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Index terms:
Brain, CT, 10.12111, 10.12113
Brain, infarction, 10.78
Cerebral blood vessels, flow dynamics
Computed tomography (CT), angiography, 10.12116
Computed tomography (CT), perfusion study

Published online before print
10.1148/radiol.2331030028
Radiology 2004; 233:79–86

Abbreviations:
ASPECT = Alberta Stroke Program Early CT
CBF = cerebral blood flow
CBV = cerebral blood volume
NIHSS = National Institutes of Health Stroke Scale
TTP = time to peak

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Acute Stroke Assessment with CT: Do We Need Multimodal Evaluation?[1]

PURPOSE: To assess detection of stroke and prediction of extent of infarction with multimodal computed tomographic (CT) evaluation (unenhanced CT, perfusion CT, and CT angiography) in patients suspected of having acute stroke.

MATERIALS AND METHODS: Forty-four consecutive patients with a mean National Institutes of Health Stroke Scale score of 10.45 and suspected of having ischemic stroke of the anterior circulation were examined with multi–detector row CT within 8 hours (mean, 3.05 hours) of onset of symptoms. All evaluations were performed with the knowledge that acute stroke was suspected but without detailed clinical information. The extent of ischemia or final infarction on the baseline unenhanced CT scan and follow-up images was assessed with the Alberta Stroke Program Early CT score. Different perfusion maps and follow-up images were assessed to determine the percentage of the ischemia-affected hemisphere. Each component, as well as the multimodal CT evaluation, was compared with follow-up unenhanced CT scans or magnetic resonance images after a mean time of 2.32 days.

RESULTS: Multimodal CT revealed true-positive findings in 30 of 41 patients and true-negative findings in three, resulting in a sensitivity of 78.9%. Unenhanced CT, CT angiography, and perfusion CT showed sensitivities of 55.3%, 57.9%, and 76.3%, respectively. In eight patients, small infarctions (mean size, 1.47 cm) that were proved at follow-up were missed with all modalities at initial multimodal CT. With perfusion CT, four of these small infarctions were missed within the white matter of the section levels. Maps of cerebral blood flow showed the best correlation with the final size of infarction with an r^2 value of 0.71.

CONCLUSION: The presented multimodal CT evaluation improves detection rate and prediction of the final size of infarction in comparison with unenhanced CT, CT angiography, and perfusion CT alone.

Acute stroke is the third leading cause of death in the United States. Every year, about 600 000 individuals experience a stroke. More than 85% of strokes have an ischemic origin (1). The estimated direct and indirect costs related to stroke in the United States amounted to $45.4 billion in 2001 (2).

New therapeutic options for assessment of patients with ischemic stroke, such as intravenous or intraarterial lysis therapy, were established within the past decade (3–8). Fibrinolysis therapy offers substantial benefits to selected patients with acute brain ischemia (4). On the other hand, this treatment may have severe side effects, especially secondary intracranial hemorrhage. Currently, every effort is made to better identify the subgroup of patients that benefits from such new therapeutic possibilities. Moreover, the time windows for intravenous and intraarterial lysis therapy are only 3 and 6 hours, respectively, after the onset of symptoms. Thus, specialized clinical examination and diagnostic imaging are required within a short period of time (3,7–9).

Unenhanced computed tomography (CT) of the brain is still the primary imaging modality used in the exclusion of intracranial hemorrhage and the revelation of early signs of brain infarction (10–12). In the very early stage of brain infarction, however, these signs can be depicted only in a portion of patients. Thus, the use of unenhanced CT alone

TABLE 1
Scan Parameters of Multimodal CT Evaluation

Parameter	Unenhanced Helical CT		Perfusion CT	CT Angiography
	Infratentorial	Supratentorial		
Section collimation (mm)	4 × 1	4 × 2.5	4 × 5	4 × 1
Table feed (mm)	2.7	6.8	0	5
Scan direction	Caudocranial	Caudocranial	Dynamic series	Caudocranial
Rotation time (sec)	1	1	0.75	0.5
Field of view (cm)	25	25	25	25
Kilovoltage	120	120	80	120
Tube current (mAs)	350	400	180	110
Reconstructed section thickness (mm)	4	7	2 × 10	1.25
Reconstruction increment (mm)	4	7	0	0.8

comprises some uncertainty of assessment. The current therapeutic opportunities in patients with acute stroke require reliable information about the location and size of brain ischemia. To accomplish these demands, in the late 1990s, perfusion CT was presented as an imaging modality to be used in patients with acute stroke (13–15). CT angiography is another imaging modality that is being used increasingly in the evaluation of patients with acute cerebral ischemia to reveal the origin of infarction and the site of cerebral artery occlusion (16,17). CT angiography allows detailed assessment of the intra- and extracranial vasculature with thin-section multiplanar views, especially when the multi–detector row technique is used (18).

Each of these CT modalities has been evaluated in terms of feasibility and reliability in the early assessment of a stroke. The aim of this study was to assess the detection of a stroke and the prediction of the extent of an infarction by using multimodal CT evaluation, which included unenhanced CT, perfusion CT, and CT angiography, in patients suspected of having acute stroke.

MATERIALS AND METHODS

Study Criteria

This prospective study was approved by the local ethics committee, and permission was granted for the investigation. Informed consent was obtained from all included patients or their relatives.

All patients suspected of having hemispheric ischemic stroke of the anterior circulation who underwent multimodal CT within 8 hours of the onset of symptoms were included. Exclusion criteria were intracerebral hemorrhage at unenhanced CT, clinically suspected cerebellar or brainstem infarction, age of less than 18 years, pregnancy, or contraindications for contrast agent administration, such as a known allergy to an iodine-containing contrast agent or reduced renal function (creatinine level ≥ 2.0 mg/dL [176.8 μmol/L]).

Study Population

Multimodal CT was performed in 44 consecutive patients (mean age, 64.5 years; age range, 29.1–89.8 years), including 30 men (mean age, 64.6 years; age range, 29.1–82.6 years) and 14 women (mean age, 64.3 years; age range, 34.6–89.8 years), within an average time of 3.05 hours (range, 0.5–8.0 hours) after onset of symptoms. Neurologic impairment at admission was assessed with the National Institutes of Health Stroke Scale (NIHSS) (19). In general, a NIHSS score of less than 8 reflects a mild stroke, a score of 8–15 reflects a moderate to severe stroke, and a score of more than 15 reflects a severe stroke. The average NIHSS score was 10.45 (range, 0–27). Recovery was assessed by using the modified Rankin scale (20). The modified Rankin scale is a global assessment of patient function. It is based on the patient's ability to perform activities of daily living, and scores range from 0, which indicates no symptoms at all, to 6, which indicates death. The modified Rankin Scale revealed a mean score of 2.93 (range, 0–5). In three patients, follow-up with CT or magnetic resonance (MR) imaging revealed a site of infarction in the brain stem ($n = 2$) or cerebellum ($n = 1$). According to study criteria, these three patients were not considered for further evaluation.

Initial Imaging

A multi–detector row CT scanner (Somatom Volume Zoom; Siemens Medical Solutions, Erlangen, Germany) was used for data acquisition.

An unenhanced CT examination of the entire brain was performed with 4-mm reconstruction width for the infratentorial region and 7-mm reconstruction width for the supratentorial region. The gantry tilt was parallel to the orbitomeatal line.

Dynamic perfusion CT data were obtained at the level of the basal ganglia. This section includes the vascular territories most frequently affected by an acute stroke, namely the middle cerebral artery territory. The gantry tilt was perpendicular to the posterior segment of the superior sagittal sinus; this minimized calculation errors with the perfusion CT software that were caused by partial volume effect. After administration of 40 mL of the nonionic contrast agent iopromide with a concentration of 300 mg iodine per milliliter (Ultravist 300; Schering, Berlin, Germany) followed by administration of 20 mL of isotonic saline—both injected with a flow rate of 8 mL/sec in a cubital vein—CT was performed with a starting delay of 4 seconds. The sampling frequency for the dynamic series was one image per second for a time period of 40 seconds. The detector collimation was four rows, each was 5 mm, and two adjacent 10-mm-thick sections were reconstructed.

CT angiography was performed with a scanning range that extended from the level of C6 to the level of the lateral ventricles and a reconstructed section width of 1.25 mm. A 100-mL dose of nonionic contrast agent with an iodine concentration of 300 mg per milliliter and a 20-mL dose of isotonic saline (Braun, Helsungen, Germany) were administered in a cubital vein with a flow rate of 3 mL/sec by using a test bolus–triggered delay. The scanning parameters are listed in Table 1.

About 5 minutes were needed for the

positioning of the patient. The pure scanning times for unenhanced CT, perfusion CT, and CT angiography were 45 seconds, 40 seconds, and 35 seconds, respectively. Including planning of the different components, the overall examination took about 8 minutes. Postprocessing in the clinical work-up for perfusion CT and CT angiography starts simultaneously with the scanning and took about 5 minutes for each component. In total, imaging, postprocessing, and film reading takes about 20 minutes.

Follow-up Imaging

Follow-up imaging was performed with CT ($n = 28$) or MR imaging ($n = 16$) within 1–11 days (mean, 2.32 days) of admission. CT was considered sufficient for follow-up if *(a)* ischemia was clearly visualized at the initial examination, *(b)* the critical situation of the patient did not allow MR imaging, or *(c)* the patient had contraindications for MR imaging. For all other patients, MR imaging was performed. The follow-up examination was to be performed 3 days after admission. Exceptions were allowed in case of unproved infarction at initial imaging with an earlier follow-up CT examination performed on day 1 or 2 or permanent monitor status of the patient in the stroke unit that resulted in delayed follow-up on day 4 or later. For follow-up with CT, the scanning protocol was the same as that which has already been described for unenhanced CT. MR imaging was performed with a stroke protocol and a 1.5-T MR imager (Vision; Siemens Medical Solutions) and consisted of a transverse fluid-attenuated inversion-recovery sequence (repetition time msec/echo time msec, 9000/110; section thickness, 5.0 mm), a transverse diffusion-weighted sequence (5100/137; section thickness, 5.0 mm), and a sagittal T2-weighted sequence (3000/96; section thickness, 3.0 mm) of the brain stem. In the case of follow-up with MR imaging, the diffusion-weighted imaging sequence was used to measure the size of the infarction.

Evaluation Procedure

All physicians who performed evaluations were blinded to the detailed clinical information, but they were aware that an acute stroke was suspected. The baseline unenhanced CT scans and follow-up images were reviewed separately by two neuroradiologists (including C.G.) in consensus for early signs of infarction (12). Both readers had 10 years of experience in radiology and 5 and 4 (C.G.) years of experience in neuroradiology. Both sets of images were evaluated according to the Alberta Stroke Program Early CT (ASPECT) score guidelines (21) for the extent of infarction. Unenhanced CT scans were judged to be true-positive if a suspected area of infarction correlated with the site of infarction on the follow-up images. True-negative unenhanced CT scans showed no signs of ischemia on the unenhanced scan and no signs of infarction on follow-up images. False-positive unenhanced CT scans were suspicious for ischemia, but signs of infarction were seen on the follow-up studies. False-negative unenhanced CT scans did not demonstrate suspected ischemia, but infarction was clearly confirmed with the follow-up study. The size of infarction on the follow-up images was measured at the levels of the perfusion CT sections, and the percentage of ischemic brain tissue was noted in relation to the size of the hemisphere.

The perfusion CT images of each section were analyzed separately off-line at a workstation by using the perfusion CT software package (Siemens Medical Solutions, Forcheim, Germany). The maximum-slope model we used is derived from a radiolabeled microsphere technique that is used to measure organ blood flow and has been described elsewhere (14,22). From the acquired dynamic data, perfusion parameters were calculated (ie, maps of cerebral blood flow [CBF], cerebral blood volume [CBV], and time to peak [TTP] enhancement were obtained). The different color-coded perfusion maps were evaluated in consensus by a neuroradiologist (S.P.K.) and a neurologist (D.G.N.) for pathologic perfusion deficits (23,24). The perfusion CT scan was judged to be true-positive if an ischemic perfusion abnormality was diagnosed as an infarction on the follow-up images. True-negative perfusion CT scans showed no signs of ischemia and no signs of infarction on follow-up images. False-positive perfusion CT scans revealed a suspected perfusion abnormality, but no infarction was depicted on follow-up images. False-negative perfusion CT scans did not demonstrate a suspected perfusion abnormality, whereas infarction was clearly confirmed on follow-up images. The size of ischemia on perfusion CT scans was quantified as a percentage of affected hemisphere for all three perfusion maps in both sections separately.

Size measurements were performed by using the freehand region of interest tool of the perfusion CT software and the postprocessing workstation of the CT and MR imager with automated calculation of the marked area in square centimeters.

The acquired CT angiography data were reviewed with the three-dimensional mode of the Wizard workstation (Siemens Medical Solutions, Erlangen, Germany) with transverse, sagittal, and coronal views. Images obtained with CT angiography were graded as abnormal or normal by a neuroradiologist (S.P.K.) and a neurologist (E.M.N.) in consensus. Criteria of abnormal CT angiographic findings were occlusion or relevant stenosis (more than 50%) of the internal carotid artery or of a major intracranial arterial branch.

Statistical Analysis

Baseline unenhanced CT scans and perfusion CT maps were compared with follow-up studies. CT angiographic findings were correlated with the presence or absence of infarction on baseline unenhanced CT scans and follow-up images. The original data of the ASPECT score of the unenhanced CT and follow-up examinations were compared with contingency table analysis. The continuous data of percentage of ischemic hemisphere of the perfusion CT maps in comparison to the follow-up examinations were evaluated with regression analysis. For both analyses, r^2 values were calculated. The r^2 value is used to measure the proportion of the total variation accounted for by the model. The remaining variation is attributed to random error. The r^2 value is 1 if the model fits perfectly. An r^2 value of 0 means that the fit is no better than the mean. All statistics were calculated by using SPSS 10.0 software (SPSS, Chicago, Ill).

In a descriptive analysis, true-positive, true-negative, false-positive, and false-negative rates, as well as sensitivities, were calculated for the different CT components and the multimodal CT evaluation.

In addition, the subgroup of patients with mild neurologic symptoms, which resulted in a NIHSS score of 5 or less, were evaluated separately.

RESULTS

Unenhanced CT in Comparison to Follow-up Imaging

In 21 of 41 patients, signs of ischemia on the baseline unenhanced CT scans were confirmed with signs of infarction on the follow-up images. In one patient,

TABLE 2
Distribution of ASPECT Scores at Baseline Unenhanced CT and Follow-up Examinations

ASPECT Score at Baseline Unenhanced CT	ASPECT Score at Follow-up Examinations											
	10	9	8	7	6	5	4	3	2	1	0	Total
10	3	6	3	2	1	0	0	1	0	0	0	16
9	0	1	0	0	0	0	0	0	0	0	0	1
8	0	0	2	4	2	0	0	0	0	0	2	10
7	0	1	0	2	0	0	0	0	0	0	0	3
6	0	0	0	1	2	0	0	0	0	0	0	3
5	0	0	0	0	0	0	0	0	1	0	0	1
4	0	0	0	0	0	1	0	0	0	0	0	1
3	0	0	1	0	1	0	0	0	0	0	0	2
2	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	8	6	9	6	1	0	1	1	0	2	37

Note.—Data are numbers of patients. Table contingency analysis revealed a correlation coefficient in the comparison of baseline unenhanced CT and follow-up examination of $r^2 = 0.42$.

initial unenhanced CT was the only method used to demonstrate acute brain ischemia. The sensitivity for signs of ischemia on unenhanced CT scans was 55.3%. True-negative results were shown in three of 41 examined individuals. No evidence for brain ischemia was found on the baseline unenhanced CT scan in 17 of 41 patients, but the findings of a follow-up examination confirmed the presence of an infarction. In four of these 17 individuals, however, signs of ischemia on the baseline unenhanced CT scan were assumed not to be at the site of final infarction but to be in the contralateral unaffected hemisphere. All of these false-positive cases could be ruled out with perfusion CT and were excluded from further table contingency analysis. Table 2 summarizes the distribution of the ASPECT score for the baseline unenhanced CT scans and the follow-up images for the remaining 37 patients. The contingency table analysis revealed a correlation coefficient of 0.42.

CT Angiography in Comparison to Baseline and Follow-up Imaging

CT angiography demonstrated abnormal findings in 22 of 41 patients with infarction on the follow-up images, resulting in a sensitivity of 57.9%. CT angiography revealed occlusion of the internal carotid artery or the middle cerebral artery in 18 patients and stenosis of more than 50% of the internal carotid artery in four. In five of the 22 patients with abnormal findings at CT angiography, the baseline unenhanced CT scan revealed no signs of ischemia; however, in four patients with true-positive signs of ischemia on the unenhanced CT scan, findings at CT angiography were unremarkable.

Perfusion CT in Comparison to Baseline Unenhanced CT and Follow-up Imaging

In consideration of all different perfusion maps, perfusion CT revealed perfusion deficits in 29 of 41 patients; these perfusion deficits were confirmed by infarction at the follow-up examinations. The sensitivity for detecting ischemic perfusion deficits with perfusion CT was 76.3%. In three of 41 individuals, true-negative findings at perfusion CT were confirmed with unremarkable findings at follow-up examinations. In nine patients with infarction at the follow-up examinations, the results of perfusion CT were false-negative. The mean size of all missed infarctions was 1.47 cm^2 (range, 0.1–4.5 cm^2); however, only four of the nine missed infarctions with a mean size of 1.59 cm^2 (range, 0.5–3.0 cm^2) were located within the sections of the perfusion CT scan. No false-positive perfusion CT scans were noted.

Detection Rate for the Different Perfusion CT Sections

A total of 29 individuals presented with ischemia within the perfusion CT sections. Two patients had to be excluded from this part of the evaluation because they had only one section that was sufficient for diagnosis. In the CBF maps, abnormal perfusion was found on only one section in six patients, whereas 21 individuals had perfusion deficits on both sections. The calculated correlation coefficient for the comparison of the size of ischemia in the CBF map and the final size of infarction at follow-up is 0.71 (Fig 1). CBV maps revealed abnormal findings in 24 individuals, and perfusion deficits in only one section were found in three patients. The correlation coefficient is 0.69 for the size of brain ischemia on the CBV map and the final size of infarction on the follow-up images (Fig 2). The TTP maps showed abnormal perfusion in one section in four patients and in both sections in 23 patients. The correlation coefficient is 0.22 for TTP and follow-up examination in terms of assumed and proved size of infarction.

Patients with NIHSS Score of 5 or Less

Images obtained in 14 of 41 patients (34%) with an NIHSS score of 5 or less were reviewed separately, as this subgroup was remarkably large compared with the size of other studies. In 11 of these 14 individuals, follow-up images revealed an infarction. Baseline unenhanced CT demonstrated signs of brain ischemia in two patients, and CT angiography showed vessel occlusion or severe stenosis in three of 11 patients, resulting in a sensitivity of 18.2% and 27.3%, respectively. In consideration of all components, the multimodal CT evaluation showed signs of ischemia in eight of 11 patients with a sensitivity of 72.7%. In three patients, infarction was missed in all components; however, the mean size of these infarctions was small (1.67 cm^2).

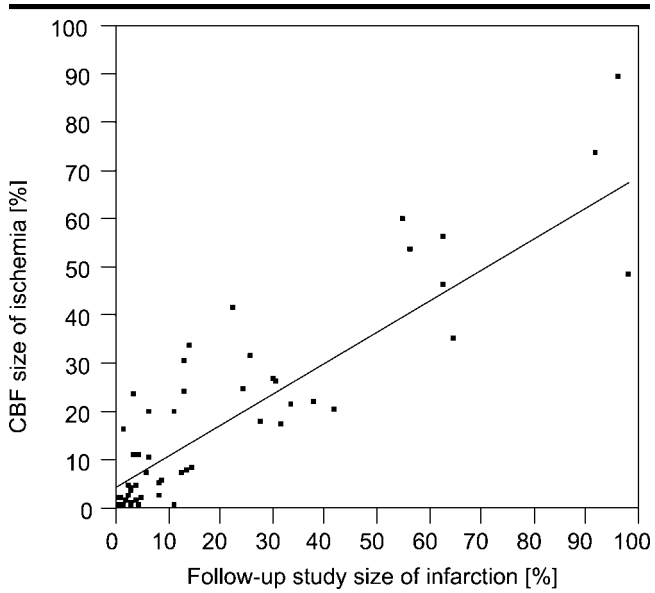

Figure 1. Regression-analysis model shows size of perfusion abnormality in the CBF maps in correlation to size of infarction of follow-up scans quoted in percentage of affected hemisphere. Perfusion CT and follow-up findings are well correlated ($r^2 = 0.71$, $P < .001$).

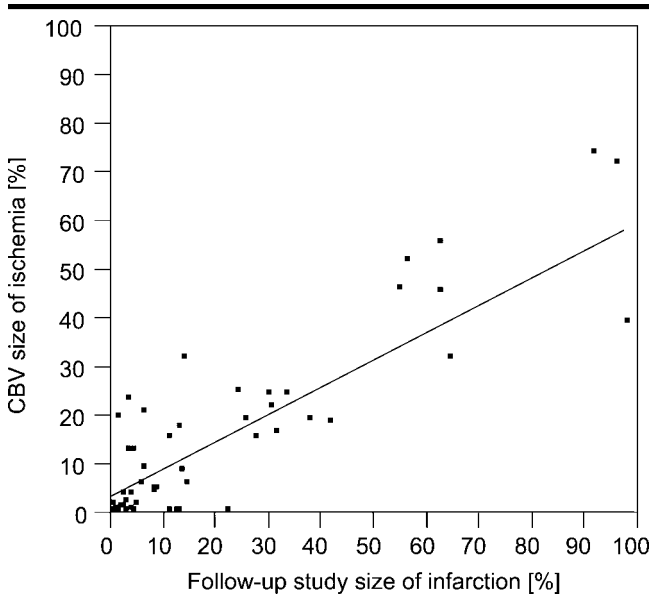

Figure 2. Regression-analysis model shows size of perfusion abnormality in CBV maps in correlation to size of infarction of follow-up scans quoted in percentage of affected hemisphere. Perfusion CT and follow-up findings are well correlated ($r^2 = 0.69$, $P < .001$).

Multimodal CT Evaluation

In consideration of all components of the multimodal CT evaluation, 30 of 41 patients had true-positive results with infarction at the follow-up examination (Table 3), resulting in a sensitivity of 78.9%. In one of these patients, signs of ischemia were found only on the initial unenhanced CT scan, whereas the results of perfusion CT and CT angiography were unremarkable. Three of 41 individuals had true-negative findings. In eight patients, a brain infarction was found at the follow-up examination; however, the multimodal CT evaluation showed no evidence of brain ischemia. The mean size of all these infarctions was 1.59 cm^2 (range, 0.1–4.5 cm^2). Three of the eight missed infarctions were found at the sections level of the perfusion CT scan. These three infarctions had a size of 0.4–3.0 cm^2. No patient had false-positive findings, which was proved in the follow-up examinations. A clinical case is illustrated in Figure 3.

No statistically significant differences between the distributions according to sex and age were found.

DISCUSSION

The ability to rapidly and accurately depict the location and extent of acute brain ischemia is of major clinical importance. Besides the prognostic value of depicting acute brain ischemia, which was discussed in an article by our study group (25), it also affects the therapeutic decision, in particular regarding the risks-to-benefits ratio of possible thrombolytic therapy.

Unenhanced CT, especially in patients with acute stroke, is known to have some uncertainty in terms of depiction of early signs of infarction and quantification of affected tissue. In our study, the sensitivity for early signs of infarction was 55.3%. This finding is within the range of findings of previous studies with reported sensitivities between 45% and 88% (12,26,27) depending on the time of examination. Moreover, the large number of patients with a baseline NIHSS score of 5 or less in our study has to be taken into consideration, as a greater portion of transient ischemic attacks or small infarctions can be presumed to exist in this subgroup on the basis of the presented clinical findings. Accordingly, this subgroup revealed that unenhanced CT had a sensitivity of less than 20% for infarction. The estimated extension of infarction calculated according to the ASPECT score correlated poorly with the final size of infarction at the follow-up examination.

In contrast, perfusion CT showed a good correlation for the size of perfusion deficit in the CBF and CBV maps with the final size of infarction. The size of perfusion deficit of the CBF maps demonstrated the best correlation with the final size of infarction at the follow-up examination (28).

In consideration of all perfusion maps, perfusion CT had a sensitivity of 76.3% for perfusion deficit. This sensitivity is lower than that found in several other studies for perfusion CT (13,28,29). One must take into account, however, that most of these reports did not describe the clinical stroke severity of the included individuals with the NIHSS score or Rankin scale. In our study, one-third of the patients had NIHSS scores of 5 or less at admission. However, the multimodal CT evaluation proved that detection rates for this subgroup were similar to those of the total population, indicating that multimodal CT can improve the detection rate, especially in patients with minor neurologic symptoms.

CBF and TTP maps were more sensitive for perfusion disturbances than were CBV maps. In all different perfusion maps, a certain portion (12.5%–22.2%) showed perfusion deficits only in one section. Thus, the use of multi–detector row CT with two sections and a total coverage of 20 mm seems to improve the detection rate compared with that of a single-section technique.

More and more, CT angiography is considered a valuable tool in the assessment of acute stroke, as it can depict the origin of thromboembolism and the site of vessel occlusion (16,17). CT angiogra-

TABLE 3
Summary of Results

Patient No.	Age (y)	Sex	Multimodal CT Evaluation: Unenhanced CT	Perfusion CT: Section 1*	Perfusion CT: Section 2†	CT Angiography	Follow-up Examination
1	61	Male	Negative‡	Negative	Negative	Negative	Positive
2	49	Female	Positive	Positive	Positive	Positive	Positive
3	60	Male	Negative	Positive	Positive	Positive	Positive
4	37	Male	Negative	Negative	Negative	Negative	Positive
5	75	Male	Negative	Positive	Positive	Negative	Positive
6	74	Male	Positive	Positive	Positive	Positive	Positive
7	71	Male	Positive	Positive	Positive	Positive	Positive
10	52	Female	Negative	Negative	Negative	Negative	Positive
11	73	Male	Negative	Negative	Positive	Positive	Positive
12	75	Female	Negative	Negative	Positive	Negative	Positive
13	54	Male	Positive	Positive	Positive	Positive	Positive
14	58	Male	Positive	Positive	Positive	Positive	Positive
15	70	Male	Positive	Positive	Positive	Positive	Positive
17	62	Male	Negative	Negative	Negative	Negative	Positive
18	74	Female	Positive	NA§	Positive	Positive	Positive
19	83	Male	Positive	Positive	Positive	Negative	Positive
20	73	Female	Positive	Positive	Positive	Positive	Positive
21	76	Male	Positive	Positive	Positive	Positive	Positive
22	29	Male	Negative	Negative	Negative	Negative	Positive
23	67	Male	Positive	Positive	Positive	Positive	Positive
24	69	Male	Negative	Positive	Positive	Negative	Positive
25	48	Male	Positive	Positive	Positive	Negative	Positive
26	71	Male	Positive	Positive	Positive	Positive	Positive
27	71	Male	Negative‡	Negative	Positive	Positive	Positive
28	42	Male	Negative‡	Negative	Negative	Negative	Positive
29	69	Male	Negative	Positive	Positive	Negative	Positive
30	62	Male	Positive	Positive	Positive	Positive	Positive
31	74	Female	Negative	Positive	Positive	Positive	Positive
32	58	Male	Positive	Positive	Positive	Positive	Positive
33	35	Female	Negative	Negative	Negative	Negative	Negative
34	76	Female	Positive	NA§	Positive	Positive	Positive
35	76	Male	Negative	Negative	Negative	Negative	Positive
36	47	Female	Positive	Positive	Positive	Negative	Positive
37	62	Female	Positive	Positive	Positive	Positive	Positive
38	72	Male	Negative	Negative	Negative	Negative	Negative
39	90	Female	Positive	Positive	Positive	Positive	Positive
40	75	Male	Positive	Negative	Positive	Positive	Positive
41	68	Female	Positive	Negative	Negative	Negative	Positive
42	74	Male	Negative	Negative	Negative	Negative	Negative
43	47	Female	Negative	Negative	Negative	Negative	Positive
44	71	Male	Negative	Positive	Positive	Positive	Positive

Note.—Patients 8, 9, and 16 excluded, in accordance with study criteria, because of proved infarction of the posterior circulation. NA = not applicable.
* Section 1 = at the site of basal ganglia.
† Section 2 = just superior to section 1.
‡ Early signs of infarction on unenhanced CT scans were not at the site of confirmed infarction on the follow-up study but at the contralateral unaffected hemisphere; therefore, these results were counted as false-negative.
§ These sections of perfusion CT were technically insufficient for calculation.

phy has demonstrated an accuracy that is comparable to that of digital subtraction angiography and MR angiography in terms of the detection rate of major vessel occlusion (30–32). In our patients, the sensitivity for vessel occlusion or severe stenosis was 57.9% in patients with proved infarction at the follow-up examination. A published report described a sensitivity of 60% (33).

Results with other perfusion techniques, such as xenon CT, single photon emission CT, and positron emission tomography, have confirmed the reliability of information they provide about cerebral perfusion; however, they never became standard procedures for evaluation of acute stroke because data acquisition was too time-consuming or availability was too low (34,35).

In consideration of all components, multimodal CT evaluation had a sensitivity of 78.9% for infarction. As already mentioned, the lack of description of the clinical stroke severity in previous studies (13,28,29) has to be considered in terms of comparability. In contrast with unenhanced CT alone, the detection rate could be increased to about 40% with the use of multimodal CT in our examined patients.

Other imaging techniques, such as diffusion- and perfusion-weighted MR imaging, offer excellent information about ischemic brain tissue (36–39). First, the results of comparative studies showed an advantage of MR imaging in terms of detection rate compared with that of unenhanced CT. Diffusion-weighted MR imaging was shown to have a sensitivity of up to 95% in the early detection of brain ischemia (26,40,41). MR imaging is excluded in patients with several conditions (ie, those with a pacemaker, certain types of implants [42]); moreover, MR imaging is not available 24 hours a day, 7

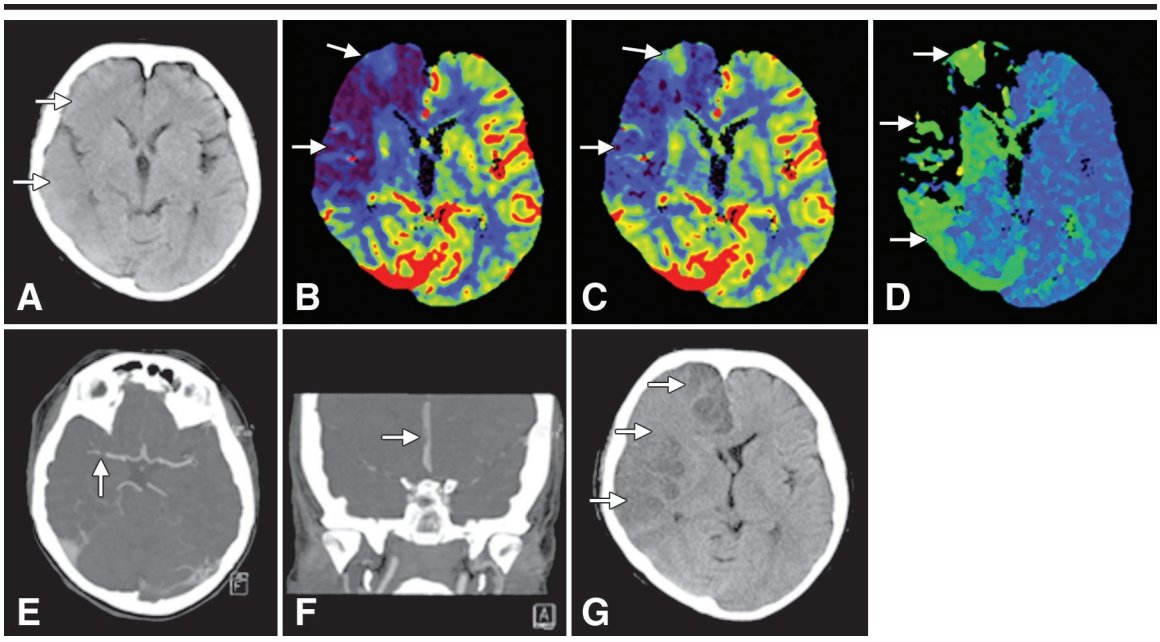

Figure 3. Images obtained in a 61-year-old woman with acute left-sided hemiplegia. *A,* Transverse unenhanced CT scan obtained 2 hours after onset of symptoms shows slight crowding of the sulci and reduced differentiation of gray and white matter (arrows) in the right middle cerebral artery territory at the level of basal ganglia; however, an accurate prediction of the extension of the ischemia is difficult. Immediate transverse perfusion CT scans obtained at the level of basal ganglia reveal marked malperfusion (arrows) in the CBF (*B*) and CBV (*C*) maps, as well as increased time to peak (horizontal arrows) in the TTP (*D*) map for the right anterior and medial middle cerebral artery territory and the right anterior cerebral artery territory. On the basis of these findings, no intravenous lysis therapy was performed. CT angiography confirms, *E,* occlusion of the right middle cerebral artery at the M1/M2 segment in the transverse view (arrow) and, *F,* occlusion of the right anterior cerebral artery in the coronal view (arrow). *G,* Transverse CT scan obtained at 48 hours of follow-up displays infarction (arrows) in the right anterior cerebral artery and middle cerebral artery territories.

days a week in most hospitals. Furthermore, the clinical condition of patients with acute stroke can make MR imaging difficult or impossible. Thus, further studies with larger numbers of patients are needed to confirm the superiority of MR imaging; also, comparative studies of perfusion CT and MR imaging are needed.

Several issues in the present study and the proposed technique need to be addressed in terms of study limitations. First, follow-up imaging, which allowed us to detect and quantify cerebral infarction, consisted of two different modalities, MR imaging and CT. This reflects the need for further investigation with MR imaging in patients with stroke symptoms but an initially inconspicuous CT scan. Second, the time of follow-up varied. This is related to the impossible balance between the need for scheduled follow-up imaging in patients whose condition is critical and the need for permanent monitoring in the stroke unit.

In conclusion, because CT is still the primary imaging modality in patients with acute stroke, multimodal CT evaluation improves the rate of detection of infarction in comparison with unenhanced CT alone. Small brain ischemia, however, particularly lacunar infarction outside of the perfusion CT section levels, can be missed. Thus, the regression line was not forced to fit through the origin in the regression analysis, as there is no general coincidence of the absence of a perfusion abnormality on the perfusion CT section levels, and no infarction was seen on the follow-up images. CBF maps derived from the dynamic perfusion CT study showed a good correlation with the final size of infarction. The use of multi–detector row CT demonstrated improved detection rate of perfusion deficits up to 40%, particularly in patients with minor neurologic symptoms (ie, patients with an NIHSS score ≤ 5). CT angiography was the third component of the evaluation and can give hints as to the cause of infarction and the site of vessel occlusion. We believe multimodal CT evaluation can aid decision making for treatment of patients suspected of having a stroke.

Acknowledgments: We are indebted to the patients who participated in this study. We gratefully acknowledge the assistance of the clinical residents and technicians of the Department of Clinical Radiology and the stroke fellows of the Department of Neurology at the University Hospital of Muenster, Muenster, Germany.

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