Three-dimensional computerized tomography angiography in the diagnosis of cerebrovascular disease

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Computer-generated three-dimensional reconstruction of the intracranial vascular system obtained by contrast-enhanced computerized tomography (CT) has been used in the diagnosis of 20 patients with known or suspected intracranial cerebrovascular disease. This technique allows visualization of the intracranial vasculature without exposing patients to the risks associated with intra-arterial angiography. The color prints and videotape images generated have been used to diagnose the presence of intracranial aneurysms, arteriovenous malformations, and venous angiomas. They have also been used to rule out structural abnormalities in patients with suspected intracranial vascular pathology and to screen patients with a strong family history of intracranial aneurysm. In 11 patients who underwent both three-dimensional CT angiography and intra-arterial angiography, the diagnostic correlation was 100%. No complications from the procedures or from incorrect diagnosis have been encountered. Although this technique requires further development and clinical evaluation, the authors' early experience with three-dimensional CT angiography suggests that this may become a valuable tool in the diagnosis of patients with cerebrovascular disease.

**Key Words** • aneurysm • cerebrovascular disease • computerized tomography • angiography • three-dimensional reconstruction • vascular malformation

It is well known that the intracranial vasculature can be seen on computerized tomography (CT) scans of the head following intravenous administration of iodinated contrast material and that such contrast-enhanced scans are useful in the diagnosis of intracranial vascular anomalies. However, the resolution of these studies is such that small lesions, particularly vascular aneurysms near the base of the skull, may not be visualized. Even if a vascular anomaly is seen, CT scans are usually inadequate for surgical planning except in emergency situations where delaying surgical therapy to obtain additional neuroradiological information poses a substantial risk to the patient.

Three-dimensional CT angiography uses the data obtained on a contrast-enhanced CT brain scan to generate three-dimensional images of the intracranial vasculature. The three-dimensional CT angiographic images are transferred to color prints and videotape. Videotape images can be rotated up to 180° from right to left and from rostral to caudal, allowing excellent visualization of the anatomical relationship of vascular lesions to normal vasculature and the surrounding structures. We present our early experience with the use of three-dimensional CT angiography in 20 patients with known or suspected cerebrovascular disease.

Clinical Material and Methods

In this procedure, CT* is performed usually with the patient in the supine position, with the orbito-meatal line perpendicular to the floor. No gantry angulation is used. The angle of the head is, however, not critical as long as the CT scan slices cover the entire field of interest. A scout view of the head and upper cervical spine is obtained. A No. 20 or larger intravenous infusion line is placed and connected to an injector.† An intravenous infusion of non-ionic, iodinated contrast solution‡ is started at a rate of 3 ml/sec for 20 seconds and is continued thereafter at a rate of 1 ml/sec until 180 ml has been infused in patients weighing more than 40 kg. For patients less than 40 kg in weight, a total

† Injector manufactured by Medrad, Pittsburgh, Pennsylvania.
‡ Isovue 300 contrast solution manufactured by Squibb Diagnostics, Princeton, New Jersey.
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contrast medium infusion of 2.5 ml/kg is used. Dynamic mode scanning is begun 30 seconds after the start of the infusion of contrast medium. A radiographic technique of 120 kV, 140 mA, and a 2-second scan time is used to produce 22 scan slices in the dynamic mode; any additional scan slices are subsequently acquired in a nondynamic mode. The "detail" reconstruction algorithm is used. A scan slice thickness of 3 mm with table increments of 2 mm were used in all patients but one. Total scan time is about 10 minutes with these parameters.

After scanning is completed, the CT data are transferred to an independent graphics workstation via nine-track tape. The workstation consists of a SPARCstation-1+ with a 24-bit full-color graphics board for user interaction and a Magnum RISC computer with a 16-bit video card for numerical computation and video output. The workstation operates the CliniX-3D high-resolution three-dimensional imaging software package.[2] A three-dimensional matrix of image data is created from the original CT slices. Each element in this matrix is assigned x, y, and z coordinates and constitutes one voxel of volume information. Each voxel is a 16-bit unsigned integer contained in main memory. Actual image information is stored in 12 bits of each integral value, leaving 4 bits for flags. The resolution of the matrix is 256 × 256 × 4 voxels.

The three-dimensional CT angiographic images are created using the transformation described by Foley and van Dam[3] and a proprietary trilinear interpolation algorithm. Contrast medium-containing structures on the original CT slice data can be flagged using a simple computer segmentation routine to eliminate display of bone. Finished images are output in video format onto a video laser disk,* then recorded onto a VHS cassette using a standard videocassette recorder. Each video sequence consists of two 180° rotations in 3° increments around the rostral-caudal and left-right axes. The video format thus produces three-dimensional views of the cerebral vasculature and any vascular anomaly. Color prints are also produced for each study using a 4Cust thermal color printer.†

Results

Three-dimensional CT angiography has been used for evaluation of 20 patients (12 females and eight males, ranging in age from 9 to 78 years) with known or suspected cerebrovascular disease. Initially, three-dimensional CT angiography was obtained in patients who had previously been diagnosed by intra-arterial angiography or a three-dimensional CT angiography diagnosis was confirmed by intra-arterial angiography. In the initial 11 patients studied, seven aneurysms were found in four patients and an arteriovenous malformation (AVM) was found in one patient diagnosed by three-dimensional CT angiography; in all cases, the findings were confirmed by intra-arterial angiography and at surgery. Six patients did not demonstrate intracranial vascular pathology on three-dimensional CT angiography or intra-arterial angiography. The diagnostic correlation between three-dimensional CT angiography and intra-arterial angiography was 100% in these 11 patients.

As confidence in the reliability of the study increased, three-dimensional CT angiography was used as a diagnostic procedure in patients for whom intra-arterial angiography was contraindicated. Studies have been performed in nine such patients; in eight, no intracranial vascular lesions were revealed and a venous angioma was diagnosed in one pediatric patient. Intra-arterial angiography was not carried out in these patients, as it did not appear warranted based on the clinical situation.

The clinical application and results of three-dimensional CT angiography in this series of 20 patients are summarized in Table 1. No complications related to performance of the three-dimensional CT angiographic studies or to misdiagnosis have been encountered to date. Brief illustrative case histories demonstrating the use of this diagnostic procedure in patient care are presented below. It should be noted that the videotape format of three-dimensional CT angiography allows analysis of images rotated in two different planes, which permits an accuracy of interpretation not possible with color prints. Therefore, the clinical value of three-dimensional CT angiography cannot be fully appreciated from the published illustrations.‡

Illustrative Case Reports

Case 1

This 59-year-old woman presented with two recent episodes of transient right arm and hand weakness and dysphasia. She was fully anticoagulated with Coumadin (warfarin sodium) because of previous mitral valve replacement. Ultrasound evaluation of the heart and extracranial carotid arteries did not reveal a source of embolism. A contrast-enhanced CT scan performed at another institution demonstrated a high-density circular lesion on one slice just above the left internal carotid artery bifurcation, raising the possibility of an intracrana-

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* Laser disk manufactured by Panasonic Industrial Co., Secaucus, New Jersey.
† Printer manufactured by duPont de Nemours and Co., Wilmington, Delaware.
‡ A demonstration videotape may be obtained on loan by contacting Aesculys Research Group, 85 Mechanic Street, Suite 420, Lebanon, New Hampshire 03766; or telephone 603-448-4900 or 800-522-6695.
TABLE 1
Clinical summary of 20 patients undergoing three-dimensional CT angiography and intra-arterial angiography (3D-CTA)*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Indications</th>
<th>3D-CTA</th>
<th>Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59, F</td>
<td>TIA</td>
<td>? aneurysm on CT</td>
<td>carotid apex aneurysm</td>
<td>carotid apex aneurysm</td>
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<td>2</td>
<td>50, F</td>
<td>III palsy, hemiparesis</td>
<td>basilar &amp; PCA aneurysms</td>
<td>normal</td>
<td>normal</td>
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<tr>
<td>3</td>
<td>68, F</td>
<td>headache, diplopia, ? aneurysm on CT</td>
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<td>normal</td>
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<tr>
<td>4</td>
<td>33, F</td>
<td>headache, seizure</td>
<td>AVM</td>
<td>AVM</td>
<td>AVM</td>
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<tr>
<td>5</td>
<td>42, M</td>
<td>III palsy</td>
<td>normal</td>
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<td>normal</td>
</tr>
<tr>
<td>6</td>
<td>66, M</td>
<td>III palsy</td>
<td>normal</td>
<td>normal</td>
<td>normal</td>
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<tr>
<td>7</td>
<td>52, F</td>
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<td>normal</td>
<td>normal</td>
<td>normal</td>
</tr>
<tr>
<td>8</td>
<td>76, F</td>
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<tr>
<td>9</td>
<td>66, F</td>
<td>SAH</td>
<td>basilar, PCoA, &amp; AChA aneurysms</td>
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<tr>
<td>10</td>
<td>54, M</td>
<td>SAH, III palsy</td>
<td>ACeA aneurysms</td>
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<tr>
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<td>SAH</td>
<td>normal</td>
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<td>12</td>
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<td>anisocoria</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
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<td>13</td>
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<td>ND</td>
<td>ND</td>
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<td>14</td>
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<td>ND</td>
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<tr>
<td>15</td>
<td>11, M</td>
<td>seizures, flow void on MRI</td>
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<tr>
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<td>ND</td>
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<td>19</td>
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<td>hearing loss, tinnitus, normal family history of aneurysm</td>
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<tr>
<td>20</td>
<td>9, F</td>
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<td>normal</td>
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</tbody>
</table>

* TIA = transient ischemic attack; CT = computerized tomography; III = third cranial nerve; SAH = subarachnoid hemorrhage; MRI = magnetic resonance imaging; PCA = posterior cerebral artery; AVM = arteriovenous malformation; ACeA = anterior communicating artery; PCoA = posterior communicating artery; AChA = anterior choroidal artery; ND = not done.

Pink meningioma (Fig. 1 upper left). Three-dimensional CT angiography was performed which revealed an aneurysm of the left internal carotid artery apex (Fig. 1 lower). The patient was subsequently admitted to our hospital and the administration of Coumadin was discontinued. Anticoagulation was maintained with intravenous heparin which was stopped prior to intra-arterial angiography. Angiography confirmed the existence of an aneurysm (Fig. 1 upper right), which was successfully clipped. Postoperative angiography demonstrated obliteration of the aneurysm. Heparin anticoagulation and oral Coumadin were restarted 48 hours after craniotomy. The patient had an unremarkable hospital course and was discharged home 1 week postoperatively when anticoagulation with Coumadine had been achieved. She has had no further transient ischemic attacks.

Case 2
This 50-year-old woman presented with a 6-week history of progressive spastic left hemiparesis, left hemisensory changes, and a partial left third nerve palsy. Magnetic resonance (MR) imaging revealed an aneurysm of the left internal carotid artery apex (arrow). Upper Right: Intra-arterial angiogram showing a left internal carotid apex aneurysm.

Fig. 1. Case 1. Upper Left: Contrast-enhanced computerized tomography (CT) scan showing a high-density circular lesion (arrow) suspicious for an aneurysm. Lower: Three-dimensional CT angiogram demonstrating an aneurysm of the left internal carotid artery apex (arrow). Upper Right: Intra-arterial angiogram showing a left internal carotid apex aneurysm.
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Fig. 2. Case 2. Upper Left: Magnetic resonance image showing a lesion of mixed signal intensity suspicious for a giant aneurysm of the basilar apex. Lower: Three-dimensional computerized tomography angiogram demonstrating thrombosed (blue-shaded area) and nonthrombosed portions of a giant basilar apex aneurysm (large arrow) and a left proximal posterior cerebral artery aneurysm (small arrow). Upper Right: Intra-arterial vertebral angiogram showing the nonthrombosed portion of a giant basilar apex aneurysm.

Fig. 3. Case 3. Upper Left: Contrast-enhanced computerized tomography (CT) scan revealing a high-density circular lesion (arrow) suspicious for an aneurysm of the left internal carotid artery. Lower: Three-dimensional CT angiogram showing no evidence of aneurysm. The internal carotid artery (large arrow) and posterior cerebral artery (small arrow) are well visualized. Upper Right: Intra-arterial angiogram showing a large left internal carotid artery with no evidence of aneurysm.

Partial third nerve paresis on the left side with no pupillary changes. No subarachnoid blood was seen on a CT scan with contrast enhancement, but there was concern regarding the possibility of a left internal carotid artery aneurysm (Fig. 3 upper left). She was transferred to our neurosurgery service where on initial evaluation it was found that her headache and third nerve paresis had resolved. A three-dimensional CT angiogram was obtained and no intracranial vascular anomaly was seen (Fig. 3 lower). Pancerebral intraarterial angiography revealed no aneurysm of the left internal carotid artery (Fig. 3 upper right) or other vascular lesion. A thorough medical evaluation failed to determine the cause of the transient signs and symptoms, which have not recurred.

Case 4

This 33-year-old woman presented with a generalized convulsion and postictal headache. Evaluation at another institution showed her to be neurologically intact. Anticonvulsant medication was started; MR imaging demonstrated a low signal intensity lesion consistent with an AVM of the right frontal lobe. Three-dimensional CT angiography and intra-arterial angiography were performed confirming the presence of an AVM (Fig. 4). The AVM was totally excised and the patient's postoperative course has been uneventful.

Discussion

Intra-Arterial Angiography

Intra-arterial cerebral angiography is, at present, the definitive neuroradiological procedure for most cerebrovascular disorders. Although the incidence of permanent neurological deficit from intra-arterial angiography is quite low, complications can occur even with the most skillful angiographer. The risks of hematoma at the site of arterial puncture, hypotension, nausea and vomiting, urticaria, cardiac dysrhythmia, circulatory failure, and transient or permanent neurological deficits must be weighed against the value of
the information to be obtained from the study.8-12 The risks of angiography are increased in older patients, in patients with diffuse cerebrovascular disease, and in patients with uncontrolled hypertension, frequent transient ischemic attacks, or recent subarachnoid hemorrhage (SAH).6-12 The use of a larger volume of contrast material and prolonged procedure times is also associated with an increased complication rate.2,8-12,14 Some patients, particularly children, may require general anesthesia in order to obtain an adequate intra-arterial study.10

Alternative Studies

A reliable method for visualizing the intracranial vasculature without the risks associated with intra-arterial angiography would be a valuable clinical tool. Intravenous digital angiography, MR angiography, and three-dimensional CT angiography are alternative methods of cerebrovascular imaging. Because of inadequate image quality and the large volume of contrast agent required, intravenous digital angiography has not proved to be an acceptable substitute for intra-arterial angiography in most clinical circumstances.2,14 Three-dimensional CT angiography and/or MR imaging angiography may, however, prove to be acceptable alternatives.

Magnetic resonance imaging has been used to delineate intracranial and extracranial vascular structures.4,15 Various gradient-echo and spin-echo techniques and reconstruction algorithms have been employed to produce both "bright blood" and "black blood" vascular images.3,15 Good correlation between MR angiographic images and vascular imaging obtained by intra-arterial contrast angiography has been documented.3,15 The advantages and disadvantages of MR angiography versus intra-arterial angiography are similar to those of three-dimensional CT angiography and are discussed below.

Three-Dimensional CT Angiography

Our experience to date suggests that three-dimensional CT angiography may be a safe and reliable alternative to intra-arterial angiography in many clinical circumstances. Although severe idiosyncratic reactions to iodinated contrast agents have been reported,8 adverse reactions to intravenous administration of non-ionic agents are uncommon and most are mild and transient.8 Three-dimensional CT angiography, like MR angiography, avoids the potential complications of arterial injury and embolization that may occur with intra-arterial angiography.4,9-12,14,15 With our limited experience we have to date encountered no complications related to three-dimensional CT angiography.

The safety of three-dimensional CT angiography has encouraged us to use this diagnostic study as a screening examination in patients in whom we would have been reluctant to proceed with intra-arterial angiography. For example, two children in our series who would have required heavy sedation or general anesthesia for intra-arterial angiography underwent three-dimensional CT angiography with minimal sedation. Other such patients have included those with severe acute-onset headache without CT or lumbar puncture evidence of SAH, patients with an isolated cranial nerve deficit, and patients with a strong family history of aneurysm. Although three-dimensional CT angiography has been used as a definitive diagnostic procedure in these patients, it should be stressed that this procedure remains an experimental diagnostic tool and the limitations are not yet clearly delineated. If unequivocal angiographic diagnosis is essential, intra-arterial angiography continues to be the diagnostic gold standard.
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Three-dimensional CT angiography has proved to be a valuable tool for surgical planning and an aid for instructing residents. The videotape format allows three-dimensional viewing of vascular lesions and surrounding structures in a way not possible with two-dimensional radiographs.

**Limitations**

Several potential limitations to the use of three-dimensional CT angiography exist. Small vascular lesions that could be diagnosed by intra-arterial angiography might not be visualized by this study. Further clinical experience is needed comparing three-dimensional CT angiography with intra-arterial angiography and surgical findings to determine the incidence of false-negative studies. Such clinical trials are presently being planned.

Another potential limitation of three-dimensional CT angiography is separation of arterial from venous structures when both demonstrate contrast enhancement. For instance, imaging of the intracavernous portion of the carotid artery may be inadequate with three-dimensional CT angiography because of contrast enhancement of the cavernous sinus. The image quality has varied considerably in this series, with the intracavernous portion of the carotid artery readily visualized in some patients and obscured by cavernous sinus enhancement in others.

Poor delineation of a vascular anomaly within a fresh clot may also represent a limitation of three-dimensional CT angiography. Because of the high density of fresh clot on CT, a contrast medium-containing aneurysm or vascular malformation might be difficult to differentiate from surrounding clot. We have not performed this study in a patient with a large intraparenchymal or thick subarachnoid clot and thus cannot comment on the reliability of three-dimensional CT angiography in this situation. Other studies have suggested that contrast-enhanced CT can delineate aneurysm from surrounding clot, and further clinical experience is needed to determine if three-dimensional CT angiography will be an acceptable method of vascular imaging in this situation.

Perhaps the most significant limitation to the routine use of three-dimensional CT angiography at present is the delay between CT scanning and the availability of the reconstructed images. There is currently a 12- to 24-hour delay which is unacceptable in cases where rapid therapeutic intervention may be needed. With an on-site workstation this interval could be decreased to about 2 hours and with increasing computer power could be diminished still further. Advances in CT technology such as helical-scanning CT and a higher iodine content in non-ionic contrast material, may also increase the speed and definition of three-dimensional CT angiography.

**MR Angiography**

A comparison of three-dimensional CT angiography and MR angiography shows that each has advantages and disadvantages; MR angiography does not require the use of intravenous contrast agents or ionizing radiation and therefore avoids the small risk associated with contrast-enhanced CT scanning. Obscuration of arterial anatomy by venous sinuses or clot is also less of a problem with MR angiography than with three-dimensional CT angiography. Conversely, MR angiographic images are more likely to be distorted by cerebrovascular lesions producing turbulent blood flow; this is not a problem with three-dimensional CT angiography. It should also be noted that a combination of these modalities may be possible since the reconstruction algorithm we use in three-dimensional CT angiography has also been applied here to data generated from MR imaging.

**Conclusions**

At present, both MR angiography and three-dimensional CT angiography are methods by which the intracranial vasculature can be imaged with minimal risk to the patient. Further clinical experience will determine whether either of these methods will be a clinically acceptable substitute for intra-arterial angiography. However, our experience to date suggests that three-dimensional CT angiography may prove to be a potentially valuable tool in the diagnosis of cerebrovascular disease.

**Addendum**

Since submission of this paper, an additional seven patients have been studied with three-dimensional CT angiography. Three AVM's and one giant internal carotid-posterior communicating artery aneurysm diagnosed by this method were confirmed by intra-arterial angiography and at surgery. In three other patients, three-dimensional CT angiograms were normal and no further radiological studies have been carried out.

**References**


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