Computerized tomography angiography of ruptured cerebral aneurysms: factors affecting time to maximum contrast concentration

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Object. This study was conducted to assess the diagnostic value of three-dimensional computerized tomography (3-D CT) angiography in demonstrating cerebral aneurysms in 42 consecutive patients presenting with acute subarachnoid hemorrhage (SAH).

Methods. To obtain the volume data for selective visualization of the cerebral arteries without enhancement of the venous system, the time delay was established between the injection of contrast medium and the start of scanning by using two different methods. The circulation time was calculated with Schad’s formula in the first 13 cases, but the results were not satisfactory. In the 29 subsequent cases the time delay was established using a single-level dynamic CT prescan. The dynamic prescan demonstrated the statistical differences in peak time with regard to patient age, SAH grade, and the postresuscitation state after cardiopulmonary arrest. The 3-D CT angiograms were generated from the volume data by using a voxel transmission method. Computerized tomography angiography obtained after optimally adjusted time delay demonstrated the contour of the cerebral arteries in 97% of cases, and aneurysms were detected in 93%. Enhancement of the cavernous sinus and major cortical veins was avoided. Even in patients who suffered cardiopulmonary arrest, images of the major arteries were clearly demonstrated after resuscitation.

Conclusions. In an emergency situation, CT angiography with a dynamic prescan may be an alternative to magnetic resonance angiography or digital subtraction angiography in the diagnosis of ruptured aneurysms. This modality would also be useful for the precise assessment of small aneurysms, blebs, and aneurysms adjacent to the cavernous sinus.

KEY WORDS • ruptured cerebral aneurysm • angiography • computerized tomography • three-dimensional reconstruction

With recent advances in computerized tomography (CT), most intracranial aneurysms larger than 3 mm can be detected on three-dimensional (3-D) CT angiography.1,16 This technique provides preoperative images that are useful for planning microsurgical approaches, especially in cases of giant or thrombosed aneurysms.8,16 It has become diagnostically equivalent to magnetic resonance (MR) angiography in that it provides multiple views of aneurysms, and it can be used in an emergency situation when MR angiography cannot.

In cases of acute subarachnoid hemorrhage (SAH), however, it is not easy to obtain consistently acceptable images of the aneurysm, especially in patients with poor-grade lesions. When the timing of the contrast injection and scanning are not adjusted precisely, the enhancement can vary from examination to examination, even in the same patient.3 This variation may be caused by changes in intracranial pressure and circulatory hemodynamics. Moreover, venous enhancement can result in a misleading diagnosis, that is, cavernous sinus enhancement can obscure paraclinoid aneurysms and a crossing vein could appear as a small aneurysm.16 In the present study, we performed 3-D CT angiography after adjusting the timing of the imaging relative to the contrast injection. This allowed us to evaluate prospectively the efficacy of this method for demonstrating cerebral aneurysms and for planning neurosurgical intervention in patients with acute SAH within 6 hours after presentation.

Clinical Material and Methods

Between October 1994 and October 1996, a total of 65 patients with acute SAH caused by rupture of a cerebral saccular (berry) aneurysm were transferred to our institution. From this population, 3-D CT angiograms obtained in 42 patients were evaluated within 6 hours after the
onset of the hemorrhage. The remaining 23 patients were excluded from the study because 3-D CT angiography was performed more than 6 hours posthemorrhage. The patients’ blood pressure was controlled by means of intravenously administered nicardipine. Buprenorphine hydrochloride was administered intravenously to sedate the patient when necessary. Patients in cardiopulmonary arrest were examined after resuscitation. The patients’ clinical status was assessed at the time of admission according to the World Federation of Neurological Surgeons (WFNS) grading scale.

The findings on the initial routine CT scan were classified according to the grading system of Fisher, et al. The patients were divided into two groups depending on the method used to determine the circulation time from the superior vena cava to the internal carotid artery (ICA). In the first 13 cases the circulation time was calculated using Schad’s formula: circulation time (t) = n × 60 / f (seconds), in which n was the coefficient and f was the heart rate just prior to scanning.

In the 29 subsequent patients the circulation time was measured by using a dynamic study. The examination was performed using a CT scanner with the gantry angle set parallel to the orbitomeatal line, and a routine serial CT volume scan was obtained prior to the dynamic study. The single-level dynamic CT scanning was performed at the level of the intracavernous ICA, which includes the cavernous sinus, and in most cases the basilar artery (BA). Radiographic parameters were set at 175 mA and 120 kV to minimize radiation exposure. The slice thickness was set at 10 mm. Fifteen milliliters of iopamidol (300 mgI/ml) was injected with the power injector at a rate of 4 ml/second via a catheter placed in the superior vena cava. Starting at the time of injection of the contrast medium, the Hounsfield Units (HU) of the regions of interest, that is, both ICAs and the BA, were measured and time-enhancement curves were created. The time of maximum vascular enhancement was defined as the peak time. It took approximately 5 minutes to determine the circulation time.

The preliminary study demonstrated that the peak time for enhancement of the cavernous sinus was 4 to 6 seconds longer than for the intracavernous ICA in Grades II and III and 8 to 13 seconds longer in patients classified as Grades IV and V. The level of the volume scan was adjusted so that the C3–4 portion of the ICA was included in the lowest 8 to 10 mm of the imaging volume. Using this method, we acquired the data at the level of the cavernous sinus.

Fig. 1. Upper: A 3-D CT angiogram generated using the voxel transmission technique showing an incidental unruptured right paraclinoid aneurysm. The contour of the aneurysm is clearly delineated (encircled area). The rolling configuration of the intracavernous ICA and absence of cavernous sinus enhancement is demonstrated. Lower Left and Right: Digital subtraction angiogram showing the contour of the aneurysm (arrows). The ruptured PCoA aneurysm is not demonstrated in these projections.

Fig. 2. Four routine projections on 3-D CT angiography showing an ACoA aneurysm. The anteroposterior (A), submentovertex (B), left posterior oblique (C), and right posterior oblique (D) projections and the DS angiography studies of the case (E–G) are displayed.
Three-dimensional CT angiography in SAH

sinus prior to enhancement of the sinus. The upper BA was included in the imaging volume. In selected cases in which the initial routine CT scan indicated the presence of a posterior inferior cerebellar artery (PICA) or distal anterior cerebral artery (ACA) aneurysm, the level of the volume scan was adjusted to include those targets.

After the axial CT volume data were acquired, they were transferred to a computer workstation. The CT angiography images were generated at a 1-mm reconstruction pitch by using a surface rendering method in the first six cases. A voxel transmission method was used in the remaining 36 cases (Fig. 1). The threshold was adjusted carefully to erase artifacts while we observed axial slice images of the volume data. Therefore, the threshold was 120 to 150 HU in the 13 preliminary cases and 150 to 200 HU in the 29 subsequent cases. The radiological technicians routinely prepared the images in the following four projections: anteroposterior, submentovertex, right posterior oblique, and left posterior oblique (Fig. 2).

Before surgery, the patients also underwent digital subtraction (DS) angiography, which included the optimum projections determined by 3-D CT angiography. Angiographic images were displayed on a 1024 x 1024 matrix. Four-vessel studies were performed using a No. 5.5 French catheter and iopamidol (300 mgI/L). The rotational technique was used when necessary. The total 180° rotation was accomplished in 6 seconds, and exposures were obtained at 7.5 frames per second.

Computerized tomography angiography, viewed in the four routine projections, and DS angiography, including standard and rotational views, were evaluated preoperatively by two neurosurgeons (Y.N. and T.Y.) to identify the ruptured aneurysm. The diagnosis of a ruptured aneurysm was confirmed by surgical findings except in five patients who were transferred in cardiopulmonary arrest.

Values are expressed as a mean ± standard deviation (SD). A Mann–Whitney U-test or chi-square test was applied when appropriate to determine statistical significance.

Sources of Supplies and Equipment

The nicardipine hydrochloride (Perdipine) was purchased from Yamanouchi Pharmaceutical Co., Ltd., and the buprenorphine hydrochloride (Lepetan) from Otsuka Pharmaceutical Co., Ltd., both in Tokyo, Japan. The Hitachi CT scanner (model W-3000) and computer workstation were both obtained from Hitachi Medical Corp., Tokyo, Japan. The iopamidol (Iopamiron) was acquired from Nihon–Schering, Tokyo, Japan. The iopamidol (Iopamiron) was acquired from Nihon–Schering, Tokyo, Japan. The iopamidol (Iopamiron) was acquired from Nihon–Schering, Tokyo, Japan. The Philips Integris angiographic unit (model V3000) was acquired from Philips Medical Systems, Shelton, CT.

Results

Clinical Characteristics and Overall Complications

The clinical characteristics of the patients are summarized in Table 1. All the patients in this study were examined by means of 3-D CT angiography before they entered the intensive care unit and soon after their vital signs were stable. The volume scan was obtained 60 to 351 minutes (175 ± 80 minutes) after the onset of bleeding. No complications were associated with the use of 3-D CT angiography. All patients were studied by means of rotational DS angiography before surgery except for one who experienced rebleeding before the scheduled DS angiography.

Determination of the Peak Time

Time-enhancement curves were obtained in all cases studied. In one patient, a low but sustained level of enhancement was maintained following a low level of peak enhancement. In another, the peak times in the ICAs on either side were not equal (Fig. 3). In those two patients, conventional DS angiography demonstrated no variation of the vascular anatomy or significant arteriosclerotic changes from the aortic arch to the ICAs and BA. The peak time to enhancement of the BA was measured in 27 cases. The difference in the peak time of the BA and ICA was 0 to 2 seconds in 23 cases, 3 to 6 seconds in three cases, and longer than 6 seconds in one case. There were statistical differences in the peak time with regard to patient age, WFNS grade, and the postresuscitation state from cardiopulmonary arrest. However, no differences were detected with regard to gender and Fisher grade (Table 2).

Demonstration of Ruptured Aneurysms

The level of the volume scan included the C1–2 segments of the ICA, the M1–2 segments of the middle cerebral artery (MCA), the A1–3 segments of the ACA and the upper BA except in three cases. In one case, the routine serial CT scan showed a dense clot in the fourth ventricle, and thus a ruptured PICA aneurysm was suspected. In the other
two cases, ruptured distal ACA aneurysms were suspect-
ed because the hematoma was formed around the genu of
the corpus callosum.

In the first 13 cases, good cerebral arterial images were
obtained in nine (69%), and a ruptured aneurysm was
demonstrated on the routine 3-D projections in 10 (77%)
of 13 cases. In two cases arterial enhancement was not
achieved in the volume acquisition. In one case a small
anterior communicating artery (ACoA) aneurysm could
not be demonstrated because it was poorly delineated.

In the 29 subsequent cases excellent or good cerebral
arterial images were obtained in all but three, and a rup-
tured aneurysm was demonstrated on the routine 3-D pro-
jections in 25 cases (86%) (Table 3). The arterial images
were excellent in 18 cases (62%) and clearly demonstrated
the contour of the ICAs (C1–4), the MCAs (M1–2), the
ACAs (A1–3), the upper BA, and the origin of their branch-
es. The arterial images were good in eight cases (28%)
and were clinically useful despite some blurry contours of
part of a major artery. In the remaining three cases, the
images of part of a major or peripheral artery were poor.

In one patient harboring a small ruptured ACoA aneurysm
that projected inferiorly and was surrounded by a fenest-
ated ACoA and both pericallosal arteries, the lesion
could not be recognized on the CT angiogram. All other
aneurysms were visible on one of the routinely 3-D–re-
structured CT projections except in two cases of posteri-
or communicating artery (PCoA) aneurysms (Fig. 4). In

### TABLE 2

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<th>Factor</th>
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<tr>
<td></td>
<td>ICA</td>
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<tr>
<td>age (yrs)</td>
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<tr>
<td>≤69 (23 patients)</td>
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<tr>
<td>≥70 (6 patients)</td>
<td>19.7 ± 7.1</td>
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<tr>
<td>female</td>
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<tr>
<td>WFNS grade</td>
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<tr>
<td>II–IV</td>
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<tr>
<td>V</td>
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<tr>
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* Values are expressed as the mean ± SD. Abbreviation: NS = not significant.

### TABLE 3

<table>
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<th>Arterial Visualization</th>
<th>Aneurysm Detection</th>
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<td>excellent</td>
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<tr>
<td></td>
<td>on additional views</td>
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<td>good</td>
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<td>7</td>
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<td></td>
<td>on additional views</td>
<td>0</td>
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</table>

Fig. 3. Three-dimensional CT angiogram showing an ACoA aneurysm in a patient transferred to our hospital in car-
diopulmonary arrest. The peak time to maximum enhancement was 20 seconds for the right ICA, 26 seconds for the left
ICA, and 36 seconds for the BA. Note the irregular surface of the left ICA and poor visualization of the MCA. Only the
PCAs are demonstrated in the posterior circulation. The volume scan was started 23 seconds after injection of the con-
trast medium.
those cases, the diagnosis of a ruptured PCoA aneurysm was made with the aid of DS angiography. Even in patients with poor-grade lesions, including those transferred in cardiopulmonary arrest, acceptable arterial images were obtained for precise assessment of a ruptured aneurysm (Fig. 5). Venous enhancement was visible in the straight sinus and its immediate branches in all cases, but was not visualized around the circle of Willis. However, blurred venous images were observed over the MCA (\(M_{1-2}\)) and along the pericallosal artery (\(A_{2-3}\)) in cases of optimum arterial enhancement.

**Discussion**

In most previous studies of 3-D CT angiography, a fixed time-delay technique (usually more than 20 seconds) was used between the injection of contrast material and the start of scanning. With such a technique, the enhancement of cerebral vessels was affected by a number of factors, such as body weight and size, cardiac output, metabolic status, degree of hydration, and the age of the patients. In the first 13 cases in our study, we set the time delay by using Schad’s formula on the basis of the patient’s heart rate, but the method failed to depict cerebral arteries in three cases. In the 29 subsequent cases, we measured the time to maximum vascular enhancement by using a single-slice dynamic prescan with a small amount of contrast medium prior to the volume scan. After we adjusted the time delay by using a dynamic prescan, on subsequent 3-D CT angiographic studies the cerebral arteries were successfully demarcated in all patients except one. A patient’s age, clinical grade of SAH, and postresuscitation state are factors that may be considered in adjusting the time delay.

In the first 13 cases, relatively low threshold levels (100–150 HU) were necessary to generate 3-D CT images. The contour of the arterial wall was still blurred, and it was difficult to diminish adjacent venous images. In the 29 subsequent cases, adjustment of the time delay resulted in excellent arterial visualization, and the 3-D CT images could be generated at higher threshold levels (150–200 HU). The walls of the cerebral arteries and the aneurysm domes were visualized as a smooth surface that delineated the aneurysms of the infraclinoid ICA as clearly separated from the bone, even in the case of a juxtaadural ring aneurysm (Fig. 1). Because cavernous enhancement was absent in all cases, the intracavernous segment of the ICA was beautifully demonstrated when the voxel...
transmission method was used. We tried to diminish residual venous enhancement as much as possible. Although this may not be regarded as a problem by some authors, our study demonstrated that residual venous enhancement located around the MCA (M_1) and the pericallosal artery (A_c), as well as the bifurcation of the arterial branches, made diagnosis difficult in cases of aneurysms smaller than 2 mm.

Aneurysms as small as 1 mm were not detected on 3-D CT angiography. All aneurysms larger than 2 mm were detected by means of this modality except for one case in which the arteries were only poorly visualized. The smallest aneurysm detected was 2.2 mm and was located at the anterior choroidal artery. These findings are consistent with previous studies that have indicated that 2 mm could be the lower limit of aneurysm detection on 3-D CT angiography.1

Our results indicate that the peak time for maximum contrast enhancement depends on certain clinical factors in patients with acute SAH. When CT angiography is performed without a dynamic prescan, a time delay of 8 to 12 seconds is recommended in patients younger than 70 years of age and with a clinical status of Grade II to IV. In patients 70 years or older, or with a clinical status of Grade V, the time delay may be adjusted approximately 20 seconds. However, individualization of the time delay by dynamic prescan would provide more reliable information for a detailed preoperative assessment than for a simple demonstration of the aneurysm. In cases of cardiopulmonary arrest a dynamic prescan is indispensable because the peak time of maximum arterial enhancement varies considerably among patients (13–36 seconds). Although the procedure for the dynamic study requires extra time and an extra volume of contrast medium, it actually took only approximately 5 minutes, and only a small amount (15 ml) of additional contrast medium was needed. Because 80 ml was adequate for the volume scan, the total volume of iopamidol used for the whole procedure was less than 100 ml.

The sensitivity and specificity of aneurysm detection may differ between observers.17 The selected projection of these studies for the reconstructed images is also important. In the present study, the detection of two small aneurysms measuring 2.5 mm and 3 mm was not possible on the four routine views obtained; additional images were required. The other 24 aneurysms, which were larger than 3 mm, were all detected on the routine views, consistent with the results of previous investigators.16 However, for a detailed study of aneurysms in unusual locations, such as the distal ACA, PICA, and PCoA, lesions smaller than 2 mm, and aneurysms adjacent to the cavernous sinus, additional image reconstruction was needed.

Three-dimensional CT angiography is valuable for detecting small aneurysms located in the ACoA complex or the MCA trifurcation, lesions that are often not easily diagnosed on DS angiography because of the presence of the adjacent arterial branches. Small aneurysms were demonstrated by rotating the 3-D CT angiographic images on a video monitor. However, such findings should be confirmed on DS angiography because the origin of small perforating vessels and adjacent veins may mimic small aneurysms or blebs.

Computerized tomography angiography often provides more valuable information than DS angiography about the anatomy of an aneurysm as well as adjacent vessels and bone structures. However, CT angiography does not demonstrate collateral vessels, small perforating vessels, arteriosclerotic changes, and vasospasm as clearly as does DS angiography. Thus, surgery based solely on 3-D CT angiography seems possible and may be indicated in acutely deteriorating patients with ruptured aneurysms associated with large intracerebral hematomas.11,12 However, surgery based on this modality may not be indicated in all cases.

In the present series, the cerebral arterial trunks and ruptured aneurysms were demonstrated in all five patients who were transferred in cardiopulmonary arrest. All five suffered brain death within 12 to 48 hours despite intensive management including continuous monitoring of their intracranial pressure and general status.13 However, a recent report has indicated that 20% of cardiopulmonary arrest patients with SAH may recover functionally when quickly resuscitated by a bystander.15 We therefore believe that an effort to diagnose such patients quickly and accurately is still important to give them a chance for neurosurgical intervention.

Computerized tomography angiography is less expensive than MR angiography, and its sensitivity is similar.6,8,10,14 Compared with MR angiography, 3-D CT angiography is not affected by flow-related artifacts, and motion artifacts are much rarer.14 The latter modality is faster than MR angiography and can be performed in poor-grade patients with acute SAH. It also provides useful presurgical information, such as the presence of calcification of the aneurysm neck and the lesion’s anatomical relationship to the skull base.

Conclusions

This prospective study demonstrated that the peak time of maximum arterial enhancement differs among patients. The patient’s age, SAH grade, and postresuscitation state from cardiopulmonary arrest were the major factors that significantly affected the time to maximum contrast concentration. When the time delay was individually adjusted, 3-D CT angiography was suitable for the assessment of ruptured aneurysms in patients with acute SAH. Because venous enhancement was minimal, this modality also provided clear images that helped us make an accurate diagnosis of aneurysms adjacent to the cavernous sinus. Although neurosurgical intervention after 3-D CT angiography alone is possible, at least in selected cases, further study is needed to confirm its universal feasibility as the sole presurgical study with no information obtained from conventional or DS angiography.

Acknowledgments

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