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Tomographic DSA Using Temporal Filtration: Initial Neurovascular Application

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A preliminary study showed that encouraging laboratory results reported previously using tomographic digital subtraction angiography (DSA) can be transferred to clinical application for neurovascular imaging. Tomography may show cervical carotid disease more clearly than standard DSA images, and it eliminates the interference caused by overlapping vessels. Production of multiple tomographic image planes from a single set of projection data, *tomosynthesis*, must be incorporated into this imaging system before tomographic DSA becomes clinically useful. This is a practical reality with the present equipment; clinical evaluation of this new capability is underway.

Digital subtraction angiography (DSA) methods produce adequate images of arteries in many parts of the body after injection of intravenous contrast material [1–4]. Yet, numerous problems commonly occur with intravenous DSA, including severe contrast dilution, patient motion artifacts, and overlap of simultaneously filled arteries. A method was developed at our institution that combines the advantages of DSA and tomography, with the goal of improving the clinical value of intravenous DSA [5]. Our initial clinical experience with neurovascular imaging using tomographic DSA is summarized.

Materials and Methods

The apparatus used and the basic theory of the tomographic filtering approach that we developed is described elsewhere [5]. Briefly, a conventional circular tomography device (CGR Exatome) has been modified in two ways. The film tray has been replaced by a 23/15/10 cm imaging intensifier and television camera mounted beneath the table (fig. 1). The tomographic motion is run continuously at a repetition rate of 1 rps. A continuous x-ray exposure is made during this rotation for a duration of 10–15 sec spanning the arrival and washout of contrast material within the artery of interest.

The hardware used for video processing is virtually the same as that we used for nontomographic DSA [6–9]. The processor accepts 30 frames/sec video into one of two memories (each 480 × 792 × 16 bits) arranged in parallel. Each memory can be programmed to perform a sliding time average on video image sequences in real time or in a postprocessing mode. The time "window" over which averaging occurs is set differently for the two memories. The outputs of the two images are subtracted and the updated difference displayed at 30 frames/sec. Image variations that occur on time scales roughly equal to the difference in the magnitudes of the two sliding time windows are enhanced. Stationary structures are completely removed, so this process is equivalent to DSA where image averaging (integration) also is used.

For tomographic applications, each sliding time window is set longer than 1 sec (the time for one tomographic swing), so that each memory records a continuously updated tomogram. The difference in time windows is set between 3 and 6 sec so as to be sensitive to the contrast bolus. The resulting display has removed static anatomy and has blurred arteries that lie outside of a certain range of focus, leaving a sharp image of vascular anatomy near a prechosen plane of interest. Significantly, the tomographic processing also blurs out patient motion artifacts [5].

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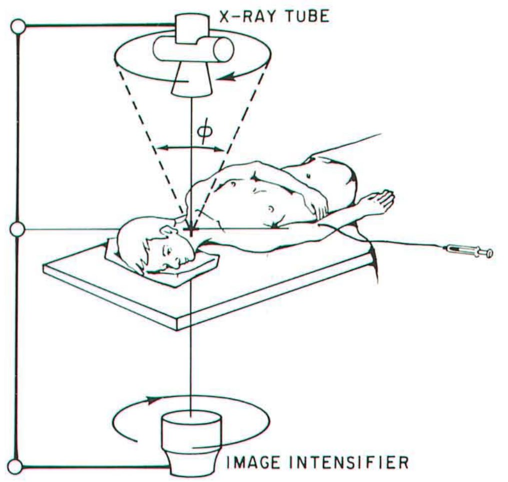


Fig. 1.—Position for lateral tomographic DSA examination of cervical carotid bifurcation. Standard, commercially available tomographic unit (CGR Exatome) has been modified to include image intensifier tube/television system under patient table. Tomographic angle, ϕ, is indicated.

The spatial resolution and blurring properties of our system as implemented so far are as follows. The limiting spatial resolution at the plane of focus for a 15 cm field of view is greater than 1.5 lp/mm measured at a 45° angle to the television scan lines. This resolution includes the effects of analog storage (0.75 inch [1.9 cm] videotape) and reprocessing from videotape. The amount of image blurring depends on the tomographic angle (fig. 1), which can be varied from zero to 20° on our device. The relation between the amount of blurring, B, and the vertical displacement, ΔZ, of a particular level from the plane of optimal focus is given as: $B \approx 2M\Delta Z \tan(\phi/2)$, where the geometric magnification is M and the tomographic angle is ϕ. For the geometry that we used ($M = 1.3$; $\phi = 10°$) the relation is $B \approx 0.23\ \Delta Z$. This means that within a tomographic plane with a 1 cm thickness (±0.5 cm), the amount of blurring is less than 1.1 mm, whereas information from a level 5 cm above or below is blurred by greater than 1 cm.

A nonsubtracted tomographic image sequence also could be formed and observed in real time by using one of the two memories contained in the temporal filtration device. This memory was used in a continuous averaging mode with a time window of 1 sec, and produced a tomographic image sequence during fluoroscopic x-ray exposure. By varying the tomographic level during the exposure, the plane of focus could be changed slowly and viewed dynamically. This feature facilitated patient positioning and level selection before contrast injection.

Seven patients have been studied with this system to examine either cervical or intracranial vasculature. The tomographic plane of interest in the neck was estimated with the aid of a pencil-sized Doppler flow probe. The patient's head was turned into the lateral position. The Doppler device then was placed over the common carotid artery near the bifurcation and held horizontally where the pulse signal was loudest. The tomographic fluoroscopic system was activated and the table height adjusted until the Doppler probe was seen in sharp focus. The probe then was removed and the study performed with 36–40 ml injection of 76% contrast material injected via central venous catheter. Video recording of the filtered fluoroscopic sequence was made during the passage of the contrast bolus through the neck vessels.

The tomographic plane of interest was estimated in the intracranial studies either by focusing on an object such as an aneurysm clip or by choosing a bony landmark such as the sella turcica before injecting the contrast material intravenously.

The digitally recorded data could be passed through the filtration device a second time, if desired, to further supress residual tomographic motion.

The technical factors for the reported studies were 60 kVp, 25 mA for the neck and 60 kVp, 50 mA for the head. A 15 cm field of view usually was chosen for these studies. The patient exposure rate was about 100–200 mR/sec. About 15 sec of fluoroscopy was required for each angiographic study.

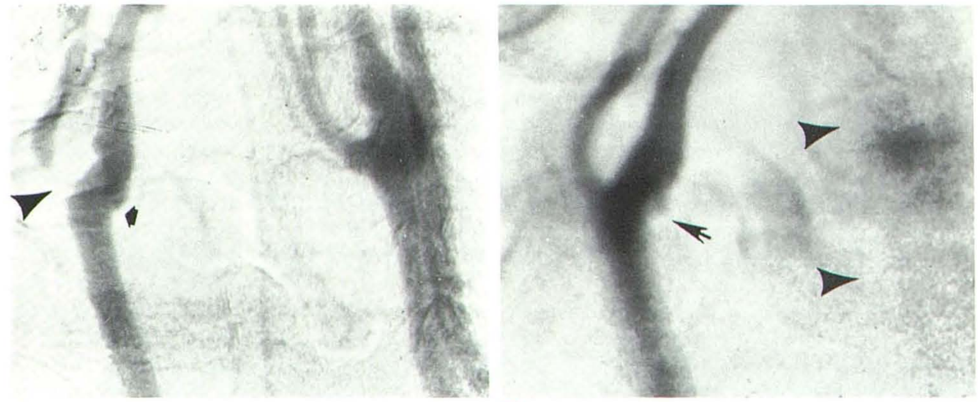
Results

All of the images obtained in these initial few patients were of interest and added some useful information to standard nontomographic DSA images. Perhaps the most provocative result is shown in figure 2. Figure 2A is an image from a standard (nontomographic) video sequence in a patient having transient ischemic neurologic symptoms. The right carotid bifurcation shows minimal irregularity along the posterior wall of the internal carotid branch and an apparent stenosis of the external carotid division. The tomographic DSA image (fig. 2B) reveals what appears to be an ulcerated plaque along the posterior wall of the internal carotid branch. The apparent external carotid stenosis proved to be a computer "overshoot" artifact. Note the blurring of the right common carotid artery leading up to the plane of best focus at the bifurcation, and also the extreme blurring of the left carotid artery in this tomographic view. The patient was undergoing a trial of medical management, so surgical correlation was not possible.

Figure 3A is a tomographic image made after central intravenous contrast injection in a patient having a large pituitary mass. The tomographic plane of focus clearly demonstrates severely stretched initial segments of the anterior cerebral arteries coursing over the mass and also shows the main middle cerebral artery trunks in good focus. Note the blurring of the proximal intracranial cartotid artery trunks lying behind the tomographic plane of best focus. Figure 3B from the same case shows sharp visualization of the internal cerebral veins in this midline lateral tomographic image. Note that none of the superficial cortical veins on either side are visualized. A faint tumor stain is seen outlining the pituitary mass.

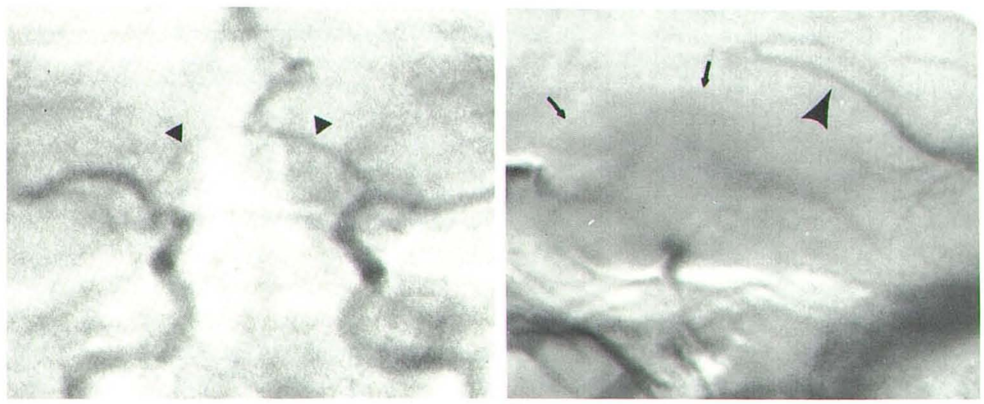
Discussion

DSA has proven clinical value in a wide range of applications. Low cardiac output, patient motion artifacts, and overlap of simultaneously filled arteries compromise the clinical value of a significant number of intravenous DSA studies. Correct patient positioning is obviously helpful in reducing the arterial overlap problem. However, eliminating arterial overlap is not always possible. For example, in a study of selective cervical arteriography reported by Kaseff [10], "The lateral cervical view was clearly required for a diagnostically adequate display of the (carotid) bifurcation in 37% (74/200) of instances."



A B

Fig. 2.—**A,** Standard DSA study of cervical carotid arteries. Minimal irregularity along posterior wall of right internal carotid artery near its origin (*arrow*). Apparent narrowing of origin of external carotid division (*arrowhead*). **B,** Tomographic image of same vessel reveals what appears to be ulcerated plaque at origin of right internal carotid artery (*arrow*). External carotid stenosis was artifactual. High degree of blurring of left carotid artery (*arrowheads*).



A B

Fig. 3.—**A,** DSA tomogram after injection of 36 ml of 76% contrast material into superior vena cava. Excellent visualization of stretched, attenuated initial segments of anterior cerebral arteries (*arrowheads*). Main trunks of middle cerebral arteries are also sharply in focus bilaterally, while proximal intracranial internal carotid trunks are blurred by tomographic motion. **B,** Lateral DSA tomogram, midline section, shows sharp image of internal cerebral veins (*arrowhead*), with no visualization of cortical veins on either side. Faint pituitary tumor blush (*arrows*).

The development of DSA equipment designed to operate with standard, continuous fluoroscopic input raised the prospect that tomographic fluoroscopy might be incorporated into the system's function [5]. Because of the real-time, recursive subtraction processing capability of our DSA unit, both digital subtraction and fluoroscopic tomography can be performed simultaneously to image cardiovascular anatomy. This preliminary work indicates that tomographic DSA methods will be useful for neurovascular applications. Figure 2 raises the prospect that not only will tomographic DSA eliminate vessel overlap problems, but may improve our ability to visualize atherosclerotic lesions such as small ulcerated plaques at the cervical carotid bifurcation. A prospective study of this question with surgical correlation is underway. Another effect that we have observed but not quantitated is that the tomographic blurring inherent in this method appears to diminish image artifacts caused by patient motion, such as swallowing movements. Similar motion artifact suppression also has been seen in abdominal imaging experiments.

Figure 3 shows that smaller intracranial arterial and venous structures can be seen clearly with tomography, with excellent suppression of overlapping vascular structures by the tomographic process.

Despite our efforts to localize planes of maximum interest before contrast injection, repeat studies usually were needed before the desired vascular structures were focused sharply. Because of contrast load limitations, it will be necessary to visualize more than one tomographic plane per intravenous injection before this new technique becomes practical. The production of multiple tomographic image planes from a single set of projection data, called *tomosynthesis*, was developed about a decade ago [11, 12]. These reconstruction schemes appear to be directly applicable to tomographic DSA imaging [13]. A number of image planes can be reconstructed from levels on either side of the plane mechanically chosen. They can be photographed individually, as well as viewed in correct three-dimensional orientation in the volume-viewing system developed here [14]. The incorporation of tomosynthesis software into our tomographic system is underway.

Intraarterial tomographic DSA studies may also yield valuable new information. Exploitation of this technique will be carried out as tomosynthesis software becomes available online.

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