Comparison of Perfusion Computed Tomography and Computed Tomography Angiography Source Images With Perfusion-Weighted Imaging and Diffusion-Weighted Imaging in Patients With Acute Stroke of Less Than 6 Hours’ Duration

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Background and Purpose—We aimed to determine the diagnostic value of perfusion computed tomography (PCT) and CT angiography (CTA) including CTA source images (CTA-SI) in comparison with perfusion-weighted magnetic resonance imaging (PWI) and diffusion-weighted MRI (DWI) in acute stroke <6 hours.

Methods—Noncontrast-enhanced CT, PCT, CTA, stroke MRI, including PWI and DWI, and MR angiography (MRA), were performed in patients with symptoms of acute stroke lasting <6 hours. We analyzed ischemic lesion volumes on patients’ arrival as shown on NECT, PCT, CTA-SI, DWI, and PWI (Wilcoxon, Spearman, Bland–Altman) and compared them to the infarct extent as shown on day 5 NECT.

Results—Twenty-two stroke patients underwent CT and MRI scanning within 6 hours. PCT time to peak (PCT-TTP) volumes did not differ from PWI-TTP ($P=0.686$ for patients who did not undergo thrombolysis/$P=0.328$ for patients who underwent thrombolysis), nor did PCT cerebral blood volume (PCT-CBV) differ from PWI-CBV ($P=0.893$/$P=0.169$). CTA-SI volumes did not differ from DWI volumes ($P=0.465$/$P=0.086$). Lesion volumes measured in PCT maps significantly correlated with lesion volumes on PWI ($P=0.0047$, $r=1.0$/$P=0.0019$, $r=0.897$ for TTP; $P=0.0054$, $r=0.983$/$P=0.0026$, $r=0.871$ for CBV). Also, PCT-CBV lesion volumes significantly correlated with follow-up CT lesion volumes ($P=0.0047$, $r=1.0$/$P=0.0046$, $r=0.819$).

Conclusions—In hyperacute stroke, the combination of PCT and CTA can render important diagnostic information regarding the infarct extent and the perfusion deficit. Lesions on PCT-TTP and PCT-CBV do not differ from lesions on PWI-TTP and PWI-CBV; lesions on CTA source images do not differ from lesions on DWI. The combination of noncontrast-enhanced CT (NECT), perfusion CT (PCT), and CT angiography (CTA) can render additional information within <15 minutes and may help in therapeutic decision-making if PWI and DWI are not available or cannot be performed on specific patients. (Stroke. 2004;35:1652-1658.)

Key Words: stroke, acute ■ perfusion ■ computed tomography ■ angiography ■ magnetic resonance imaging

The advent of new magnetic resonance imaging (MRI) techniques such as perfusion-weighted imaging (PWI) and diffusion-weighted imaging (DWI) has improved diagnostic imaging in stroke. However, computed tomography (CT) scanners are more widely available and less expensive than MRI scanners and are often located in the emergency departments even of smaller community hospitals. Usually, CT is used to exclude intracranial hemorrhage (ICH) or tumor, but it can also be used to detect early signs of an infarct. Besides ICH exclusion, the depiction of infarct core and total hypoperfused brain and vessel status is expected to be shown by a comprehensive imaging tool such as stroke MRI. The aim of our study was to determine the diagnostic value of perfusion CT (PCT) and CT angiography (CTA) including CTA source images (CTA-SI) in comparison with PWI and DWI in stroke patients <6 hours after symptom onset.

Patients and Methods

Our target group consisted of patients aged 18 to 85 years with symptoms of acute stroke within the first 6 hours. Patients with...
Imaging and Clinical Assessment

All patients were examined with a multislice CT scanner (Somatom Volume Zoom; Siemens) and immediately thereafter with a 1.5-T whole-body MR imager (EDGE; Philips) equipped with enhanced gradient hardware for echo planar imaging. Our noncontrast-enhanced CT (NECT), CTA, CTA-SI, and stroke MRI protocols have been described in detail elsewhere.5,6 The perfusion CT technique in this study has been described by König et al.7,8 In brief, axial dual-section dynamic CT at the level of the basal ganglia was performed to encompass areas of the anterior, posterior, and middle cerebral artery territories. For each study, a bolus of 50 mL of nonionic iodinated contrast agent (Ultravist; Schering) was injected into a cubital vein with a power injector at a rate of 10 mL/s. A sequence of 2 * 40 images was then collected at a rate of 1 image per second. To achieve cerebral perfusion data, we used a commercial Perfusion CT software (Siemens), which allows the calculation of cerebral blood flow (CBF), cerebral blood volume (CBV), and time to peak (TTP) maps.9

For CTA, another 65 mL of a nonionic contrast medium were injected at an injection rate of 5 mL/s for 40 mL followed by another 25 mL at 2.5 mL/s. After a delay of 17 seconds, spiral scanning was performed: beam collimation 4 * 1.0 mm, slice width 1.5 mm, normalized spiral pitch 1.0, 120 kV, and 125 mAs. For diagnosis we used the CTA-SI and the 3-dimensional reconstructions of the data sets. Both the NECT and CTA-SI were evaluated by changing the window width and center level during visual review to accentuate potentially subtle foci of low attenuation or enhancement.

PCT imaging is restricted to the subvolume covered by the total detector width of 20 mm (2 adjacent slices of 10 mm each). To allow comparison of PCT images with CTA-SI and MR images, the observers manually outlined the infarct area in the corresponding slices using the same angulation. Regarding the PCT-TTP and PCT-CBV maps, the threshold for manually outlining the lesions was set according to the color code: yellow, orange, and red for PCT-TTP lesions (corresponding to a TTP increase of >84 seconds), and violet and dark blue (corresponding to a CBV value of ~30% to 40% of normal gray matter values) for PCT-CBV lesions (Figures 1E, 1F, and 2E, 2F). This method has proven to be quick, practicable, and robust under clinical conditions (regarding the feasibility in patients with acute stroke, when quick diagnosis is required). The threshold for manually outlining the lesions on PWI and DWI was set according to the hyperintensity on the maps (Figures 1G, 1H, 2G, 2H). The outlined infarct areas were then multiplied with the slice thickness and added up to 20 mm thickness for comparison with PCT lesion volumes. The final infarct volume was determined on day 5, according to CT images. All PCT, CTA, DWI, and PWI lesion volumes were measured in random sequence by independent observers blinded to the patients’ identity and clinical status and to previous measurement results.

Statistical Analysis

For statistical analysis we used a standard software package (StatView 5.0 MedCalc 7.1.0.1). Demographic data and time intervals of examinations and descriptive statistics of scores are given as median values with ranges. We used the nonparametric Wilcoxon test and Bland–Altman plots to compare CT and MRI measurements. Correlations between lesion volumes from different imaging parameters were analyzed using Spearman-rank correlation. The analysis was performed separately for patients with and without thrombolysis. To further test the hypothesis that CT and MRI measurements yield equivalent results, we additionally used linear regression analysis on the subset of patients who had any kind of anomaly in the imaging procedures.

Results

From February 2002 to April 2003, 1087 stroke patients were treated in our dedicated neurological emergency room. Of these, 71 patients were initially eligible for this study. Eighteen had an ICH and 8 denied consent for participation. Of the remaining 45 patients, 19 could not undergo MRI because of stroke severity or pacemakers, ie, the MR protocol was only performed in 26 of 45 cases (feasibility 58%). Three had a history of contrast agent allergy, ie, the complete stroke CT protocol (NECT, CTA, PCT) was performed in 42 of 45 cases (feasibility 93%). One patient was later excluded because he had experienced recurrent embolisms. Therefore, 22 patients (8 women, 14 men, mean age 66.7 years, range 39 to 84 years) were consecutively enrolled in this prospective study (Table 1). Thirteen patients received standard thrombolytic therapy with recombinant tissue plasminogen activator (rt-PA). The infusion was started during or after stroke MRI in all 13 patients.

PCT, CT, CTA, and MRI were successfully completed in all patients without any side effects. Both stroke CT and stroke MRI protocols were performed within the first 60 minutes to 6 hours after stroke onset (CT: 60 minutes to 5 hours 15 minutes, mean 2.33 ± 0.4 hours; MRI: 1 hour 15 minutes to 6 hours, mean 3.0 ± 1.12 hours). The time interval between CT and MRI ranged from 15 minutes to 2 hours (0.75 ± 0.40 hours).
scan time was between 16 and 32 minutes (mean 23 minutes). In no instance was thrombolytic treatment delayed by imaging.

Of the 22 patients, 6 showed early signs of infarction on the NECT images. Three had cortical hypodensity and 3 had a hyperdense artery sign. In these 6 patients the observers also depicted lesions on PCT-TTP and PCT-CBV and on day 5 NECT (Table 2).

Eleven patients had a vessel occlusion seen on both CTA and MRA at the same location. Ten of the 22 patients had an initial vessel occlusion in the anterior or middle cerebral circulation according to CTA and MRA, and 1 patient had occlusion of the distal basilar artery. Six patients each presented with either a proximal or a distal middle cerebral artery (MCA) main stem occlusion, whereas 1 had MCA branch occlusion and 3 had distal internal carotid artery (ICA) occlusion according to the initial CTA. All but 1 of the 11 patients without vessel occlusion on CTA and MRA showed no initial DWI lesion in the 2 adjacent slices.

Comparison of CT and MR Results and Correlation With Follow-Up Infarct Volumes

PCT lesion sizes did not differ significantly from PWI lesion size TTP ($P=0.686$ for patients who did not undergo thrombolysis/$P=0.328$ for patients who underwent thrombolysis; $P=0.893/P=0.169$ for CBV; Wilcoxon) at baseline (Table 3a). Bland–Altman plots confirmed the equivalence of both modalities (Figure 3). Furthermore, the difference between CTA-SI lesion volumes and DWI lesion volumes did not reach statistical significance ($P=0.465/P=0.086$; Wilcoxon).

In all patients, the lesion volume measured in PCT maps significantly correlated (Spearman rank) with the lesion volume on PWI (TTP; $r=1.0/r=0.90$ for TTP; $r=0.98/r=0.87$ for CBV). Significant correlation was also found between CTA-SI and DWI lesion volumes ($r=0.98/r=0.92$) as well as between PCT-CBV and DWI lesion volumes ($r=1.0/r=0.87$). PCT-CBV lesion volumes significantly correlated with follow-up CT lesion volumes ($r=1.0/r=0.82$).

Linear regression analysis emphasized the principal equivalence of CT and MR lesion sizes. To avoid bias by zeros, we restricted the analysis to the subset of patients with imaging lesions (n=16). Table 3b shows that lesion sizes in TTP, CBV, and CTA-SI/DWI can be presented as proportional to each other (intercept=0) with a factor close to 1. Remarkably, this is also true for the lesion size in follow-up as predicted by PCT-CBV (ratio 1.03).

In all cases of vessel occlusion, DWI lesions corresponded to lesions in the PCT maps, even though lesions on PCT-CBV usually were slightly larger than on DWI (ratio 1.35). To estimate the influence of only using 2 adjacent slices in PCT,
we also completely outlined the final infarct volume on day 5 in the whole brain. Here, we also found a significant correlation between PCT-CBV ($r=0.98/r=0.88$) and PCT-CBF ($r=0.98/r=0.82$) lesion volumes and the final infarct volume regarding not only the corresponding 2 slices on the follow-up but also the complete infarction.

**Discussion**

Although DWI seems to be superior in direct comparison to NECT, stroke MRI at present is fully (24 hours) available only in major stroke centers. In particular, most patients with symptoms of acute hemispheric stroke are treated in general hospitals that do not have this access to MRI.

We performed CT, PCT, CTA, and stroke MRI within an average time interval of 2.33 hours for CT and 3.0 hours for MRI after symptom onset in 22 patients. Although safety and reliability were not investigated according to predefined parameters, the overall performance of the combination of CT, PCT, and CTA was good: All data could be analyzed, and no patient had allergies or renal insufficiency after contrast administration. Because of the short investigation time of CT/PCT/CTA, the scan can be performed rapidly with fewer movement artifacts than in MRI, especially in severely ill patients. Also, patient access is far easier than in the MRI scanner. The higher practical feasibility of CT was also evident in our study: although 93% of patients eligible for the study were eligible for CT and the procedure was successfully performed, this applied to only 58% of the patients with respect to MRI.

In the past, various perfusion imaging techniques have been reported to be useful in the clinical investigation of patients with acute stroke. Recent studies with PCT have shown that various combinations of perfusion parameters can be used to predict outcome after ischemic stroke. Schramm et al Comparison of PCT and CTA-SA With PWI and DWI

### Table 1. Baseline Stroke Scales, Location of Vessel Occlusion, Early Signs, and Lesion Sizes at Baseline and Outcome for Both PCT Slices

<table>
<thead>
<tr>
<th>Patient</th>
<th>Baseline NIHSS</th>
<th>Vessel Occlusion</th>
<th>Early Signs of Infarction (NECT)</th>
<th>Thrombolysis</th>
<th>PCT-CBF Lesion Size (mL)</th>
<th>PCT-CBV Lesion Size (mL)</th>
<th>PCT-TTP Lesion Size (mL)</th>
<th>CTA Source Image Lesion Size (mL)</th>
<th>PWI-TTP Lesion Size (mL)</th>
<th>PWI-CBV Lesion Size (mL)</th>
<th>DWI Lesion Size (mL)</th>
<th>Follow-up CT Lesion Size (mL)</th>
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</thead>
<tbody>
<tr>
<td>P.B., 59 y</td>
<td>1 8</td>
<td>—</td>
<td>No</td>
<td>IV</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B.L., 63 y</td>
<td>2 10</td>
<td>—</td>
<td>No</td>
<td>IV</td>
<td>4.67</td>
<td>4.57</td>
<td>4.17</td>
<td>2.44</td>
<td>16.46</td>
<td>7.20</td>
<td>0.0</td>
<td>8.10</td>
</tr>
<tr>
<td>W.D., 65 y</td>
<td>3 10</td>
<td>Distal MCA main stem</td>
<td>No</td>
<td>—</td>
<td>32.93</td>
<td>31.81</td>
<td>37.08</td>
<td>31.33</td>
<td>70.21</td>
<td>49.79</td>
<td>36.51</td>
<td>42.99</td>
</tr>
<tr>
<td>O.J., 71 y</td>
<td>4 4</td>
<td>—</td>
<td>No</td>
<td>No</td>
<td>1.89</td>
<td>1.59</td>
<td>1.58</td>
<td>1.65</td>
<td>1.78</td>
<td>0.58</td>
<td>2.05</td>
<td>2.60</td>
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<tr>
<td>A.L., 79 y</td>
<td>5 19</td>
<td>Proximal MCA main stem</td>
<td>Cortical hypodensity</td>
<td>IA</td>
<td>72.95</td>
<td>59.00</td>
<td>76.11</td>
<td>50.61</td>
<td>65.36</td>
<td>53.61</td>
<td>35.00</td>
<td>73.75</td>
</tr>
<tr>
<td>C.H., 73 y</td>
<td>6 27</td>
<td>—</td>
<td>No</td>
<td>No</td>
<td>22.76</td>
<td>18.69</td>
<td>24.82</td>
<td>22.13</td>
<td>28.41</td>
<td>22.05</td>
<td>20.38</td>
<td>23.44</td>
</tr>
<tr>
<td>A.B., 61 y</td>
<td>7 13</td>
<td>ICA</td>
<td>Cortical hypodensity</td>
<td>IV+IA</td>
<td>96.95</td>
<td>71.67</td>
<td>127.24</td>
<td>35.60</td>
<td>131.18</td>
<td>54.88</td>
<td>32.72</td>
<td>73.38</td>
</tr>
<tr>
<td>J.B., 69 y</td>
<td>8 6</td>
<td>—</td>
<td>No</td>
<td>IV</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>G.S., 66 y</td>
<td>9 10</td>
<td>—</td>
<td>No</td>
<td>No</td>
<td>15.59</td>
<td>10.63</td>
<td>19.38</td>
<td>5.28</td>
<td>16.33</td>
<td>5.61</td>
<td>5.43</td>
<td>14.03</td>
</tr>
<tr>
<td>C.S., 67 y</td>
<td>10 15</td>
<td>MCA branch</td>
<td>No</td>
<td>No</td>
<td>15.99</td>
<td>10.63</td>
<td>19.38</td>
<td>5.28</td>
<td>16.33</td>
<td>5.61</td>
<td>5.43</td>
<td>14.03</td>
</tr>
<tr>
<td>W.A., 58 y</td>
<td>11 7</td>
<td>Proximal MCA main stem</td>
<td>HMCA</td>
<td>No</td>
<td>55.17</td>
<td>37.56</td>
<td>95.70</td>
<td>21.35</td>
<td>90.10</td>
<td>36.11</td>
<td>40.50</td>
<td>51.40</td>
</tr>
<tr>
<td>G.A., 82 y</td>
<td>12 6</td>
<td>—</td>
<td>No</td>
<td>IV</td>
<td>38.40</td>
<td>21.83</td>
<td>46.03</td>
<td>0.0</td>
<td>5.76</td>
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<tr>
<td>E.S., 84 y</td>
<td>13 9</td>
<td>—</td>
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<td>No</td>
<td>12.83</td>
<td>0.0</td>
<td>23.25</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>H.R., 73 y</td>
<td>14 7</td>
<td>—</td>
<td>No</td>
<td>IV</td>
<td>5.80</td>
<td>1.87</td>
<td>10.71</td>
<td>0.0</td>
<td>10.38</td>
<td>0.0</td>
<td>3.50</td>
<td>0.0</td>
</tr>
<tr>
<td>H.W., 66 y</td>
<td>15 8</td>
<td>—</td>
<td>No</td>
<td>No</td>
<td>32.94</td>
<td>19.53</td>
<td>32.96</td>
<td>14.77</td>
<td>38.75</td>
<td>17.57</td>
<td>17.31</td>
<td>14.80</td>
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<tr>
<td>T.R., 70 y</td>
<td>16 12</td>
<td>Distal MCA main stem</td>
<td>No</td>
<td>IV</td>
<td>5.00</td>
<td>1.87</td>
<td>10.71</td>
<td>0.0</td>
<td>10.38</td>
<td>0.0</td>
<td>3.50</td>
<td>0.0</td>
</tr>
<tr>
<td>J.K., 76 y</td>
<td>17 11</td>
<td>ICA</td>
<td>HMCA</td>
<td>N</td>
<td>22.89</td>
<td>10.15</td>
<td>87.96</td>
<td>4.96</td>
<td>89.39</td>
<td>20.64</td>
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<td>15.05</td>
</tr>
<tr>
<td>A.S., 67 y</td>
<td>18 14</td>
<td>Proximal MCA main stem</td>
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<td>No</td>
<td>52.16</td>
<td>25.50</td>
<td>97.62</td>
<td>30.29</td>
<td>90.41</td>
<td>27.65</td>
<td>15.90</td>
<td>8.08</td>
</tr>
<tr>
<td>R.S., 39 y</td>
<td>19 8</td>
<td>Basilar artery</td>
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<td>No</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>K.S., 53 y</td>
<td>20 7</td>
<td>Distal MCA main stem</td>
<td>Cortical hypodensity</td>
<td>N</td>
<td>44.95</td>
<td>31.59</td>
<td>65.04</td>
<td>26.70</td>
<td>71.59</td>
<td>15.17</td>
<td>21.31</td>
<td>17.27</td>
</tr>
<tr>
<td>D.S., 57 y</td>
<td>21 28</td>
<td>ICA</td>
<td>HMCA, hyperdense of left lentiform nucleus</td>
<td>N</td>
<td>62.95</td>
<td>24.84</td>
<td>86.10</td>
<td>21.83</td>
<td>62.95</td>
<td>15.14</td>
<td>12.43</td>
<td>19.43</td>
</tr>
<tr>
<td>E.L., 69 y</td>
<td>22 5</td>
<td>—</td>
<td>No</td>
<td>No</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Median (Range)</td>
<td>NA 10</td>
<td>NA</td>
<td>(0–86.95)</td>
<td>(0–71.67)</td>
<td>(0–127.24)</td>
<td>(0–50.61)</td>
<td>(0–131.18)</td>
<td>(0–64.88)</td>
<td>(0–40.5)</td>
<td>(0–73.75)</td>
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</table>

IV indicates intravenous; IA, intraarterial; NA, not applicable; NIHSS, National Institutes of Health Stroke Scale; HMCA, hyperdense middle cerebral artery.
Although the sensitivity in detecting X-ray hypoattenuation on NECT is highly specific for irreversible brain damage, the sensitivity in detection of X-ray hypoattenuation on NECT is low (50% to 70%), the complete infarction.

In hyperacute stroke, the combination of PCT and CTA can increase the diagnostic value of diagnosing ischemic stroke is lower than for DWI in the first few hours. CTA can increase the diagnostic value of diagnosing ischemic stroke is lower than for DWI in the first few hours.

Verely reduced CBV has emerged as an important predictor for essentially nonviable tissue. In patients with clinical symptoms of ischemic stroke but no pathologic findings in NECT, PCT, and CTA, a large MCA infarction can be excluded. This information may be sufficient for the therapeutic decision to not perform thrombolysis, although smaller ischemic tissue volumes outside the 2-cm section covered by perfusion CT may be missed. Even though dynamic PCT is essentially a 2-dimensional technique, which on current multi-slice CT (MSCT) scanners is restricted to a relatively small volume, we were able to show that this does not seriously limit patient management in acute stroke caused by MCA occlusion. In cases of large MCA infarctions, we found a highly significant correlation between PCT-CBF and PCT-CBV lesions volumes with the final infarct volume, regarding not only the corresponding 2 slices on the follow-up but also the complete infarction.

Even though the reported diagnostic yield of NECT within 6 hours after symptom onset is low (50% to 70%), the detection of X-ray hypodensity on NECT is highly specific for irreversible brain damage. Still, the sensitivity in diagnosing ischemic stroke is lower than for DWI in the first few hours. CTA can increase the diagnostic value of CT. Furthermore, previous studies have shown that lesion volumes on CTA-SI significantly correlate with the lesion volumes on baseline DWI.

In MRI, a PWI/DWI mismatch reflects the ischemic penumbra to a certain extent and therefore makes it possible to pragmatically estimate the size of tissue at risk for irreversible infarction. We stress that the combination of CT, CTA-SI, and PCT also provides similar information. Here, the volume of the affected brain area that has inadequate blood supply can be estimated by the difference between the CTA-SI lesion volumes and the PCT-CBF lesion volumes. CTA gives information about the vessel occlusion, if present, and can show the irreversibly damaged brain tissue and the status of the collateral vessels at the same time. In our study, PCT-CBV lesions were slightly larger than DWI lesions (which may depend on the visual threshold chosen for the analysis of the PCT-CBV maps), but PCT-CBV lesions correlated well with follow-up CT lesion volumes.

Our results correspond to findings of a recently published study. These authors also found a statistically significant correlation between CT and MR abnormalities regarding TTP and CBF. However, in our study we found a higher correlation and a higher level of significance, which is probably because of the fact that we examined all patients within the first 6 hours after stroke onset.

### Conclusion

In hyperacute stroke, the combination of PCT and CTA can render important diagnostic information regarding the infarct.

| TABLE 2. Presence and Absence of Early Signs of Infarction on NECT Regarding PCT Lesions, DWI Lesions, Vessel Occlusion, and Regarding Infarct Lesion on Day 5 |
|---------------------------------|-----------------|-----------------|
|                                | NECT early signs | No NECT early signs |
|                                | (N=6)            | (N=16)           |
| PCT-TTP lesion                 | 6                | 10               |
| PCT-CBF lesion                 | 6                | 10               |
| PCT-CBV lesion                 | 6                | 9                |
| DWI lesion                     | 6                | 7                |
| Vessel occlusion               | 6                | 5                |
| Lesion day 5                   | 6                | 7                |

<table>
<thead>
<tr>
<th>TABLE 3B. Statistical Results of Linear Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable/Independent</td>
</tr>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>PCT-TTP/PWI-TTP</td>
</tr>
<tr>
<td>PCT-CBV/PWI-CBV</td>
</tr>
<tr>
<td>CTA-SI/DWI</td>
</tr>
<tr>
<td>PCT-CBV/DWI</td>
</tr>
<tr>
<td>FUPCT-CBV</td>
</tr>
</tbody>
</table>

Patients with positive findings in any of the imaging techniques (N=16). All correlation coefficients (r) are significant (P<0.001); none of the intercept values is significantly different from 0 (second column). Setting the intercept to 0 does not change the significance (third column).

FU indicates follow-up lesion on day 5.

In MRI, a PWI/DWI mismatch reflects the ischemic penumbra to a certain extent and therefore makes it possible to pragmatically estimate the size of tissue at risk for irreversible infarction. We stress that the combination of CT, CTA-SI, and PCT also provides similar information. Here, the volume of the affected brain area that has inadequate blood supply can be estimated by the difference between the CTA-SI lesion volumes and the PCT-CBF lesion volumes. CTA gives information about the vessel occlusion, if present, and can show the irreversibly damaged brain tissue and the status of the collateral vessels at the same time. In our study, PCT-CBV lesions were slightly larger than DWI lesions (which may depend on the visual threshold chosen for the analysis of the PCT-CBV maps), but PCT-CBV lesions correlated well with follow-up CT lesion volumes.

Our results correspond to findings of a recently published study. These authors also found a statistically significant correlation between CT and MR abnormalities regarding TTP and CBF. However, in our study we found a higher correlation and a higher level of significance, which is probably because of the fact that we examined all patients within the first 6 hours after stroke onset.

### Conclusion

In hyperacute stroke, the combination of PCT and CTA can render important diagnostic information regarding the infarct.
and the perfusion deficit. Lesions on PCT-TTP and PCT-CBV do not differ from lesions on PWI-TTP and PWI-CBV, and lesions on CTA source images do not differ from lesions on DWI. The combination of NECT, PCT, and CTA can render additional information within <15 minutes and may help in therapeutic decision-making if PWI and DWI are not available or cannot be performed on a specific patient. Lesions on PCT maps and CTA-SI highly correlate with perfusion and diffusion-weighted stroke MRI, allowing estimation of the tissue at risk in a similar fashion.

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Editorial Comment

Specificity of Stroke Imaging: Disregarded and Neglected

Brain imaging in acute stroke patients can be effective on 6 different levels:1 (1) It will reduce health care costs, if it prevents disability and death of stroke victims. (2) Brain imaging will improve the clinical outcome of stroke patients, if it identifies the patients who benefit from specific treatment. (3) To identify these patients, brain imaging must provide relevant information that is unavailable from other sources for the appropriate choice of treatment. (4) This could be brain images that allow the exclusion of brain hemorrhage and other diseases that mimic ischemic stroke, and allow assessment of ischemic edema and perfusion disturbance, mass effect, arterial wall pathology, and obstruction. (5) The imaging modality should be sensitive and specific for stroke pathology early after symptom onset. (6) This requires the imaging modality to have the technical capacity to reliably detect the relevant stroke pathology.

In this issue, Schramm et al2 compare computed tomography (CT) and MRI (MRI) techniques that assessed brain perfusion, brain water diffusion, and the resulting ischemic infarct in acute stroke patients. In a group of 22 patients,
among them 9 patients without a brain infarct on follow-up CT, Schramm et al did not detect a statistical difference regarding the lesion volumes on time-to-peak (TTP) maps and on cerebral blood volume (CBV) maps provided by CT and MRI, observed no difference when comparing the lesion volumes on CT angiography (CTA) source images with the lesions on diffusion-weighted MRI (DWI), and found a significant correlation when comparing the lesion volumes on CT-CBV maps and on follow-up CT.

These valuable observations allow one not only to compare between CT and MRI, but invite one to think about the specificity of imaging information, and raise several questions:

(1) Does the lack of a statistical difference in lesion volumes and its significant correlation really mean that different imaging modalities assess the same pathology?

The authors subdivided their already small group of patients into those whom they treated with thrombolysis (n=13) and those they did not treat (n=9) after perfusion imaging. The risk to miss small differences between such small groups is rather high. They did not report how the MRI perfusion maps were created and why they obtained CBF maps from CT only. Nevertheless, even if one takes the entire group, the lack of a statistical difference regarding the “lesion” volumes and a high correlation between CT- and MRI-perfusion parameters suggest that CT and MRI detect the same volume of contrast flow disturbance on TTP and CBV maps, which is not a surprise, if similar techniques are used to create such maps. It is interesting that the authors observed a high correlation between the volumes of hypotenuating brain tissue on CTA source images and of DWI “lesions” with no significant difference of the mean values. Hypotenuation on CTA source images is caused by ischemic edema and a lack of contrast enhancement reflecting a reduced CBV, whereas the increased signal on DWI is caused by the restricted water diffusion in brain regions with diminished extracellular fluid space and cellular edema. A reduction of the extracellular fluid space and a decline of the apparent diffusion coefficient were found at a CBF threshold of 30 mL per 100 g min. This explains why hypoattenuation of ischemic brain tissue is highly predictive for ischemic damage.7

(2) Can we consequently conclude that one imaging modality can replace another?

The observations of Schramm et al suggest that it does not matter whether one takes CT or MRI to detect tissue volumes of decreased CBV or prolonged TTP. The CTA source images may serve as a surrogate for DWI although they are likely to display a different pathology. In light of the relatively low feasibility to perform MRI, it is surprising that the authors did not conclude to prefer CT to MRI.

(3) Are the lesions that were compared relevant for treatment of ischemic stroke?

What is the “diagnostic value” of perfusion maps (not “perfusion-weighted imaging”) the authors were looking for? Time-to-peak maps appeared most sensitive in detecting brain perfusion disturbance; however, a reference standard is not available. All 16 patients with TTP prolongation developed infarcts on the follow-up CT with the exception of 3 patients who were treated with thrombolysis. The follow-up CT remained normal in all 6 patients with normal TTP at baseline. This supports the view that reperfusion therapy is unnecessary in patients without a deficit on perfusion CT. The authors may have missed the therapeutic impact of this specific information. They treated 2 patients with IV thrombolysis who had no arterial occlusion and no perfusion deficit, but did not treat 5 patients with perfusion deficits or arterial obstructions, among them 1 patient with basilar artery occlusion and 1 patient with a proximal MCA occlusion. It appears as if the diagnostic and therapeutic impact of a normal CT or MRI in acute stroke patients is widely underestimated. Schramm et al regard the “diagnostic yield” of unenhanced CT as low by neglecting the impact of normal CT in patients with acute stroke. A normal CT excludes major ischemic damage with high specificity and thus allows reperfusion therapy – in my personal experience – even beyond accepted time windows. From the data of this paper, I conclude that reperfusion therapy makes no sense if CT does not show a perfusion deficit of the affected brain region.

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