Comparison of CT and CT Angiography Source Images With Diffusion-Weighted Imaging in Patients With Acute Stroke Within 6 Hours After Onset

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Background and Purpose—Although stroke MRI has advantages over other diagnostic imaging modalities in acute stroke patients, most of these individuals are admitted to emergency units without MRI facilities. There is a need for an accurate diagnostic tool that rapidly and reliably detects hemorrhage, extent of ischemia, and vessel status and potentially estimates tissue at risk. We sought to determine the diagnostic accuracy of the combination of non–contrast-enhanced CT, CT angiography (CTA), and CTA source images (CTA-SI, showing early parenchymal contrast enhancement) in comparison with a multiparametric stroke MRI protocol in patients with acute stroke within 6 hours after onset.

Methods—Non–contrast-enhanced CT, CTA, stroke MRI including diffusion-weighted imaging (DWI), and MR angiography (MRA) were performed in patients with symptoms of acute stroke within 6 hours after onset. We analyzed infarct volumes on days 1 and 5 as shown on CTA-SI, DWI, and T2-weighted images (Wilcoxon, Mann-Whitney, Spearman tests), estimated the collateral status, and assessed clinical outcome (modified Rankin Scale, Barthel Index, National Institutes of Health Stroke Scale, Scandinavian Stroke Scale).

Results—We analyzed the data of 20 stroke patients who underwent CT and MRI scanning within 6 hours (mean, 2.83 and 3.38 hours, respectively). Vessel occlusion was present in 16 of 20 patients. CTA-SI volumes did not differ from DWI volumes (P=0.601). Furthermore, the CTA-SI lesion volumes significantly correlated with the initial DWI lesion volumes (P<0.0001, r=0.922) and with outcome lesion volumes (P=0.013 r=0.736). Patients with poor collaterals experienced infarct growth (P=0.0058) and had a significantly worse clinical outcome (all P<0.012); patients with good collaterals did not (P=0.176).

Conclusions—The combination of non–contrast-enhanced CT (exclusion of intracranial hemorrhage), CTA (vessel status), and early contrast-enhanced CTA-SI (demarcation of irreversible infarct) allows diagnostic assessment of acute stroke with a quality comparable to that of stroke MRI. Furthermore, it is possible to distinguish patients at risk of infarct growth from those who are not according to the collateral status, in analogy with the stroke MRI mismatch concept. (Stroke. 2002;33:2426-2432.)

Key Words: contrast media ■ magnetic resonance imaging, diffusion-weighted ■ stroke, acute ■ tomography, x-ray computed

Because of its overall availability, CT is still the imaging modality of choice for identifying the underlying pathology in the initial hours of acute stroke. Usually, CT is used to exclude intracranial hemorrhage or tumor, but it can also be used to detect early signs of an infarct. In 2 studies, for the first 2 hours after stroke onset, no change in density was seen in ischemic tissue,1 but low density was observed in 66% of 657 patients scanned during the first 6 hours.2 There remains, however, the need for a stroke imaging tool that is fast, has a sufficiently high sensitivity for detecting both intracerebral hemorrhage and ischemia within the first 6 hours, can identify the hypoperfused brain tissue, if present, and shows occlusion of major arteries at the base of the brain. The advent of new MRI techniques such as perfusion-weighted (PWI) and diffusion-weighted (DWI) imaging has revolutionized diagnostic imaging in stroke.3–11 However, CT scanners are more widely available and less expensive than MRI scanners and are often located in the emergency departments of even smaller community hospitals. Acute stroke is treated not only at specialized academic medical centers; indeed, the majority of patients present in local general hospitals that have no MRI facilities.12 Since in the past few years several studies have

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demonstrated the potential of thrombolytic therapy to improve the clinical outcome in patients with acute hemispheric stroke, a diagnostic tool is needed that quickly shows not only lesion size but also vessel occlusion and that provides information about the collateral circulation. The aim of this study was to address the following questions: (1) Do CT angiography (CTA) source images (CTA-SI) allow detection of ischemic brain lesions in patients with acute ischemic stroke? (2) Is the sensitivity of CTA-SI comparable to that of DWI? (3) Does the hypoperfused brain area seen on CTA-SI correlate with the final infarct? (4) Does the collateral status reflect the risk of infarct growth?

Our hypothesis was that if stroke MRI is not available, the diagnostic value of a combination of non–contrast-enhanced CT, CTA, and early contrast-enhanced CTA-SI is comparable to that of a multiparametric stroke MRI, including DWI, in patients with acute stroke within 6 hours after onset.

Subjects and Methods

Patients

In a prospective study, we investigated the clinical and imaging findings of 20 consecutive patients (7 women, 13 men; mean age, 60.7 ± 9.9 years). Our target group consisted of patients showing symptoms of acute ischemic stroke within the first 6 hours. Stroke onset was defined as the time the patient was last known to be without any neurological deficit. Exclusion criteria were age <18 or >80 years, a significant preexisting neurological deficit (modified Rankin Scale score >1), unstable vital signs, or general MRI contraindications. Exclusion criteria for CTA were a history of contrast medium allergy or renal failure. All patients received a non–contrast-enhanced CT scan to exclude intracranial hemorrhage before enrollment in the study. To avoid any delay in initiating treatment due to investigational CT and stroke MRI, the neuroradiologist on call was paged from the neurological emergency department on patient arrival. After an initial assessment of neurological status, including history, stabilization of vital parameters, and stroke emergency care, we performed CT, CTA, and MRI. The planned time for performing CT and MRI studies was <6 hours after symptom onset, with time interval between CT and MRI <1 hour. We obtained informed consent from all patients or their next of kin. The study protocol was approved by the local ethics committee. Eight patients received thrombolytic therapy with 0.9 mg/kg body wt recombinant tissue plasminogen activator (rtPA). The infusion was started during or after stroke MRI in all 8 patients.

Imaging and Clinical Assessment

All patients were examined with a state-of-the-art CT scanner (PQ 2000, Marconi) and immediately thereafter with a 1.5-T whole-body MR imager (EDGE, Marconi) equipped with enhanced gradient hardware for echo-planar imaging (EPI). Immediately after conventional CT scanning (4-mm slice thickness for the posterior fossa and 8-mm slice thickness for suprassellar structures), all patients underwent CTA of the basal cerebral circulation, including the circle of Willis. Then 130 mL of a nonionic contrast medium (Omnipaque, Schering) was infused into a cubital vein with the use of an injection pump at a rate of 5 mL/s. After a delay of 17 seconds, spiral scanning was performed, with the following parameters: slice thickness 2.0 mm, index 1.5 mm, spiral pitch 1.25, 130 kV, and 125 mA. For diagnosis we used the CTA-SI and 3-dimensional reconstructions of the data sets (surface-shaded display; Voxel Q workstation; Marconi International). The CTA data sets were analyzed by a neuroradiologist blinded to clinical data and prior results. For the MRI examination we used a circular polarized head coil. The stroke MRI protocol included an axial T2-weighted fast spin-echo sequence, an axial fluid-attenuated inversion recovery EPI sequence, an axial isotropic DWI spin-echo EPI sequence (b = 0, 333, 666, 1000 s/mm²), time-of-flight MR angiography (MRA), and PWI with an axial T2*-weighted gradient echo EPI sequence (40 data sets during and after injection of 25 mL Gd-DTPA [Magnevist, Schering AG] with a power injector [5 mL/s]). PWI data were not analyzed in this study. The MR images were postprocessed with the use of commercial image analysis software and a workstation (Marconi VISTAR). Infarct volumes were measured by manually outlining the lesion volume, multiplying it by the slice thickness, and adding the slice volumes. To define the initial infarct volume, we used the images acquired with the b = 1000 s/mm² DWI sequence. DWI abnormalities corresponded to areas of decreased signal intensity on apparent diffusion coefficient maps in all cases. The final infarct volume was determined on day 5, according to T2-weighted images. All CTA, DWI, and T2-weighted image lesion volumes were measured by observers blinded to the patients’ clinical status and to prior measurement results using a random sequence.

Statistical Analysis

For statistical analysis we used a standard software package (StatView 4.5, Abacus Concepts). Demographic data and time intervals of examinations and descriptive statistics of scores are given as mean or median values with SD or median absolute deviation and range. A Spearman rank correlation was used to determine the correlation between lesion volumes and neurological scores. Because our data are not normally distributed, we used nonparametric tests (Mann-Whitney U test, Wilcoxon test) to determine whether there were significant differences between initial and follow-up lesion volumes and clinical scores and whether there were interindividual differences in morphological and functional outcome between patients with good collateral vessel status around the lesion and patients with poor collaterals.

Results

CT, CTA, and MRI were successfully completed in all patients without any side effects. We examined 20 patients (7 women, 13 men; mean age, 60.7 ± 9.9 years; range, 41 to 76 years) who showed symptoms of acute ischemic stroke using a non–contrast-enhanced CT, CTA, and a standardized stroke MRI protocol within the first 45 minutes to 5 hours 30 minutes after stroke onset. CT was performed within the first 45 minutes to 4 hours 45 minutes after stroke onset (mean, 2.8 ± 1.33 hours), followed by MRI (range, 1 hour 15 minutes to 5 hours 30 minutes after symptom onset; mean, 3.38 ± 1.37 hours). The time interval between CT and MRI ranged from 15 minutes to 1 hour (mean, 0.55 ± 0.25 hours). Of the 20 patients, 16 had a vessel occlusion seen on both CTA and MRA. All vessel occlusions detected on CTA were seen on MRA at the same location. In every patient, the status of the collateral vessels surrounding the lesion was determined on the CTA-SI; 7 patients showed good intravascular enhancement of the perilesional vessels and were classified as good, and 13 patients showed only poor enhancement around the lesion site and were classified as poor. Table 1 provides an overview of the demographic data, including time windows, collateral status, and day 1 scores.

Four of the 20 patients had no initial vessel occlusion in the anterior or middle cerebral circulation according to CTA and MRA but showed small lesions on the initial DWI study. All but 1 of these patients had good collaterals. Two of the 3 patients with good collaterals had lacunar infarctions (DWI and T2-weighted image lesion volumes <8 mL).

Eight patients each presented with either a proximal or a distal middle cerebral artery (MCA) main stem occlusion, whereas 3 had a MCA branch occlusion and 5 had a distal
internal carotid artery (ICA) occlusion according to the initial CTA. All but 1 of these 16 patients had an abnormal initial DWI scan. Five of these patients showed good collaterals, and 11 showed poor collaterals surrounding the lesion site.

For further statistical analysis, the 20 patients were divided into 2 groups: group 1 (“poor,” n=13) consisted of the patients with poor vessel enhancement around the lesion site, and group 2 (“good,” n=7) consisted of those with good perilesional collateral status. The initial clinical deficit was significantly higher in group 1 (median National Institutes of Health Stroke Scale [NIHSS] score, 12; median Scandinavian Stroke Scale [SSS] score, 25) than in group 2 (median NIHSS score, 15; median Scandinavian Stroke Scale [SSS] score, 24), which, however, was not due to a higher proportion of left hemispheric infarctions (P=0.01 for NIHSS day 1 and P=0.05 for SSS day 1; Mann-Whitney U test). A considerable difference was found in the mean values of baseline CTA-SI lesion volumes between groups 1 (61.69 mL) and 2 (20.39 mL). However, neither the difference of baseline CTA-SI lesion volumes nor the difference of baseline DWI lesion volumes reached statistical significance (P=0.102 and P=0.053; Mann-Whitney U test) but rather only a trend toward significance. Five of 7 patients with good collaterals received rtPA as opposed to 2 of 13 patients with poor collaterals, which also represented a difference that was not statistically significant (P=0.06; Fisher exact test).

**Comparison of Initial and Follow-Up Infarct Volumes**

Neither in patients with poor collaterals (P=0.807; Wilcoxon test) nor in patients with good collaterals (P=0.6; Wilcoxon test) did CTA-SI lesion volumes differ significantly from DWI lesion volumes (P=0.601 for all patients; Wilcoxon test) at baseline. In patients with poor collateral vessel status, initial CTA-SI lesion volumes differed significantly from T2-weighted imaging lesion volumes on day 5 (P=0.0058; Wilcoxon test), whereas in patients with good collaterals no significant difference was found (P=0.176; Wilcoxon test). Day 1 DWI lesion volumes differed significantly from T2-weighted imaging lesion volumes on day 5 in patients with poor collaterals (P=0.0037; Wilcoxon test), whereas in patients with good collaterals the difference did not reach statistical significance (P=0.176; Wilcoxon test).

In all patients, the lesion volume measured on CTA-SI correlated significantly with the outcome lesion volume on day 5 T2-weighted imaging (P=0.013, r=0.736; Spearman test). When the patients were divided into 2 groups regarding perilesional collateral vessel status, both the CTA-SI lesion volumes of group 1 (poor collaterals) correlated significantly with day 5 lesion volumes (P=0.035, r=0.608; Spearman test), and the CTA-SI lesion volumes of group 2 (good collaterals) correlated significantly with day 5 lesion volumes (P=0.036, r=0.852; Spearman test). When all patients were considered together, CTA-SI lesion volumes correlated sig-

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**TABLE 1. Location of Vessel Occlusion, Baseline Stroke Scale Scores, Collaterals, Lesion Sizes at Baseline, and Outcome**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Baseline NIHSS, SSS</th>
<th>CTA Day 1</th>
<th>Collaterals in CTA-SI</th>
<th>CTA-SI Lesion Size, mL</th>
<th>DWI Day 1 Lesion Size, mL</th>
<th>T2-WI Day 5 Lesion Size, mL</th>
<th>Day 90 NIHSS, SSS, BI, mRS Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8, 28</td>
<td>No occlusion</td>
<td>Poor</td>
<td>38.30</td>
<td>42.64</td>
<td>36.32</td>
<td>3, 47, 75, 3</td>
</tr>
<tr>
<td>2</td>
<td>21, 8</td>
<td>Proximal M1</td>
<td>Poor</td>
<td>156.74</td>
<td>135.22</td>
<td>297.63</td>
<td>42, 0, 0, 6</td>
</tr>
<tr>
<td>3</td>
<td>25, 8</td>
<td>Distal ICA</td>
<td>Poor</td>
<td>96.60</td>
<td>70.23</td>
<td>126.30</td>
<td>13, 24, 45, 4</td>
</tr>
<tr>
<td>4</td>
<td>13, 24</td>
<td>No occlusion</td>
<td>Good</td>
<td>5.30</td>
<td>8.17</td>
<td>0.00</td>
<td>0, 58, 100, 0</td>
</tr>
<tr>
<td>5</td>
<td>18, 18</td>
<td>Distal ICA</td>
<td>Poor</td>
<td>89.40</td>
<td>156.50</td>
<td>262.70</td>
<td>42, 0, 0, 6</td>
</tr>
<tr>
<td>6</td>
<td>13, 25</td>
<td>Distal ICA</td>
<td>Poor</td>
<td>181.87</td>
<td>267.57</td>
<td>317.50</td>
<td>42, 0, 0, 6</td>
</tr>
<tr>
<td>7</td>
<td>21, 8</td>
<td>Distal ICA</td>
<td>Poor</td>
<td>46.71</td>
<td>62.84</td>
<td>84.40</td>
<td>13, 24, 30, 4</td>
</tr>
<tr>
<td>8</td>
<td>17, 26</td>
<td>Distal M1</td>
<td>Poor</td>
<td>93.41</td>
<td>104.06</td>
<td>175.50</td>
<td>8, 41, 50, 4</td>
</tr>
<tr>
<td>9</td>
<td>13, 24</td>
<td>Distal M1</td>
<td>Good</td>
<td>19.11</td>
<td>13.56</td>
<td>39.26</td>
<td>1, 54, 100, 1</td>
</tr>
<tr>
<td>10</td>
<td>22, 6</td>
<td>Distal ICA</td>
<td>Poor</td>
<td>0.00</td>
<td>21.35</td>
<td>51.07</td>
<td>18, 20, 15, 5</td>
</tr>
<tr>
<td>11</td>
<td>9, 31</td>
<td>No occlusion</td>
<td>Poor</td>
<td>0.00</td>
<td>0.79</td>
<td>0.69</td>
<td>0, 58, 100, 0</td>
</tr>
<tr>
<td>12</td>
<td>12, 23</td>
<td>No occlusion</td>
<td>Poor</td>
<td>0.00</td>
<td>7.10</td>
<td>13.60</td>
<td>0, 58, 100, 0</td>
</tr>
<tr>
<td>13</td>
<td>5, 42</td>
<td>Distal ICA</td>
<td>Poor</td>
<td>40.80</td>
<td>53.90</td>
<td>360.00</td>
<td>27, 13, 0, 5</td>
</tr>
<tr>
<td>14</td>
<td>10, 35</td>
<td>M2</td>
<td>Good</td>
<td>0.00</td>
<td>0.00</td>
<td>0.98</td>
<td>0, 58, 100, 0</td>
</tr>
<tr>
<td>15</td>
<td>13, 19</td>
<td>Proximal M1</td>
<td>Good</td>
<td>32.15</td>
<td>15.10</td>
<td>20.80</td>
<td>4, 50, 95, 2</td>
</tr>
<tr>
<td>16</td>
<td>15, 26</td>
<td>Proximal M1</td>
<td>Poor</td>
<td>12.50</td>
<td>3.04</td>
<td>9.40</td>
<td>9, 35, 40, 4</td>
</tr>
<tr>
<td>17</td>
<td>8, 28</td>
<td>Distal M1</td>
<td>Good</td>
<td>0.00</td>
<td>6.57</td>
<td>12.4</td>
<td>0, 58, 100, 0</td>
</tr>
<tr>
<td>18</td>
<td>19, 10</td>
<td>Proximal M1</td>
<td>Poor</td>
<td>1.95</td>
<td>5.78</td>
<td>11.30</td>
<td>10, 35, 80, 3</td>
</tr>
<tr>
<td>19</td>
<td>6, 32</td>
<td>M2</td>
<td>Poor</td>
<td>0.00</td>
<td>0.00</td>
<td>4.19</td>
<td>0, 58, 100, 0</td>
</tr>
<tr>
<td>20</td>
<td>12, 23</td>
<td>Proximal M1</td>
<td>Good</td>
<td>86.2</td>
<td>79.86</td>
<td>116.7</td>
<td>5, 45, 100, 2</td>
</tr>
</tbody>
</table>

Median or mean±SD: 13, 24.5, NA, NA. 45.05±54.98, 52.71±69.08, 97.04±120.01, 6.5, 43, 77.5, 3.

T2-WI indicates T2-weighted imaging; BI, Barthel Index; mRS, modified Rankin Scale; and NA, not applicable.
Comparison of Clinical and Morphological Outcomes

Patients with good collaterals uniformly had a significantly better clinical outcome on day 90 as measured by 4 neuro- logical and outcome scales (NIHSS, 0 versus 10; SSS, 58 ± 0 versus 35 ± 15; Barthel Index, 100 ± 0 versus 45 ± 45; modified Rankin Scale, 0 ± 0 versus 4 ± 1; all P ≤ 0.012, Mann-Whitney test). For 2 dichotomized clinical outcomes (modified Rankin Scale 0 to 1 versus 2 to 6, good versus bad; modified Rankin Scale 0 to 2 versus 3 to 6, independent versus dependent or dead), a poor collateral status predicted a significantly worse clinical outcome (P = 0.025 and P = 0.001; Fisher exact test). Day 5 T2-weighted imaging lesion volumes differed between the subgroups, being significantly larger in patients with poor collaterals (P = 0.024; Mann-Whitney test).

Table 2 shows a summary of group data and statistical analysis. CT and MR images of patients 2 and 7 are shown in Figures 1 and 2, respectively.

Discussion

Despite the enthusiastic reports of the diagnostic potential of DWI and PWI in hyperacute ischemic stroke,5,6,9,13 there is still substantial doubt regarding the feasibility, utility, and cost-effectiveness of these methods.14 Although there seems to be a clear superiority in direct comparison,15 at present this modality is only available in a few major stroke centers.16 In particular, smaller hospitals often do not have daily continuous access to MRI facilities. Conversely, the majority of patients with symptoms of acute hemispheric stroke are treated in local general hospitals. Handschu et al12 showed that of 103 patients with stroke or transient ischemic attack referred to general hospitals (with 59.3% admitted within the first 6 hours after onset of symptoms), only one third received some form of brain imaging in the course of their hospital stay, and only 1 patient received MRI. Since the time window for effective thrombolytic therapy of ischemic stroke is rather narrow, the need for a CT-based diagnostic tool with which all the important pathophysiological aspects of hyperacute stroke can be investigated is evident. Such a CT-based method must answer, in analogy to stroke MRI, 4 questions: (1) Where and how large is the actual area of infarcted brain? (2) Are any vessels occluded and, if so, where? (3) Is there any normodense brain tissue that is at risk of irreversible ischemic damage (“tissue at risk”? (4) Is there an intracerebral hemorrhage or another underlying, nonischemic disease?

In the management of a suspected stroke, it is important to confirm the diagnosis of an acute ischemic event, to eventu-
ally define the type of stroke (embolic, lacunar, watershed), and to determine the vascular territory (large vessel versus small vessel) and, if possible, the underlying etiologic mechanisms (thromboembolic, lacunar, hypotension, cardioembolic). If diffusion-weighted stroke MRI is not available, the decision to initiate intravenous rtPA treatment must be based on the clinical findings and CT scanning. The reported diagnostic yield of non–contrast-enhanced CT within 3 hours after symptom onset, however, is low (50% to 70%).\(^5\,17\,18\) On the other hand, detection of x-ray hypoaquenation on CT is highly specific for irreversible brain damage, also within the first 6 hours after ischemic stroke.\(^1\) Still, the sensitivity in diagnosing ischemic stroke is substantially lower than on DWI in the first few hours.\(^13\) CTA can increase the diagnostic value of CT\(^19\,\,22\): direct comparison of CTA and carotid ultrasound suggests that the results from CTA compare favorably with those from ultrasound.\(^23\) CTA can also reliably detect intracranial stenosis, emboli, and aneurysms of a moderate or larger size.\(^24\) Because the substrate for thrombolytic therapy is an obliterating thrombus, the ability of CTA to detect intracranial vessel occlusion suggests that it is a useful screening tool for identifying patients in whom intravenous or intra-arterial thrombolysis is appropriate.\(^25\)

Since the therapeutic time window for thrombolytic therapy is only 3 hours and up to 6 hours in selected patients,\(^26\,\,28\) the need for an improved, CT-based diagnostic tool is evident. A normal non–contrast-enhanced CT scan in acute stroke does not imply insensitivity of the method; in fact, it represents the favorable situation in which ischemic edema has not yet developed and the chance to avoid irreversible damage is still good. Unenhanced CT does not show the arterial occlusion itself; furthermore, it does not show the extent of disturbed cerebral perfusion. One might ask why simple postcontrast CT should not suffice to detect the extent of ischemic tissue. However, in comparison to postcontrast CT, CTA has the advantage of showing the leptomeningeal
collaterals surrounding the lesion of reduced parenchymal enhancement, which can be seen with both methods.

We performed CT, CTA, and stroke MRI within an average time interval of 2.83 hours for CT and 3.38 hours for MRI after symptom onset in 20 patients. Although safety and reliability were not investigated according to predefined parameters, the overall performance of the combination of CT and CTA was excellent. Because of the short investigation time of CT/CTA, the scan can be performed rapidly with fewer movement artifacts, especially in severely ill patients. No obvious complications were seen as a result of the contrast agent, all images were of high quality and could be interpreted, and there were no ambiguous decisions regarding the presence or absence of abnormalities either on the maximum intensity projection reconstruction images or on the CTA-SI. In all of our patients the necessary information was available online.

Our results show that the lesion volumes according to CTA-SI do not differ from those seen on DWI and that they also significantly correlated with the lesion volumes on baseline DWI \( (P<0.0001, r=0.922; \text{Spearman test}) \). The fact that CT/CTA was performed 45 minutes earlier than DWI, on average, is even more intriguing. Furthermore, the collateral status was predictive for a worse clinical status and larger infarct volumes at outcome. Obviously, patients with poor collaterals at the time of CTA still have tissue to lose. Therefore, in patients with a poor collateral vessel status, CTA-SI may render information similar to that of the PWI-DWI mismatch concept, in analogy with findings of Schellinger et al.\textsuperscript{29}

DWI may delineate infarcted brain tissue in \(<1\) hour after symptom onset, probably within minutes,\textsuperscript{30} although evidence is accumulating that in the very early stage of stroke DWI may demonstrate changes that are still reversible.\textsuperscript{31} PWI and DWI reveal the ischemic tissue potentially at risk.\textsuperscript{26} In MRI, a PWI-DWI mismatch may only reflect the ischemic penumbra to a certain extent and therefore make it possible to pragmatically estimate the size of tissue at risk of irreversible infarction. However, the combination of CT, CTA, and CTA-SI also renders relevant information. In this case, 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 brain area supplied by the occluded artery, with the qualitative assessment of the collateral status taken into account. In our study CTA both gives information about the vessel occlusion, if present, and can show the irreversibly damaged brain tissue at the same time. Furthermore, it provides information about the status of collateral vessels. Several studies have shown that stroke MRI as a single diagnostic tool provides critical data that have the potential to guide therapeutic decisions in hyperacute stroke patients.\textsuperscript{29,32} However, our study shows that the combination of CT, CTA-SI, and CTA reconstruction images offers a diagnostic value comparable to that of DWI. Patients with poor collateral status experienced significant infarct growth, whereas those with good collaterals did not. Therefore, the patients with poor collaterals seem to represent those who may have a PWI-DWI mismatch in analogy to stroke MRI, and the patients with good collaterals seem to represent those patients without tissue at risk (ie, small stroke, lacunar stroke, or tissue at risk already completely infarcted).

It is likely that the combination of CT and CTA is more cost-effective than stroke MRI. Still, the problem in managing acute stroke imaging is not that of deciding between CT or MRI because the majority of acute stroke patients are admitted to hospitals without MR scanners. Regarding secondary prevention (eg, antithrombotic treatment), even today many stroke patients do not receive appropriate medication because of lack of brain imaging facilities, or they receive antithrombotic treatment without a prior CT scan to exclude intracranial hemorrhage, which also represents an increased risk for those patients.\textsuperscript{33,34} When this fact is considered, the combination of CT and CTA is very effective and efficient. In the near future, currently available CT techniques may allow a more direct assessment of cerebral hemodynamic parameters because there are encouraging findings from studies of cerebral perfusion-weighted CT.\textsuperscript{35–37} which renders information regarding cerebral blood flow. Whereas the techniques in our study obtain information about the angiographic filling of the collateral vessels, the perfusion-weighted CT allows the radiologist to provide statements about regional blood flow. However, the special perfusion software is not yet available on many CT scanners serving emergency units. Nevertheless, further studies should examine the value of the combination of CT/CTA/perfusion-weighted CT in comparison to DWI/PWI MRI.

Our study also has some limitations. The fact that rtPA thrombolysis was performed in 8 patients must be addressed because reduction of DWI defects after early rtPA treatment was seen in stroke patients.\textsuperscript{38} This may have affected clinical outcome. The rate of rtPA patients in the 2 subgroups, however, did not differ significantly. Furthermore, this does not affect our main message that with CT/CTA/CTA-SI the sensitivity of diagnosis of ischemic stroke compares well with that of stroke MRI.

Although there is proof from animal experiments that CT contrast agents do not worsen ischemic stroke,\textsuperscript{39} this should be more firmly established. A prospective multicenter trial may be helpful for acquiring data in a substantially larger set of hyperacute stroke patients.

**Conclusions**

In patients with symptoms of acute stroke, a combination of non–contrast-enhanced CT and CTA is a rapid diagnostic tool and shows good correlation with diffusion-weighted stroke MRI. Since smaller hospitals often do not have (stroke) MR scanner facilities, an inexpensive and fast diagnostic protocol can be performed by combining CT and CTA. With this combination the vascular status is reliably assessed, and the presence or absence of intracerebral hemorrhage can be determined. The findings on the CTA-SI are not only consistent with the understanding of stroke pathophysiology but also predict morphological and clinical outcome. The collateral status may distinguish the patients at risk of infarct growth from those who are not. If stroke MRI is not available, combined CT/CTA/CTA-SI should be used to obtain additional information in patients with acute stroke.
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Comparison of CT and CT Angiography Source Images With Diffusion-Weighted Imaging in Patients With Acute Stroke Within 6 Hours After Onset

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