple readout sessions spaced over 3 months; disagreements in ratings were resolved by consensus.

The initial NCCT and PWCT axial source images for each patient, along with the follow-up NCCT and, in 1 case, T2-weighted MR images, were transferred to an independent PC-based workstation with a 21-in-high resolution monitor (Nokia) for analysis. Care was taken to use optimal window width and center level settings during CT image review to maximize the contrast produced by the small attenuation difference between normal and ischemic, hypodense brain parenchyma.20

Computation of the initial PWCT hypodensity volumes and follow-up infarct volumes in the MCA territory was performed with a semi-automated image segmentation software package (Alice, Parexel Corp). For each CT, hypodense ischemic brain parenchyma was visually segmented by the reviewing neuroradiologist; the resulting volumes were independently confirmed at separate readout sessions by each of the remaining 2 reviewers. All regions chosen had at least a 4–Hounsfield unit attenuation difference between hypodense, ischemic brain and the surrounding normal brain parenchyma. Areas of hemorrhage and contrast blush, representing evolving infarction, were included in the follow-up NCCT lesion volumes. Areas of chronic infarction, identified as cavitory regions with sharp geographic borders in an appropriate vascular territory, were not included (n = 4). Only MCA territory ischemic volumes were segmented.

Volume segmentation of the initial NCCT images was not performed because the precise boundaries of the ischemic hypodense regions were much less conspicuous and difficult to define on the initial NCCT images than on the initial PWCT images. Instead, the degree of mismatch between the hypodense ischemic regions observed on the initial NCCT versus PWCT images was graded visually according to the following 3-point scale: 0 = no mismatch (Figures 1 and 2), 1 = small mismatch (PWCT hypodensity volume 10% to 30% larger than the NCCT), and 2 = large mismatch (PWCT hypodensity volume >30% larger than the NCCT hypodensity volume, Figure 3). In rating mismatch, pairwise comparison of the images was done only after independent review of the NCCT images followed by the PWCT images.
ANOVA was used to examine the relationship between degree of recanalization and different parameters. Pairwise comparisons using Scheffé’s multiple comparison procedure were conducted only among those with overall significant probability value. Regression analysis of the initial PWCT hypodensity volumes with (1) final infarct volumes and (2) final clinical outcomes as measured by Rankin score was performed for all cases and again separately for each degree of recanalization. Pearson correlation coefficients were used to summarize the relationship between initial PWCT hypodensity and final stroke volumes. Linear regression models were used to examine the effects of initial PWCT hypodensity volume, degree of mismatch, timing between stroke onset and successful recanalization, NIHSS score, and degree of success of recanalization on both final infarct volume and clinical outcome. Mean NIHSS scores and lesion volumes for the good and fair versus poor outcome groups were compared by use of 1-tailed Student’s t test after an F test for variance.

**Results**

**Demographic Data and Clinical Outcome**

The Table gives the demographic, clinical, and imaging data of all patients stratified by recanalization group (complete, partial, or no recanalization) for patient age and sex, initial NIHSS score, initial PWCT hypodensity volume, final infarct volume, initial PWCT>NCCT hypodensity volume mismatch score, final Rankin outcome score, and time from stroke onset to successful recanalization. Mean time to PWCT imaging was 2.2±0.4 hours after stroke (range, 1.0 to 4.9 hours). Mean time to successful recanalization was 4.7±1.8 hours (range, 2.9 to 6.7 hours). Of the 22 patients studied, 8 had no mismatch (mismatch score, 0), 7 had a small mismatch (mismatch score, 1), and 7 had a large mismatch (mismatch score, 2). Mean time to follow-up imaging was 5.0±5.9 days (range, 24 hours to 28 days). Mean time to clinical follow-up for living patients (Rankin score) was 7.1±5.2 months (range, 1 to 15 months); a Rankin score of 6 was recorded for 5 patients who died after stroke.

A statistically significant difference in final Rankin score was present between the 3 recanalization groups (P=0.007, ANOVA); the difference in final infarct volume between the 3 groups nearly reached significance (P=0.06). After adjustment for multiple comparisons, the only difference that remained significant at the P=0.05 level was the mean Rankin score for patients with complete versus no recanalization. There was no statistically significant relationship between the success of recanalization and size of the initial PWCT hypodensity, patient age, initial NIHSS score, or degree of PWCT>NCCT mismatch.

**Final Infarct Volume Versus Initial PWCT Hypodensity Volume**

Overall initial PWCT hypodensity volume correlated significantly with follow-up infarct volume by linear regres-

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**Table 1. Demographic, Clinical, and Imaging Data**

<table>
<thead>
<tr>
<th>Degree of Recanalization</th>
<th>Sex, M/F</th>
<th>Age, y</th>
<th>Initial NIHSS Score</th>
<th>Initial PWCT Hypodensity Volume, mL</th>
<th>Final Infarct Volume, mL</th>
<th>Mismatch Score (0–2)</th>
<th>Final Rankin Score (1–6)</th>
<th>Time to Recanalization, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete (n=10)</td>
<td>4/6</td>
<td>70.8±15.0</td>
<td>18.2±4.6</td>
<td>44.8±65.5</td>
<td>54.7±62.3</td>
<td>0.7±0.8</td>
<td>1.8±1.8</td>
<td>5.0±1.1</td>
</tr>
<tr>
<td>Partial (n=8)</td>
<td>7/1</td>
<td>74.9±6.3</td>
<td>18.9±5.6</td>
<td>89.8±74.4</td>
<td>180.6±178.9</td>
<td>1.1±0.9</td>
<td>3.8±2.1</td>
<td>4.6±1.4</td>
</tr>
<tr>
<td>None (n=4)</td>
<td>1/3</td>
<td>73.8±9.2</td>
<td>20.3±3.3</td>
<td>41.6±56.0</td>
<td>214.5±132.1</td>
<td>1.2±0.5</td>
<td>5.5±1.0</td>
<td>NA</td>
</tr>
<tr>
<td>P (ANOVA)</td>
<td>NA</td>
<td>0.75</td>
<td>0.78</td>
<td>0.33</td>
<td>0.06</td>
<td>0.44</td>
<td>0.007</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Values are mean±SD stratified by degree of recanalization for patient age and sex, initial NIHSS score, initial PWCT hypodensity volume, final infarct volume, initial NCCT-PWCT mismatch score, final Rankin score, and time from stroke onset to successful recanalization.
The degree of PWCT>NCTCT mismatch was next stratified as a dichotomous variable (absent versus present) and controlled for the outcome of recanalization. For the 8 cases without PWCT>NCTCT mismatch, there was a stronger linear correlation between initial PWCT lesion volume and final infarct volume ($R^2=0.71$, $P=0.008$) than for those cases with mismatch ($R^2=0.48$, $P=0.006$). A scatterplot of initial versus final lesion volumes, with linear regression lines for the mismatch (slope, 1.6) and no mismatch (slope, 1.1) groups, is shown in Figure 5.

### Clinical Outcome Versus Initial PWCT Hypodensity Volume

Clinical outcome (Rankin score) also correlated significantly by linear regression with initial PWCT lesion volume (Pearson’s $R=0.53$, $P=0.01$) but not with initial NIHSS score (Pearson’s $R=0.33$, $P=0.13$). A scatterplot of clinical outcome versus initial PWCT lesion volume, stratified by degree of recanalization, is shown in Figure 6. All patients with either initial PWCT lesion volumes >100 mL or no recanalization had poor outcomes (Rankin scores, 4 to 6). Mean admission NIHSS scores and mean lesion volumes in the poor outcome group were significantly different compared with the good or fair outcome (Rankin scores, 0 to 3) group ($21\pm4$ versus $17\pm5$, $P=0.05$, and $106\pm79$ versus $29\pm37$ mL, $P=0.01$). Patients with initial volumes <100 mL and partial or complete recanalization all had good (Rankin scores, 0 to 2) or fair (Rankin score, 3) outcomes.

Thus, an initial PWCT lesion volume >100 mL had 100% predictive value for a poor clinical outcome, and a value <100 mL (with complete or partial recanalization) had 77% positive predictive value for a good clinical outcome.

A significant linear relationship between outcome and initial lesion volume was present in the complete ($R^2=0.45$, $P=0.03$) and partial ($R^2=0.49$, $P=0.05$) recanalization groups but not in the no recanalization group ($R^2=0.08$, $P=0.49$).
lesion volume is a stronger overall predictor of clinical outcome than is admission NIHSS score, especially for those with successful recanalization. In comparison, patients with partial recanalization demonstrate enlargement of their initial PWCT lesion volume on follow-up imaging, and clinical outcome is more likely to be worse. Post hoc analysis suggests that a cutoff volume of >100 mL may identify “poor” outcome patients. Those patients with no recanalization have large infarcts and poor clinical outcomes at follow-up, regardless of their initial PWCT lesion volumes. However, for the subset of patients whose initial PWCT lesion volumes are much larger than their corresponding NCCT lesion volumes (ie, large PWCT>NCCT mismatch), both final infarct volume and long-term clinical outcome after intra-arterial thrombolysis are more variable.

It is not surprising that perfused CBV, as imaged by PWCT imaging, should reflect approximate minimum final infarct size in this clinical setting. As cerebral perfusion pressure falls, precapillary resistance vessels dilate (ie, increased CBV) to maintain CBF. Once maximum vasodilatation has been reached, autoregulation fails and CBF begins to fall. Progressive increases in cerebral oxygen extraction can temporarily maintain cerebral oxygen metabolism. As perfusion pressure continues to fall, there is disruption of cellular metabolism, vascular collapse, and development of irreversible ischemia. In acute ischemic stroke, collapse of vessels at low CBV is likely to occur only after prolonged, severe reductions in CBF, and continued collapse would be associated with a high probability of producing infarction.

Our data support the idea that visually conspicuous reductions in CBV, at a mean of 2 1/4 hours from onset of MCA occlusion, represent regions of oligemic brain tissue with high risk of infarction. Only 1 of our 22 cases demonstrated any significant sparing of brain tissue in a territory with initially depressed perfused blood volume. This was a case of

Discussion

We have shown that for patients with early complete revascularization after proximal MCA embolic occlusion, final infarct volume is approximated by the size of the initial ischemic lesion volume visualized on PWCT imaging. In patients with MCA occlusion, a small PWCT abnormality is considered an indicator of better leptomeningeal collateral blood flow, which promotes survival of ischemic brain tissue until reperfusion occurs. We also report that in this homogeneous, highly selected patient group, initial PWCT hypodensity and final infarct volume (match had a stronger linear correlation between initial PWCT lesion volumes. Straight lines represent the linear regression for each category. The 8 cases without mismatch had a stronger linear correlation between initial PWCT hypodensity and final infarct volume ($R^2=0.71$, $P=0.008$, slope=1.1) than did the 14 cases with mismatch ($R^2=0.48$, $P=0.006$, slope=1.6).

$P=0.71$). Mean final Rankin score (the Table) was significantly lower (ie, better outcome) for patients with complete recanalization than for those with no recanalization ($P<0.05$ after multiple comparison adjustment). There was also a trend toward a significant difference in mean final Rankin score between the partial and no recanalization groups.

In cases without PWCT>NCCT mismatch, there was a significant relationship between clinical outcome and PWCT lesion volume ($R^2=0.74$, $P=0.006$). However, in cases with mismatch, there was not a statistically significant relationship between outcome and PWCT ($R^2=0.06$, $P=0.39$). Two patients with complete recanalization and mismatch scores of 2 had excellent clinical outcomes (Rankin scores 1; Figure 6) despite initial PWCT lesion volumes of just <100 mL.

![Figure 5](http://stroke.ahajournals.org/)

Figure 5. Final infarct vs initial PWCT lesion volume stratified by the presence or absence of mismatch between the admission NCCT and PWCT lesion volumes. Straight lines represent the linear regression for each category. The 8 cases without mismatch had a stronger linear correlation between initial PWCT hypodensity and final infarct volume ($R^2=0.71$, $P=0.008$, slope=1.1) than did the 14 cases with mismatch ($R^2=0.48$, $P=0.006$, slope=1.6).

![Figure 6](http://stroke.ahajournals.org/)

Figure 6. Clinical outcome (Rankin score) vs initial PWCT lesion volume stratified by degree of recanalization. All patients with initial volume >100 mL (vertical divider line) or with no recanalization had a poor clinical outcome (Rankin score, 4 to 6). Patients with complete or partial recanalization and with initial volume <100 mL had a good (Rankin score, 0 to 2) or fair (Rankin score, 3; horizontal divider line) outcome. Complete recanalization group showed a significant linear relationship between initial PWCT lesion volume and outcome ($R^2=0.45$, $P=0.03$); although the no recanalization group did not, the interpolated regression value for the final Rankin score corresponding to an initial PWCT lesion volume of 0 (Rankin score, 5.3) did reach significance ($P=0.02$).
very early PWCT imaging (1 hour after onset) and very early complete recanalization (<3 hours) of the occluded inferior MCA division (Figure 3). Studies of perfusion MRI and 99mTc-HMPAO single-photon emission CT in acute stroke patients have shown that the degree of CBV reduction in penumbral regions with borderline abnormal CBF might be useful in predicting tissue outcome.25 Lesion volume on admission CBV imaging has been shown to be a strong predictor of final infarct size.2,26,27 In our study, the slope of the linear regression line for the complete recanalization group is nearly unity (slope, 0.92; Figure 4). This suggests that at a mean time to recanalization of 4.7 hours, only a small margin of the PWCT lesion volume is typically salvageable.

Loss of the mismatch between initial NCCT and PWCT lesion volumes over time (ie, expansion of the initial NCCT lesion volume) may reflect “early” penumbral deterioration. Except in cases of very early revascularization, normal NCCT brain regions with abnormal PWCT will typically progress to infarction (Figures 2 and 3). The CBF lesion volume is generally larger than the CBV lesion volume, and enlargement of final infarct volume beyond the volume defined by the initial PWCT lesion volume may reflect “late” penumbral loss. Our data suggest that cases with a significant PWCT>NCCT lesion volume mismatch at admission are likely to have more variable final infarct volumes (Figure 5) and clinical outcomes than cases without mismatch. The NCCT lesion volumes, once visually evident, are strongly associated with irreversible infarction.28

Although we obtained quantitative PWCT lesion volumes using image segmentation software, we were forced to estimate the degree of mismatch by direct visual comparison between the abnormal NCCT and PWCT regions. Quantitative NCCT lesion volumes could not be reliably measured because of the indistinct margins and limited visual conspicuity typical of acute ischemic NCCT hypodensity. The attenuation differences between normal and edematous tissue on the initial NCCT images are typically only in the 1– to 3-Hounsfield unit range. Despite our careful use of optimal window width and center level display settings during NCCT image interpretation,29 our preliminary attempts to segment hypodense NCCT regions were characterized by marked intraobserver and interobserver variability. Indeed, many portions of the abnormal, hypodense brain tissue present on the admission NCCT images were detected only retrospectively during careful review of the NCCT scans alongside coregistered PWCT images. A potentially important role of PWCT imaging in acute stroke may be to improve detection of subtle NCCT findings of ischemia, a frequent problem in stroke clinical trials.

Our finding of a better clinical outcome for patients with complete recanalization than for those without recanalization is consistent with the report of a benefit of intra-arterial thrombolyis in the treatment of proximal MCA embolic stroke from the PROACT trial.30 It is noteworthy that in our study a PWCT lesion volume of 100 mL identified patients with a “poor” clinical outcome, because 100 mL is approximately equal to one third the brain volume supplied by an MCA.30 This result is consistent with the European data indicating that intravenous thrombolytic therapy within 6 hours of stroke onset results in poor outcome in patients with initial NCCT lesion volumes greater than one third that of the MCA territory.31,32

A limitation of our analysis is that it did not control for confounding medical conditions or final infarct location. Final infarct location sparing language and motor centers may help to explain the excellent clinical outcome in the 2 patients with initial mismatch scores of 2, despite initial PWCT lesion volumes of ~100 mL. Of the 3 of 13 patients with fair clinical outcomes who had initial lesion volumes <100 mL and partial or complete recanalization, 1 carried a diagnosis of Alzheimer’s disease, another had multiple severe concurrent medical illnesses, and the third had a small left basal ganglia hemorrhage at an anatomically critical location.

Helical CT scanners are typically more available and less expensive than MRI scanners and are frequently located in the emergency department setting. CTA with PWCT can be performed rapidly and conveniently immediately after the head NCCT examination routinely obtained to exclude hemorrhage before the consideration of thrombolytic therapy. The addition of a CTA/PWCT study is well tolerated by almost all stroke patients and seldom adds >15 minutes of scanning, postprocessing, and interpretation time to the time required for the clinically necessary NCCT examination. CTA reliably demonstrates large vessel occlusions amenable to intra-arterial thrombolysis.13–16 Despite differences in technique and the tissue characteristics they measure, both diffusion-weighted MR and PWCT imaging delineate ischemic regions likely to be irreversibly infarcted. Simultaneous review of both the NCCT and PWCT images allows a determination of mismatch between unequivocally infarcted tissue (ie, NCCT) and more conspicuous ischemic tissue with a high probability of infarction (ie, PWCT). More importantly, a small PWCT lesion (<100 mL) distal to an MCA occlusion identifies patients who will have a small final infarct and good outcome after successful thrombolysis. In contrast, stroke size will exceed the PWCT lesion volume if recanalization does not occur. By its ability to predict those patients more—rather than less—likely to benefit from MCA recanalization, PWCT can play an important role in guiding acute stroke treatment.

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References


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**Editorial Comment**

**Perfusion-Weighted CT in Acute MCA Stroke: Teaching Old Dogs New Tricks**

Introduced in 1973, CT revolutionized the approach to stroke diagnosis. The standard role of noncontrast CT in acute stroke diagnosis quickly became the detection of brain hemorrhage. For the first time, clinicians could visually distinguish a brain hemorrhage from an infarction; it turned out that traditional clinical rules had often been wrong. Many papers appeared on infarction syndromes produced by hemorrhages; large infarctions with edema and mass effect were no longer misdiagnosed as hemorrhages. More accurate stroke diagnosis had an immediate impact on stroke epidemiology and therapy; clinicians could avoid blindly anticoagulating patients with brain hemorrhages.

For “acute” brain infarction (then defined as 48 hours), the standard teaching became that the CT was “normal” for the first 24 hours after stroke onset. Not until the era of thrombolysis did we realize that, in point of fact, the
noncontrast CT was abnormal in the majority of patients with large-vessel infarction of ≤6 hours’ duration. The information had been there on CT for 20 years—we simply did not know what to look for because we were looking thru the wrong window (or a dirty window). First came the hyperdense middle cerebral artery (MCA) sign signifying MCA thrombosis. But the big change in early CT stroke diagnosis occurred in 1996 when the European Cooperative Acute Stroke Study (ECASS) linked early signs of infarction on CT in >1/3 of the MCA territory with hemorrhage risk and patient outcomes. Importantly, the ECASS investigators suggested that intravenous tissue plasminogen activator should not be given to such patients.1–6 Thus, noncontrast CT became a tool for therapeutic decision making rather than a purely anatomic imaging modality.

Recently acute stroke neuroimaging has focused on developing an “ECG” for acute stroke—a “stroke-o-gram”—that would define not only the type of stroke, but also the site of vessel occlusion, tissue at risk, and salvageable brain. MR with diffusion- and perfusion-weighted imaging combined with MR angiography has shown tremendous promise and received the most publicity in this regard, but there are huge logistical and technical barriers to obtaining emergency stroke MR in most hospitals. Noncontrast CT remains the standard acute stroke imaging modality. Taking advantage of this practicality and perhaps stimulated by the explosion of work in stroke MR, Lev et al now show that more acute stroke information can be unlocked from CT through perfusion-weighted imaging. The necessary ultrafast helical CT is potentially widely available in the emergency department setting and is less expensive than MR. A CT angiogram and perfusion-weighted CT images can be obtained simultaneously with a single injection of 100 cc of non-ionic contrast. However, it is not clear whether there are significant postprocessing delays and how quickly perfusion-weighted CT data can be made available to the clinician.

Perfusion-weighted CT employs concepts derived from acute stroke MR, although the technologies and terms are not strictly analogous. Indeed, correlations between noncontrast CT, perfusion-weighted CT, diffusion/perfusion-weighted MR, and clinical outcomes are lacking and require further investigation. Perfusion-weighted CT should not be confused with perfusion-weighted MR. Although measuring different tissue characteristics, the predictive features of perfusion-weighted CT are in many ways more analogous to diffusion-weighted MR than to perfusion-weighted MR. Perfusion-weighted CT reflects low cerebral blood volume within a collapsed vascular bed and thereby delineates the area of brain tissue doomed to infarction better than noncontrast CT. Perfusion-weighted CT is not a direct measure of tissue viability or function. Perfusion MR measures perturbed blood flow in normal or ischemic tissue and may better define brain tissue at risk or salvageable brain. As such, perfusion-weighted MR seems to correlate better with initial stroke severity (National Institutes of Health Stroke Scale score) than either diffusion-weighted MR or perfusion-weighted CT. The reversibility of perfusion-weighted CT changes is also unclear. Initially thought to represent irreversible infarction, it is now known that diffusion-weighted MR changes are reversible in some patients. The perfusion-weighted CT/noncontrast CT mismatch is therefore not analogous to the perfusion-weighted MR/diffusion-weighted MR mismatch. The apparent inability of perfusion-weighted CT to completely define brain tissue at risk (“penumbra”) and the lack of quantification may distinguish perfusion-weighted CT from other emerging acute perfusion techniques such as MR and xenon CT.

Should we perform perfusion-weighted CT, perfusion/diffusion-weighted MR, both, or, as some have suggested, neither, to better understand and treat our patients with acute ischemic stroke? These new technologies all require further rigorous validation and correlation with clinical outcomes. Although it is too early to incorporate any of these technologies into routine clinical decision making, new technologies such as perfusion-weighted CT are obviously telling us things about acute stroke that we did not know before. Just as CT moved us from pure clinical description to anatomic depiction, it is only a matter of time before our imaging approach to acute ischemic stroke shifts to pathophysiological delineation. It is reassuring and exciting for this stroke neurologist to see that not only can an old dog learn new tricks, but that there are new dogs to attack the old trickster called stroke.

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