Digital angiotomosynthesis for preoperative evaluation of cerebral arteriovenous malformations and giant aneurysms.

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Digital Angiotomosynthesis for Preoperative Evaluation of Cerebral Arteriovenous Malformations and Giant Aneurysms

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PURPOSE: To evaluate the clinical utility of the digital angiotomosynthesis technique for giving additional information regarding critical anatomy of cerebrovascular lesions before surgical intervention. **METHOD:** Seven arteriovenous malformations and three giant aneurysms were examined with digital angiotomosynthesis; these images were compared with conventional angiograms. **RESULTS:** 1) Detailed recognition of three-dimensional vascular structures of the arteriovenous malformation and giant aneurysm was facilitated by the cine mode of digital angiograms and angiotomograms. 2) Reconstructed angiotomograms could show clear separation of overlapping vessels and demonstrate fine vasculature. 3) Fine feeders, which were difficult to trace on the conventional angiogram, were more easily recognized in all cases of arteriovenous malformation. 4) Small arteries passing in close proximity to the arteriovenous malformation nidus were identifiable. 5) Fine arterial branches, being obscured by big shadows of giant aneurysms on the conventional angiograms, were well identified. 6) The anatomic relationship of bone structures to the giant aneurysm was clearly shown. **CONCLUSIONS:** Digital angiotomosynthesis is helpful for recognizing the three-dimensional and detailed vascular anatomy of arteriovenous malformations and giant aneurysms and provides neurosurgeons with useful information for preoperative evaluation.

Index terms: Cerebral angiography, technique; Aneurysm, cerebral; Arteriovenous malformation, cerebral; Angiography, preoperative

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Digital tomosynthesis is the technique of reconstructing a tomogram of an object at any desired depth through a digital technique using a set of tomographic projection images taken from different angles during a single tomographic movement of the equipment (1–7). In 1971 Miller et al (6) described the method for producing an infinite number of tomograms from a finite number of radiographic images. Subsequently Baily et al (1–3) described an electric system for synthesis and display of different tomographic planes. In 1983 Maravilla et al (8) reported "digital" tomosynthesis, the technique of reconstructing tomograms using digital manipulation of data acquired during a single tomographic swing. They assembled a digital image-processing system, in which fluororadiographic images were stored on an analog video disk recorder and then digitized with a 512 × 512 matrix by an analog-to-digital converter.

There have been a few clinical applications of digital tomosynthesis for cerebrovascular diseases (8–11). We have previously described our improved digital tomosynthesis system (9); the purpose of this report is to evaluate the digital angiotomosynthesis technique for its ability to give additional information regarding critical anatomy of cerebral vascular lesions before surgical intervention.

Methods

The system used in this study consists of an image-intensified overtable fluororadiographic television unit with linear tomographic capability of a sweep angle of 40°

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(Medix-210LS; Hitachi, Tokyo, Japan), in conjunction with a high-resolution video camera unit (V-206A) and a digital image processor (HX 2P-325; Cybernetics, Tokyo, Japan) (9). Details of the principle, system, and methods of improving the image quality were described in the previous paper (9). With this system, we obtain 30 individual projection images during a 1-second linear tomographic sweep of an x-ray tube and image intensifier. These individual projection images are digitized by an analog-to-digital converter into the digital image data of a 1024 × 1024 matrix, 8 bits depth, and stored in a frame memory. This process can be performed successively three times in our system; it is possible to obtain three projection series of different vascular phases after contrast injection. Cerebral angiography is performed with the usual technique. The amount of contrast material (ioxaglic acid, 320 mg of iodine per ml; Tanabe, Osaka, Japan) injected is a normal volume generally used for the conventional angiography. Contrast material is administered for 2.5 to 3.5 seconds with the injection rate of 3 mL per second. A continuous x-ray exposure starts from 1.5 seconds (early x-ray exposure) to 2.5 seconds (delayed x-ray exposure) after a single injection of contrast material and continues for 1 second. The x-ray exposure technique is 70 to 76 KVp, 100 mA, nearly comparable with that usually used in conventional tomography. Although it is possible to obtain image data with conventional fluoroscopic technique, we use the above-mentioned radiographic technique to achieve sufficient signal-to-noise ratio. The digital projection image data can be serially and repeatedly displayed on a high-resolution cathode ray terminal in cine mode at a real-time speed. The stored projection data are postprocessed in the digital image processor to reconstruct a tomogram at any desired plane parallel to x-ray tube movement. Reconstruction time varied from 1 to 3 seconds per single tomographic image depending on the spatial filtering technique chosen. We reconstructed angiotomograms at 2- to 5-mm intervals in arteriovenous malformations and 4-mm intervals in giant aneurysms, with an experimental tomographic plane thickness of 5 mm, for a structure running perpendicularly to the linear tomographic direction. A series of reconstructed angiotomograms can be repeatedly displayed on a cathode ray terminal at variable speeds and paged either forwards or backwards and viewed in a stop-action manner. Hard-copy films are made with a laser printer.

Results

Seven patients with arteriovenous malformation and three with giant aneurysm were studied with digital angiotomosynthesis. Examinations were completed within 30 minutes to 1 hour, and no complications were encountered. Subsequently, all patients were surgically treated with success.

Each projection image had almost the same image quality as that of the conventional angiogram. Reconstructed angiotomograms could show clear separation of overlapping vessels and demonstrate fine vasculature. Fine feeders, which were difficult to trace on the conventional angiogram, were more easily recognized in all cases of arteriovenous malformation. In five cases, small passing arteries in close proximity to nidi were well discerned. In three giant aneurysms, a small ophthalmic artery and two posterior inferior cerebellar arteries which were difficult to identify on the conventional angiograms were clearly discerned. In the giant aneurysm of the internal carotid artery, it was possible to evaluate the relationship among the parent artery, aneurysm neck, ophthalmic artery, and anterior clinoid process.

Representative Cases

Case 1. A 41-year-old man presented with subarachnoid hemorrhage. The ruptured aneurysm at the bifurcation of the right middle cerebral artery was clipped uneventfully. The conventional angiography also revealed a large arteriovenous malformation in the right parietal lobe. However, many small feeders were difficult to evaluate because numerous vessels from the anterior and middle cerebral arteries were seen as overlapping with the nidus (Figs 1A and 1E). Many feeders of the anterior cerebral artery were clearly separated from those of the middle cerebral artery on different tomographic planes. It became easier to evaluate where an individual feeder joined the nidus. Sagittal angiotomograms clearly demonstrated many fine feeders and the passing artery from the anterior cerebral artery running in close proximity to the nidus (Figs 1B–1D). A series of superficial angiotomograms showed feeders from the middle cerebral artery on the brain surface (Fig 1F). The course of drainers and its anatomic relationship to feeders and nidus were evaluated three-dimensionally by a series of angiotomograms reconstructed from data taken by delayed x-ray exposure.

Case 2. A 16-year-old woman presented with severe headache. Computerized tomographic scan revealed intraventricular hemorrhage. The conventional angiography showed an arteriovenous malformation in the splenium of the corpus callosum fed by the right anterior and posterior pericallosal arteries (Figs 2A and 2E). Angiotomograms clearly demonstrated fine feeders and a fine passing artery in close proximity to the nidus, which were hardly recognizable on the conventional angiograms (Figs 2A–2F). In this

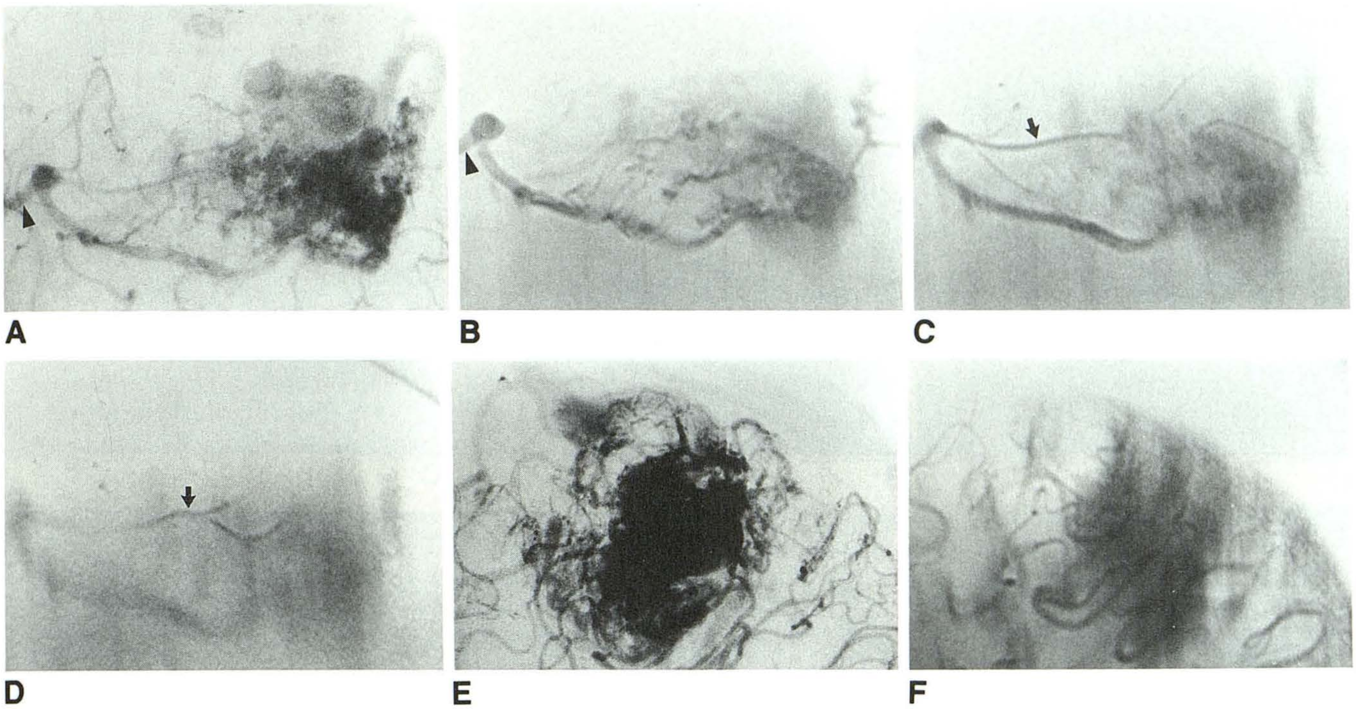


Fig. 1. Case 1: 41-year-old man with an arteriovenous malformation in the right parietal lobe.

A, Lateral view of the conventional left internal carotid angiogram. It is difficult to recognize clearly fine feeders and a passing artery from the anterior pericallosal artery. The *arrowhead* indicates the anterior pericallosal artery.

B–D, Reconstructed angiotomograms at the midsagittal plane *(B),* 5 mm to the left *(C),* and 10 mm to the left *(D)* clearly showing many fine feeders originating from the left anterior pericallosal artery and a passing artery *(arrows)* in close proximity to the nidus. The *arrowhead* indicates the anterior pericallosal artery.

E, Lateral view of the conventional right internal carotid angiogram. Numerous vessels from the anterior and middle cerebral arteries and the nidus are overlapping.

F, Superficial sagittal angiotomogram reconstructed 50 mm
branches and feeders on the brain surface.

case, because drainers were filled very early, the feeders, nidus, and drainers were all represented together on a series of angiotomograms taken by early x-ray exposure. The relationship among these three components could be well evaluated at the same time.

Case 3. A 58-year-old woman presented with bitemporal hemianopsia and deterioration of bilateral visual acuity. Conventional left internal carotid angiography (Fig 3A) revealed a giant aneurysm arising from the paraclinoid portion of the left internal carotid artery, but it was difficult to grasp detailed anatomy of the aneurysm complex because of the big shadow of the aneurysm. The position of the aneurysm neck was unclear, and the ophthalmic artery was not revealed. Reconstructed angiotomograms (Figs 3B–3D) clearly demonstrated the small ophthalmic artery and the relationship among the parent artery, aneurysm neck, and course of the ophthalmic artery as well as anterior clinoid process. Digital angiotomosynthesis findings showed that the medial half-wall of the internal carotid artery protruded as part of the aneurysm wall, and the proximal portion of the internal carotid artery and the origin of the ophthalmic artery were beneath the anterior clinoid process. It was suggested that through the left pterional approach the anterior clinoid process would need to be drilled off to confirm the origin of the ophthalmic artery and to secure the proximal internal carotid artery in preparation for possible premature rupture of the aneurysm, and that the aneurysm neck could be clipped with an angled ring clip.

Case 4. A 53-year-old man experienced right-sided numbness. Conventional left vertebral angiography (Fig 4A) revealed a giant vertebrobasilar aneurysm. The position of the aneurysm neck was unclear, and the posterior inferior cerebellar artery was not seen. The reconstructed angiotomograms showed the position of the aneurysm neck and the origin and course of the

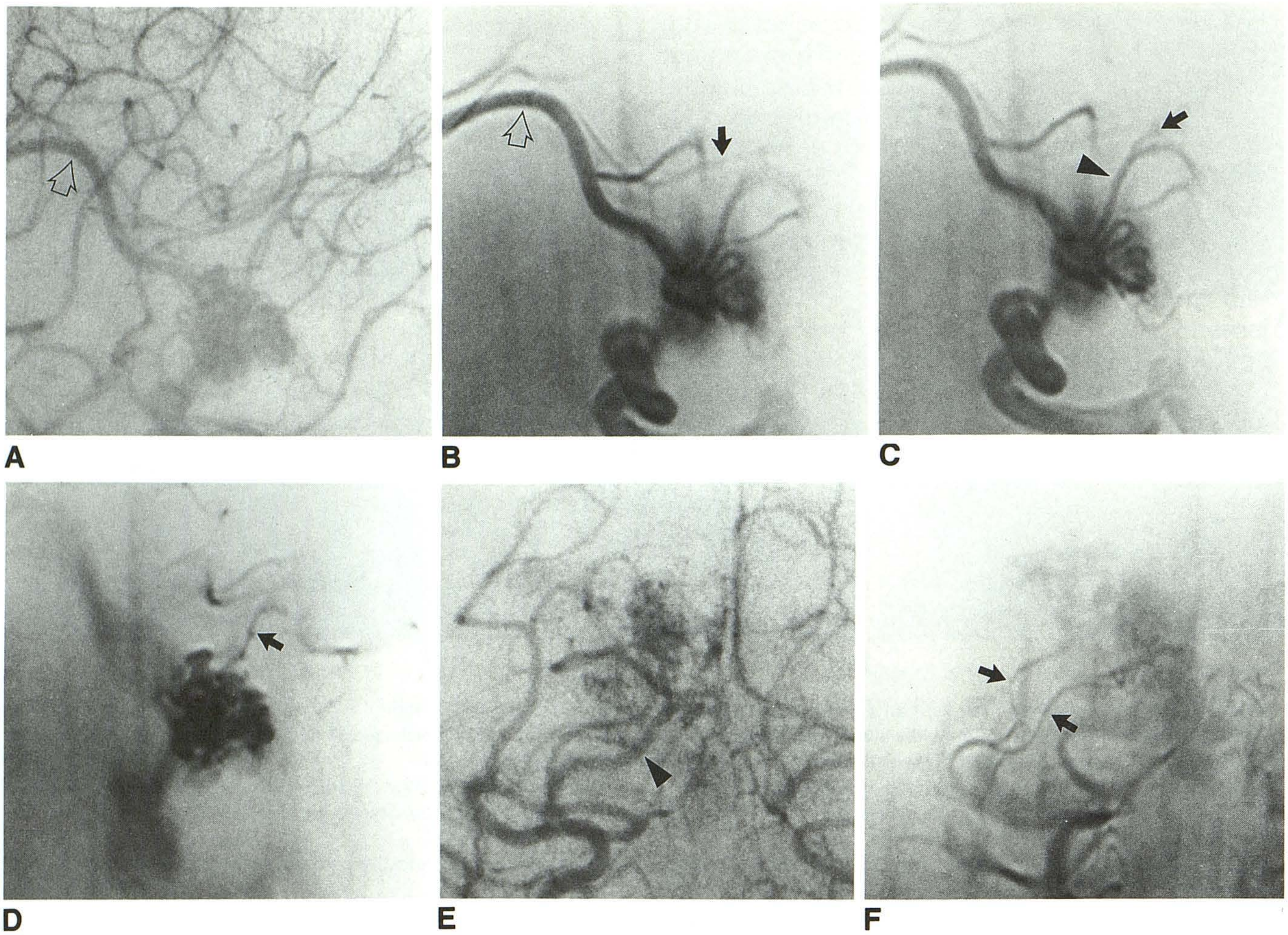


Fig. 2. Case 2: 16-year-old woman with an arteriovenous malformation in the splenium of the corpus callosum.

A, Lateral view of the conventional right internal angiogram. Small vessels around the arteriovenous malformation are difficult to evaluate. The white arrow indicates the anterior pericallosal artery.

B–D, Reconstructed angiotomograms at the midsagittal plane *(B)*, 2 mm to the right *(C)*, and 4 mm to the right *(D)* clearly showing a small feeder *(arrows)* and a small artery passing in close proximity to the nidus *(arrowhead)*. The *white arrow* indicates the anterior pericallosal artery.

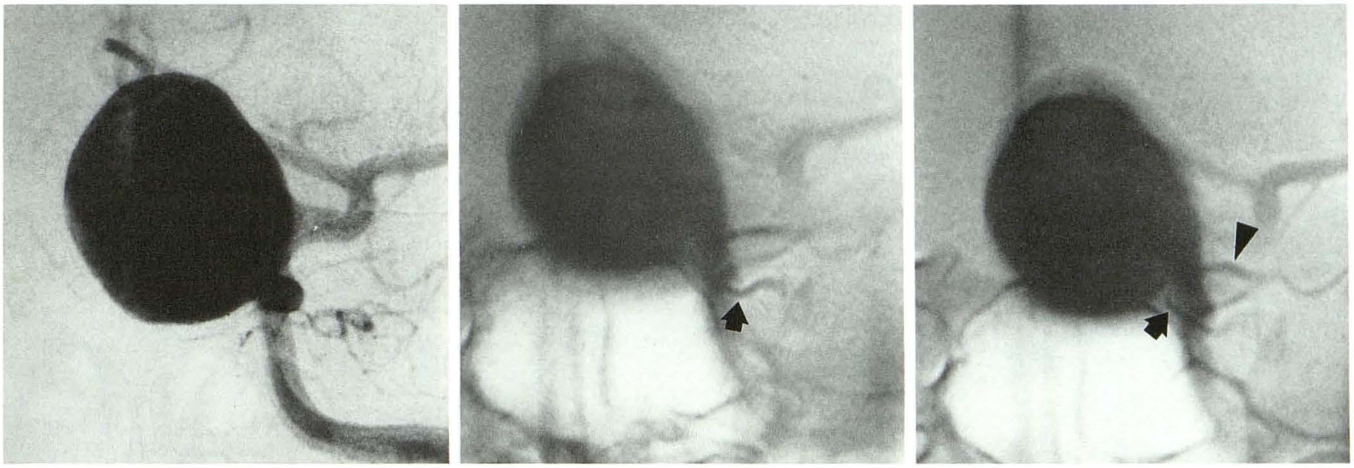
E, Anteroposterior view of the conventional left vertebral angiogram showing the posterior pericallosal artery as a feeder *(arrowhead)*. Other small feeders from the posterior cerebral artery are difficult to evaluate.

F, Reconstructed coronal angiotomogram clearly shows that two small lateral posterior choroidal arteries *(arrows)* feed the nidus besides the posterior pericallosal artery.

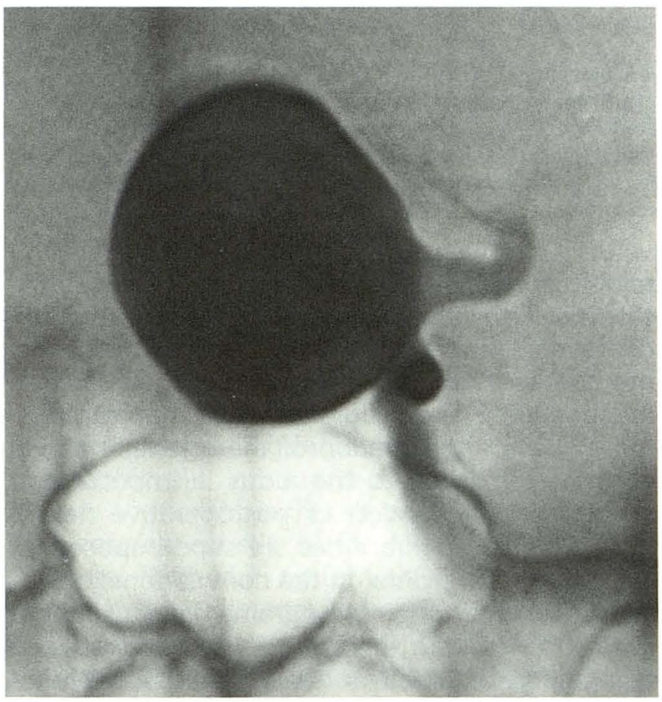
fine posterior inferior cerebellar artery (Figs 4B and 4C). The aneurysm was arising from the left vertebral artery just proximal to the vertebral union. The left vertebral artery was creeping up along the anterolateral wall of the aneurysm, and the fine posterior inferior cerebellar artery was originating from the vertebral artery just distal to the aneurysm neck. It was suggested that neck clipping parallel to the parent artery would be possible after detaching the aneurysm from the parent artery.

Discussion

An important first step for successful surgical treatment of cerebrovascular lesions such as arteriovenous malformations and giant aneurysms is a three-dimensional and accurate evaluation of the complex vascular anatomy. Although computed tomography and magnetic resonance are rapidly developing, angiography is indispensable for evaluating cerebrovascular lesions. The problem with conventional angiography is the difficulty in three-dimensionally grasping these com-



A B C



D

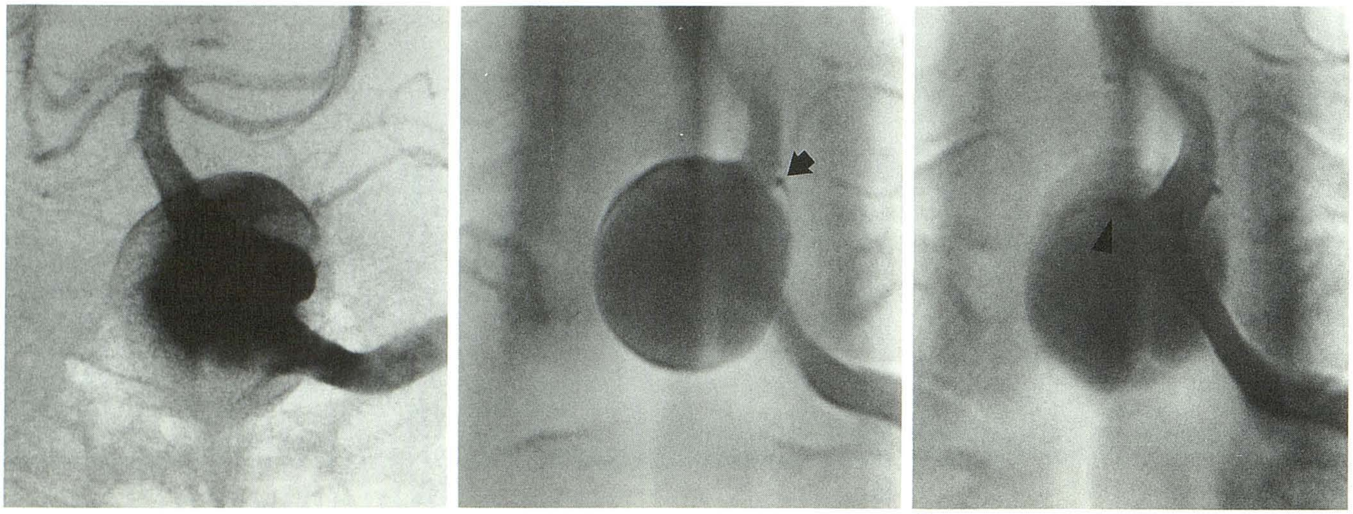
Fig. 3. Case 3: 58-year-old woman with giant aneurysm of the left internal carotid artery.

A, Anteroposterior view of the conventional left internal carotid angiogram showing a giant aneurysm of the paraclinoid portion of the internal carotid artery. The ophthalmic artery and aneurysm neck are not identifiable.

B–D, Reconstructed angiotomograms in the coronal plane clearly defining the ophthalmic artery *(arrows)* and the anterior clinoid process *(arrowhead)*. The relationship among the aneurysm neck, parent artery, ophthalmic artery, and anterior clinoid process can be evaluated.

plex structures and clearly separating overlapping vessels. One way to resolve this problem is a three-dimensional presentation of lesions by the technique of rotational angiography (12–15). Another is to make a detailed observation of different anatomic planes of blood vessels by angiotomography, but conventional angiotomography is unsuitable for dynamic studies because only one preselected tomographic plane can be obtained during one injection of contrast material. Digital tomosynthesis is suitable for dynamic study of angiography because the data can be collected during single tomographic motion in a second. Our application of digital tomosynthesis for cerebral angiography provided several advantages over conventional angiography and tomography for the preoperative evaluation of cerebrovascular lesions.

Cerebral angiotomosynthesis provides both the cine mode display of digital projection images on a cathode ray terminal like rotational angiography and angiotomograms retrospectively reconstructed at any desired depth from a single set of projection images with a single contrast injection. The cine mode display of a series of 30 projection images, which has almost the same image quality



A B C

Fig. 4. Case 4: 53-year-old man with a giant aneurysm of the left vertebral artery.

A, Anteroposterior view of the left vertebral angiogram showing a giant aneurysm of the left vertebral artery. The posterior inferior cerebellar artery and the morphology of the aneurysm neck cannot be detected.

B–C, Reconstructed angiotomograms in the coronal plane clearly define the fine posterior inferior cerebellar artery *(arrow)* originating from the vertebral artery just distal to the aneurysm. The *arrowhead* shows a jet phenomenon of opacified contrast within the aneurysm, indicating the position of the aneurysmal neck arising from the vertebral artery.

as conventional angiograms, permitted a detailed three-dimensional observation of arteriovenous malformation structures and giant aneurysm complex. Feeders, arteries, and nidus can be clearly separated from each other. Where the individual feeder comes into the nidus and the drainer goes out of the nidus can also be evaluated spatially. The jet flow of contrast material within the aneurysm can be dynamically observed, indicating the position of the aneurysm neck. Further detailed evaluation can be made with reconstructed angiotomograms. The quality of reconstructed angiotomograms presented here is acceptable for clinical use with a 1024 × 1024 matrix, 8 bits depth. The spatial resolution of tomograms obtained with this system is 2.5 line pairs per mm (9). Reconstructed angiotomograms, which can be observed on the high-resolution cathode ray terminal or on hard copies, can clearly represent fine vessels as small as 0.4 mm in size. Through the observation of a series of angiotomograms, superimposed arteries on the conventional angiogram can be easily defined without superimposition. Feeders could be easily traced distally from their origin and distinguished from surrounding arteries. The sagittal planes near the midline clearly delineated small arterial branches and fine feeders of the anterior cerebral artery in the interhemispheric fissure. The superficial angiotomograms represent the course of the middle cerebral artery and feeders on the brain surface. This information is useful for detecting the feeders in the interhemispheric fissure and on the brain surface at surgery. Small feeders from the posterior circulation also can be identified more easily. Preservation of the arteries passing in close proximity to the nidus is important at surgery for prevention of postoperative neurologic deficits. Such arteries are superimposed on the nidus and feeders on the conventional angiograms, whereas angiotomograms have a superior ability to separate them. The three-dimensional recognition of small arterial branches superimposed on the aneurysm is also facilitated by angiotomograms. Moreover, it is possible to discern the relation of the aneurysm complex to surrounding bone structures such as the anterior clinoid process. In our study the subtraction technique was not performed, because bone structures can be easily distinguished from contrast-filled vessels and are rather important landmarks for aneurysm surgery. Digital tomosynthesis can reconstruct any desired tomographic plane. However, synthesizing more tomograms closer together did not always result in more information, but rather was a waste of time. The distance of tomograms reconstructed depends on the vessel size of interest. It is advisable to reconstruct tomograms 2 mm apart for the evaluation of fine cerebral vessels.

Regarding the x-ray exposure technique, it is most important to choose the most adequate exposure delay according to the contrast filling time of the individual lesion. Generally the early x-ray exposure is suitable for observation of the arterial phase of an arteriovenous malformation, and the delayed x-ray exposure is for observation of the arterial and the venous phases together. In a relatively high-flow arteriovenous malformation, some drainers filled earlier and showed up with feeders and nidus by early x-ray exposure. Angiotomosynthesis is capable of separating all these components of an arteriovenous malformation more easily than conventional angiography and is useful for grasping the whole anatomic relation of the components. The information about relation between feeders and drainers is useful for deciding a dissection plane and identifying feeders. It is also possible to reconstruct angiotomograms presenting only the arterial phase by using the first half of 30 projection images and the late phase by the last half of projection images.

The size of the image intensifier limits the field of view, restricting the clinical application of the system. This system has an image intensifier with three display modes (4.5, 7, and 9 inches) (9), acceptable for the examination of regional vascular lesions of the brain. Tomographic blur is an important degrading factor of image quality. Tomographic blur produced by linear tomography runs in the tomographic direction as long stripes and consists mostly of the low-frequency components. With our system this blur can be reduced by one-dimensional spatial frequency filtering (9), which suppresses the low-frequency components and enhances the middle-frequency components of the image signals. However, it is necessary to distinguish carefully small vessels running in the same direction from tomographic blur by observing different tomographic planes.

Digital angiotomosynthesis is effective in grasping the three-dimensional vascular anatomy, separating overlapping vessels, and detecting fine vessels. It also has the advantages of a shorter examination time, without increasing the volume of contrast material, and without increase in the patient's exposure to radiation, compared with conventional angiography. This technique has proved to provide more useful information for surgical planning of arteriovenous malformation and giant aneurysm, which makes the surgical procedure safer and more precise. Digital angiotomosynthesis also has the potential to clarify the morphology of various other vascular lesions as well as tumors with rich vascularity. Its further clinical application is expected.

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