AJNR

Digital subtraction rotational angiography for aneurysms of the intracranial anterior circulation: injection method and optimization.

R K Tu, W A Cohen, K R Maravilla, W H Bush, N H Patel, J Eskridge and H R Winn

AJNR Am J Neuroradiol 1996, 17 (6) 1127-1136
http://www.ajnr.org/content/17/6/1127

Digital Subtraction Rotational Angiography for Aneurysms of the Intracranial Anterior Circulation: Injection Method and Optimization

Raymond K. Tu, Wendy A. Cohen, Kenneth R. Maravilla, William H. Bush, Nilesh H. Patel, Joseph Eskridge, and H. Richard Winn

PURPOSE: To optimize parameters of rotational angiography for examination of the internal carotid circulation; to compare rotational angiography with standard digital subtraction angiography (DSA) in the evaluation of aneurysms of the intracranial internal carotid circulation; and to determine tolerance and safety limits of prolonged internal carotid injection angiography. **METHODS:** Rotational angiograms were obtained during injection of the internal carotid circulation as part of the clinical angiographic evaluation of aneurysms in 41 patients. Injection rates, X-ray delays, and fields of view were studied retrospectively. Findings at rotational angiography and standard DSA were compared. Nonionic contrast material was injected over 6 seconds, and patients were studied before and after prolonged injection angiography by physical and laboratory examination, including measurement of blood pressure, pulse, and intracranial pressure. **RESULTS:** Vascular conspicuity was equivalent at carotid injection rates of 4 and 5 mL/s delivered over 6 seconds. At 3 mL/s, more image manipulation was required to see small vascular structures. One-second X-ray delay combined with 6-second injection duration provided the best arterial depiction of intracranial vessels from start to end of rotational angiography. Maximal rotational resolution was with a 17-cm field of view. Identification of aneurysms and small vessels was equivalent at all injection rates. Aneurysm detection was equivalent with rotational angiography and DSA. In 9 of 31 aneurysms, the neck was defined more clearly with rotational angiography than with DSA, compared with 2 of 31 that were seen better with DSA. Aneurysms of the intracranial internal carotid circulation were seen with rotational angiography and not DSA in 12 of 41 cases. No change was noted in clinical or laboratory findings. **CONCLUSION:** Rotational angiography provided better definition of the aneurysmal neck and greater clarity of aneurysms than did DSA; it also improved the level of confidence in predicting the presence or absence of aneurysms, especially in the anterior communicating artery; however, in our small series it did not significantly increase the detection of aneurysms. Prolonged injection angiography was well tolerated in all patients.

Index terms: Aneurysm, angiography; Angiography, technique

AJNR Am J Neuroradiol 17:1127–1136, June 1996

The purpose of diagnostic angiography in the setting of nontraumatic subarachnoid hemorrhage is to identify the presence of any or all aneurysms, profile the aneurysmal neck apart from superimposed vascular structures, clarify the relationship of surrounding vessels, delineate any irregularities of the aneurysm, and help determine the presence of vasospasm. Current catheter angiographic evaluation of intracranial aneurysms requires multiple views to delineate surgical anatomy. In cases of complicated anatomy, precise definition of the aneurysmal neck and surrounding structures can require many angiographic injections, leading to heavy radiation exposure, large contrast loads, prolonged procedure times, and increased risk of complications.

Digital rotational angiography enables vascular images to be acquired in a continuous arc.

Received August 24, 1995; accepted after revision January 25, 1996.

From the Departments of Radiology (R.K.T., W.A.C., K.R.M., W.H.B., N.H.P., J.E.) and Neurological Surgery (W.A.C., K.R.M., J.E., H.R.W.), Harborview Medical Center and University of Washington Medical Center, Seattle.

Address reprint requests to Kenneth R. Maravilla, MD, Department of Radiology, University of Washington Medical Center, 1959 NE Pacific St, Box 357115, Seattle, WA 98195.

AJNR 17:1127–1136, Jun 1996 0195-6108/96/1706–1127

The rotational technique was proposed in 1972 by Cornelius et al (1), and its clinical use was reported by Thron and Voigt in 1983 (2). Current technological refinements include precise, microprocessor-controlled, automated gantry movement; subtraction technique; automated injection timing; and high-resolution digital recording capability. Several reports have described applications of this technique (3, 4). In cases of subarachnoid hemorrhage, a single injection may clarify regions of anatomic concern, such as the aneurysmal neck, and differentiate vascular loop from aneurysm. However, to obtain optimal arterial detail throughout a 6-second rotational study, rapid selective prolonged arterial contrast infusion is timed to coincide with gantry movement.

This prolonged injection angiographic technique was described by Numaguchi et al for use in the evaluation of intracranial masses (5–7). The lesions were opacified with intraarterial injections of ionic contrast material for extended durations while polytomograms were obtained. No angiographic complications were reported in their series. Today, routine internal carotid injection rates commonly range from 4 to 7 mL/s with volumes of 8 to 12 mL, depending on the investigator, personal experience, and contrast agent used (5, 8–13).

The purpose of this study was threefold: to investigate the radiologist-defined parameters of injection rate, injection volume, and film delay necessary to maximize vascular detail; to compare rotational angiography with standard digital subtraction angiography (DSA) for the evaluation of aneurysms of the anterior circulation; and to identify safety and tolerance limits of prolonged angiographic administration of 320 mg/dL nonionic contrast medium (ioversol).

Subjects and Methods

Patient Selection

Forty-one subjects underwent internal carotid rotational angiography as part of the imaging work-up of a group of patients who were considered likely to have an intracranial aneurysm. In all patients, either a subarachnoid hemorrhage or a probable aneurysm had been detected by other imaging studies, including magnetic resonance angiography and computed tomographic (CT) angiography. CT angiography had been done as clinically indicated either to define an aneurysmal neck better or to distinguish a vascular loop from an aneurysm.

Technical Description

Equipment.—Rotational angiographic images were obtained using a Philips Integris V3000 angiographic unit (Philips Medical Systems, Shelton, Conn). The counterbalanced ceiling-suspended C-arm rotates in a continuous 180° (−90° to +90°) arc with the path of the X-ray tube passing behind the patient's head. The isocenter for the rotational field was the area of interest in the patient's head. X-ray exposures were obtained at 7.5 frames per second, and images were displayed on a 1024 × 1024 matrix. The total 180° rotation was accomplished in 6 seconds. Each vascular territory studied required two rotational runs: first a rotational mask without injection (60 exposures), followed by a second rotational run with contrast material (60 exposures). The rate of acquisition of the 180° rotational data set was approximately 1 image per 3° of rotation, resulting in 120 images per rotational angiography pair. The resulting images could be viewed with and without subtraction. Each individually photo-timed exposure within a rotational run was less than 15 milliseconds (installation of field extensions for Integris V3000 rel 3, Philips Medical Systems, Shelton, Conn).

Resolution and Phantom Study at Varying Fields of View (FOVs).—Phantom studies were conducted to quantitate the effect of rotational C-arm movement and FOV on resolution. A line-pair phantom (Nuclear Associates, Carle Place, NY) was imaged at a 17-cm, 20-cm, 25-cm, and 31-cm FOV when stationary and at the full rotational speed of 30°/s (the standard rate used for imaging patients). Two radiologists evaluated phantom resolution at each speed both with and without subtraction.

Radiation Dose: Rotational Angiography versus DSA.—To determine patients' radiation exposures, surface and lens radiation doses were measured during DSA and rotational angiography of a standard Lucite pencil dosimeter head phantom. A CT pencil dosimeter was positioned at eye level on the phantom to measure lens dose and at the occiput level to measure surface dose. Radiation exposure was measured with a CT pencil dosimeter and MDH 1015 monitor (MDH Industries, Monrovia, Calif).

Radiologist-Defined Parameters

Injection Rates and Identification of Aneurysms.—After standard DSA anteroposterior, lateral, and oblique injections were performed, a rotational angiogram was obtained with administration of 320 mg/dL iodine nonionic contrast material (ioversol; Optiray 320; Mallinckrodt, St Louis, Mo) at 3, 4, or 5 mL/s over a 6-second rotational run. The A1 and A2 segments of the anterior cerebral artery, the M1 and trifurcation regions of the middle cerebral artery, the anterior communicating artery, the posterior communicating artery, the lenticulostriate, and the anterior choroidal arteries were identified. Their detectability as individual, clearly seen structures was evaluated at each of the injection rates. Nonsubtracted and subtracted rotational angiograms were compared. The presence or absence of an aneurysm and delineation of the configuration and neck of the aneurysm on nonsubtracted and subtracted rotational angiograms were also assessed.

X-ray Delays.—An X-ray (exposure) delay of 0, 1, or 2 seconds was selected. The frame number with the first opacified intracranial vessels was recorded.

Comparison of Rotational Angiography and Standard DSA.—Rotational angiograms and standard DSA injections were reviewed consensually by two neuroradiologists for the presence or absence of an aneurysm and for the clarity with which the configuration of the aneurysm and its neck were seen. Both nonsubtracted and subtracted rotational angiograms were included. Standard DSA injections included anteroposterior and lateral projections and one oblique view obtained at injection rates of 6 mL/s for 9 mL and filming rates of 3 frames per second. DSA injections were all viewed as subtracted images. The FOV was 20 to 25 cm for anteroposterior and lateral projections, and 17 cm for oblique views. Rotational angiograms and standard DSA injections were read independently of the other study. The reference standard for the presence or absence of an aneurysm was the full clinical angiographic work-up, surgical findings, and clinical course.

Patient Evaluation and Prolonged Injection Angiography

Prolonged injection angiography was completed in 41 patients. Completed clinical evaluations including physical and neurologic examinations were obtained in all patients before and within 24 hours of angiography. Clinical history was obtained from patients' charts. Laboratory studies included hematologic, creatinine, and blood urea nitrogen measurements before and after prolonged injection angiography. Vital signs, including systolic and diastolic blood pressures, and intracranial pressure (if applicable) were recorded. Any abnormal results were chronicled.

Results

Technical

Resolution and Phantom Study Results.—As expected, the greatest resolution was achieved at the smallest FOV. At a 17-cm FOV, line pair (lp) resolution at maximal rotational speed (30°/s) was 2.87 lp/mm (Fig 1) compared with 3.19 lp/mm in a static image at the same FOV. At a 31-cm FOV, line-pair unsubtracted resolution decreased to 1.88 lp/mm at stationary and full rotational speed (Fig 2). Rotational speed (stationary versus full 30°/s speed) had little effect on resolution.

X-ray Delay.—Two rotational angiograms were obtained at 0-millisecond delay, 37 rotational angiograms were obtained at 1-millisecond delay, and 2 rotational angiograms were obtained at 2-millisecond delay. With no X-ray delay, the first 15 to 20 exposures were without vascular opacification. The true lateral view was lost (Fig 2A). A 2-second X-ray delay resulted in good initial vascular opacification (−90°); however, excessive venous filling obscured arterial detail at the end of rotation (+90°) (Fig 2B). A 1-second X-ray delay resulted in arterial vascular opacification at the initiation of gantry movement (true lateral) and throughout the entire rotational angiographic study (Fig 3).

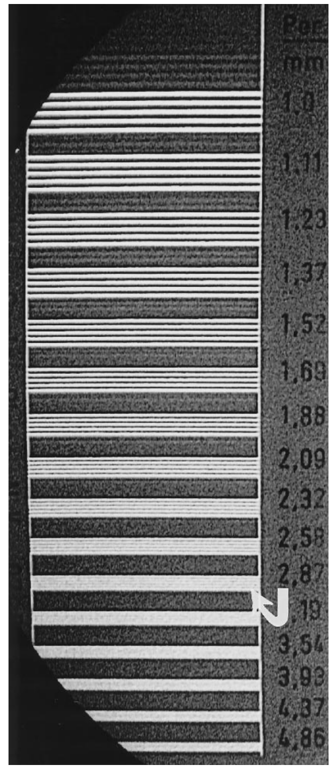


Fig 1. Line-pair (lp) phantom at 17-cm FOV and 30°/s rotation. Maximal resolution was 2.87 lp/mm (0.88 mm/lp) (*arrow*).

Radiation Dosimetry.—A standard rotational angiographic study with a mask and injection run at 17-cm FOV resulted in a 50-mR exposure to the lens of the eye and a 160-mR surface dose to the occiput. For a standard DSA filming run of 12 serial images in a posteroanterior position, the lens exposure was 39.6 mR and the back-of-skull surface exposure was 1.79 R. The lens exposure during a single rotational angiographic study was therefore 1.3-fold greater than a standard anteroposterior cerebral DSA study.

Results of Radiologist-Defined Parameters

Injection Rate and Vessel Identification.—Detection of small vascular structures was the

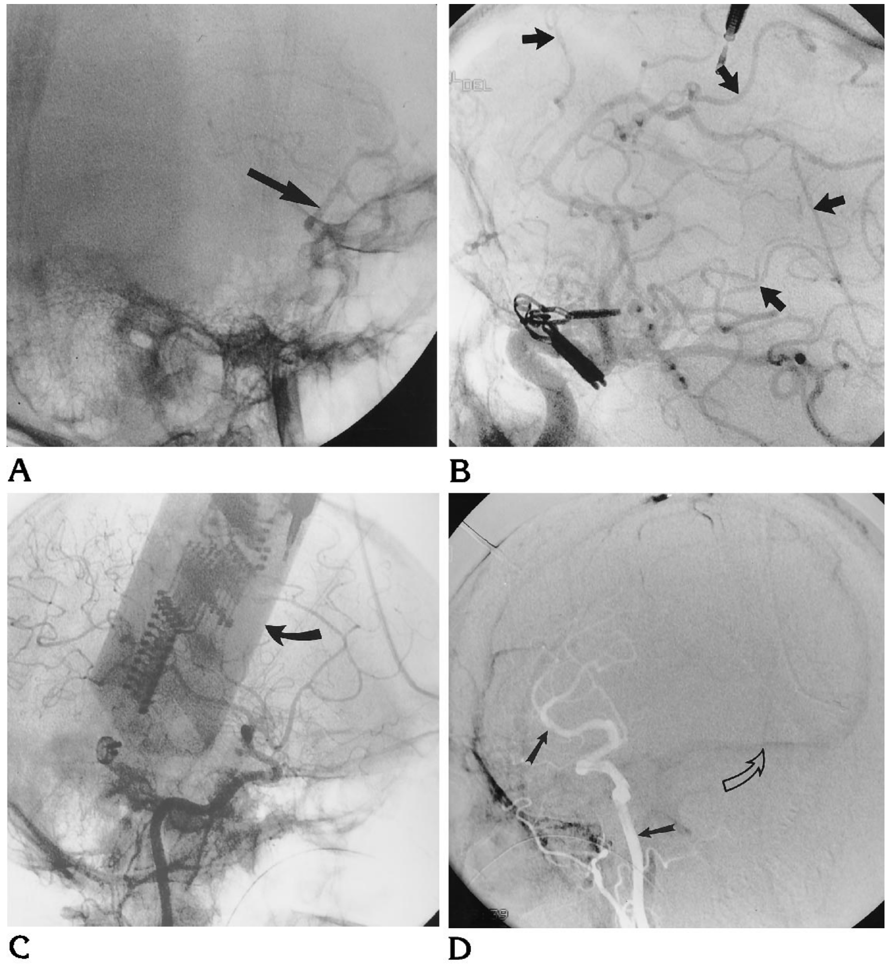


Fig 2. Examples of suboptimal radiologist-defined parameters of X-ray delay time and FOV on rotational angiograms.

A, Angiogram of left internal carotid artery. No X-ray delay results in gantry movement and no vascular opacification for 15 to 20 exposures. Filling of anterior cerebral artery (*arrow*) was not identified until late in gantry excursion.

B, Angiogram of left internal carotid artery with effect of long (2-second) X-ray delay. Note opacification of distal anterior and middle cerebral artery vessels (*arrows*) at initiation of gantry movement (−90°). Excessive venous opacification obscures arterial detail at the end of rotational angiography.

C, Angiogram of right internal carotid artery. Example of too-large FOV resulting in excessive air within the field. Failure to remove overlying tubes and lines (*arrow*) results in obscuration of anatomic detail.

D, Angiogram of right internal carotid artery with injection before mask. In addition, the FOV is too large. Superimposed arterial "white blood" (*straight arrows*) and residual venous "black blood" (*curved arrow*).

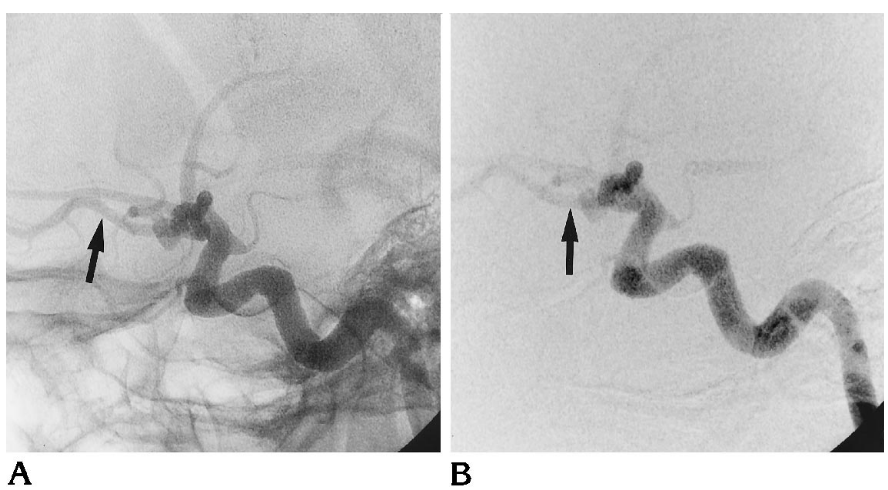


Fig 3. Examples of rotational angiograms with ideal radiologist-defined parameters of smallest FOV and 1-second X-ray delay.

Ideal opacification of initial exposure (*A*) of a standard 60-exposure rotational run. The anterior cerebral artery (arrow) is opacified. The arterial opacification at the end of the rotational run (*arrow, B*) was diagnostic. This 4-mL/s injection with 1-second X-ray delay typically required minimal image manipulation.

same at injection rates of 3, 4, and 5 mL/s (Table 1). Lenticulostriate arteries were not seen in 13 of 41 injections (Figs 4–7). Anterior choroidal arteries were suboptimal in 15 of 41 injections. Vascular detail of A1, M1, A2, trifurcation, and anterior and posterior communicating arteries at 3, 4, and 5 mL/s was equivalent, although greater vascular density (vessel-to-background contrast) was seen at the higher rates and volumes. At the 3-mL/s injection rates, electronic image density and contrast adjustments were possible but were time-intensive. Injection images obtained at 4 and 5 mL/s required fewer such adjustments.

Injection Rate and Identification and Characterization of Aneurysms.—There were 9 injections at 3 mL/s, 15 injections at 4 mL/s, and 17 injections at 5 mL/s. Nine aneurysms were detected at 3 mL/s, 9 aneurysms at 4 mL/s, and 10 aneurysms at 5 mL/s. Aneurysm detection was equivalent to standard DSA at all rotational angiography injection rates. There were no complications related to contrast administration or angiography. However, subjective evaluations by three radiologists showed that the higher injection rates were preferred.

Aneurysm Detection: Rotational Angiography versus DSA.—Three misdiagnoses with DSA were caused by overlapping vessels (Figs 4 and 8). Two misdiagnoses with rotational angiography were caused by FOV limits or overlying vessels (Table 2). In 9 of 31 aneurysms detected, the neck was seen better with rotational angiography than with DSA. In two cases, the neck was identified with DSA and not with rotational angiography. In 12 of 41 injections, presence or absence of an aneurysm in the anterior communication artery could be determined by rotational angiography but not on the standard DSA runs. Nonsubtracted and subtracted rotational angiograms each had merits on a case-by-case basis, depending on the particular anatomic region of interest and the extent of patient motion.

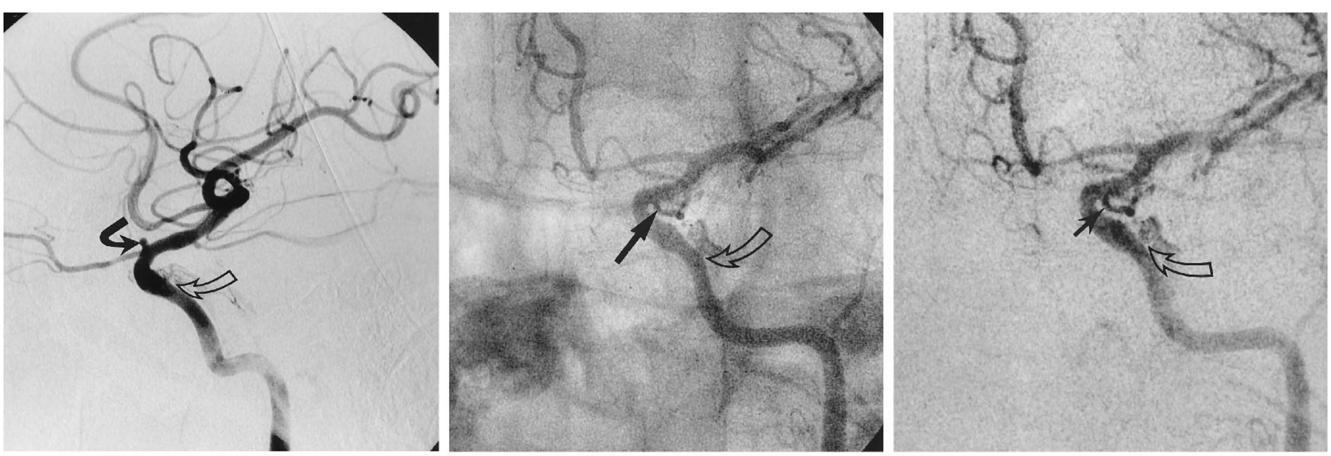
TABLE 1: Detection of small vascular structures at varying injection rates: concordance/discordance

	No. of Concordant/Discordant* Cases Comparing Rotational Angiography and DSA		
	3 mL/s	4 mL/s	5 mL/s
Lenticulostriate artery	5/4	10/5	11/6
Anterior choroidal artery origin	6/3	10/5	10/7
Total injections	9/9	15/15	17/17

* Concordance indicates detection/no detection on both rotational and conventional angiograms, discordance indicates different detection on rotational and conventional angiograms.

Prolonged Injection Angiography and Patient Tolerance

Prolonged injection angiography was completed in all 41 patients. Thirty-three patients were alert and oriented, 8 were intubated and pharmacologically paralyzed by pancuronium. No alert patient complained of discomfort. None of the 41 patients had any significant (>10%) change in blood pressure or pulse or intracranial pressure before, during, or immediately (within 1 minute) after prolonged injection angiography. Of the 37 patients in whom postangiographic clinical laboratory studies were obtained, none had significant change in electrolytes or renal function. The 4 patients who were discharged without postangiographic blood chemistry studies were all healthy at follow-up visits to the clinic. One patient died 4 days after surgery of complications unrelated to arteriography.



A B C

Fig 4. Case 1. Patient with suspected ophthalmic artery aneurysm by standard left internal carotid DSA injection (*solid arrow* in *A*). The cavernous sinus fistula is visible (*open arrow*). Left internal carotid rotational angiograms show clear delineation of a normal left ophthalmic artery (*solid arrow* in *B* and *C*). The neck of the cavernous sinus fistula (*open arrow*) is seen. Visibility of lenticulostriate arteries is poor on nonsubtracted 5-mL/s image (*B*) and even worse on subtracted image (*C*).

Fig 5. Case 3. Left internal carotid injection (rate of 3 mL/s) shows large aneurysm of the anterior communicating artery with clearly visible lenticulostriate arteries (*curved arrow*). The 18-mm circle (*straight arrow*) is used as a standard reference for measuring aneurysmal size.

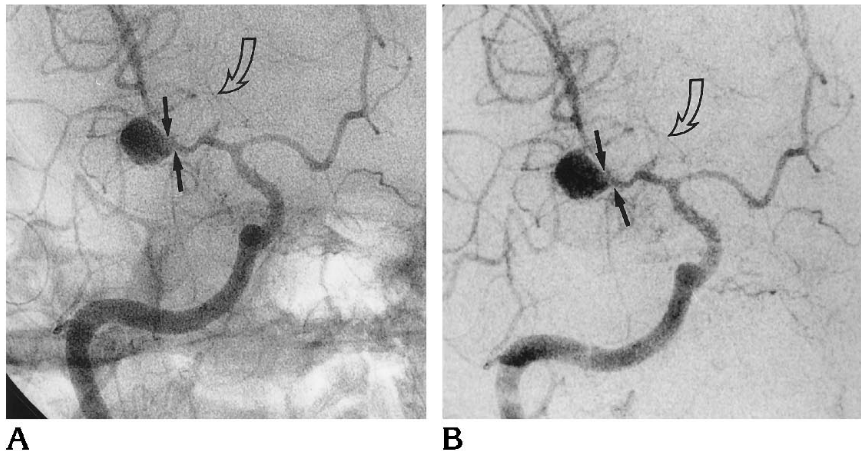


Fig 6. Case 4. Comparison of subtracted and unsubtracted rotational angiography in a patient with an aneurysm of the right middle cerebral artery.

Right internal carotid nonsubtracted (*A*) and subtracted (*B*) angiograms obtained with an injection rate of 4 mL/s. In A, the aneurysmal neck in the right middle cerebral artery trifurcation (*straight arrows*) is clearly seen on image 36 of 60. Lenticulostriate origin and course are apparent (*curved arrow*). In *B*, the aneurysmal neck (*straight arrows*) is also seen clearly, but the lenticulostriate origin and course (*curved arrow*) are seen less well, presumably because of subtle patient motion.

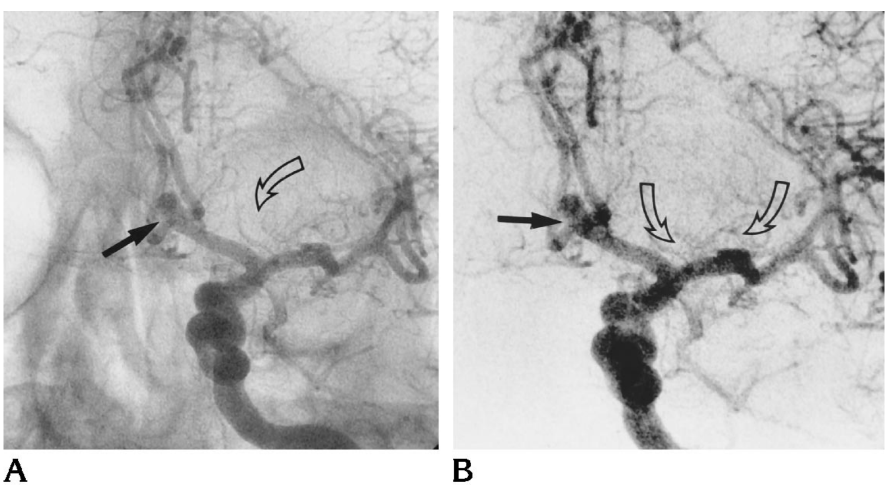


Fig 7. Case 5. Patient with anterior communicating artery aneurysm with illustration of loss of detail of lenticulostriates with subtraction.

Left internal carotid nonsubtracted angiogram (*A*) shows aneurysmal neck in the anterior communicating artery (*solid arrow*); lenticulostriates (*open arrow*) are faintly seen vessels at this 4-mL/s injection. In subtracted angiogram (*B*), aneurysmal neck (*solid arrow*) is still visible, but lenticulostriates (*open arrows*) are not as distinct.

Discussion

Conventional evaluation of aneurysms of the internal carotid circulation is inherently limited by the representation of complex three-dimensional anatomy in a two-dimensional medium. Standard DSA technique relies on anteroposterior, lateral, and multiple oblique projections to portray three-dimensional vascular anatomy completely. A rotational display of anatomy is conceptually intuitive but until recently had been technically limited.

Technical Factors

In 1972, Cornelius et al (1) described the rotational technique. Voigt et al (14, 15) used models of the skull and intracranial circulation with simulated calcifications and foreign bodies to illustrate possible applications. Various subsequent reports have illustrated some applications of the rotational technique (2, 3). Rotational angiography provides a close approximation of the three-dimensional relationship of surrounding vascular anatomy in a sin-

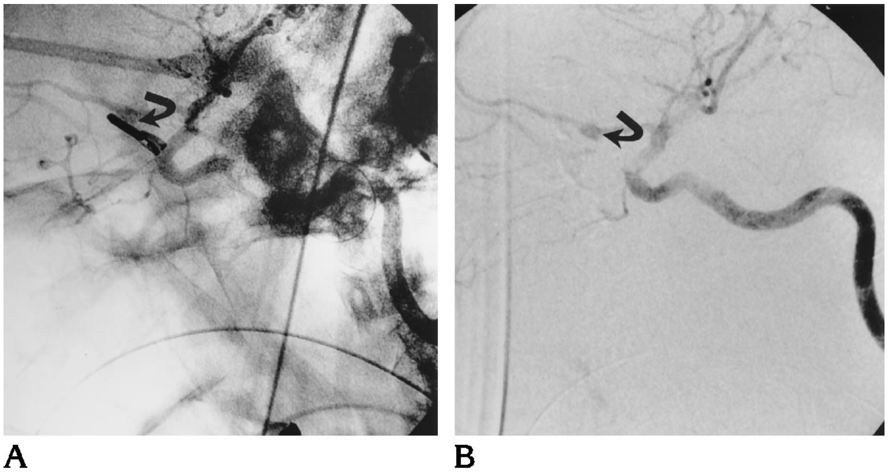


Fig 8. Case 2. Example of discordance between the standard DSA and the rotational angiogram in patient with residual aneurysm following clipping of anterior communicating artery aneurysm.

Standard DSA (*A*) obtained at 1.47 seconds of a 6-second rotational angiography study fails to show residual aneurysm (*arrow* indicates aneurysm clip). Residual aneurysm (*arrow*) is clearly seen on subtraction rotational angiogram (*B*).

TABLE 2: Total aneurysms detected in study

Aneurysm Location	No. of Aneurysms Detected		
	Rotational Angiography	DSA*	Complete Angiographic Work-up
Anterior communicating artery	7	6†	7
Posterior communicating artery	3	3	3
Middle cerebral artery	9‡	10	10
Ophthalmic artery	4	5§	4
Pericallosal artery	4	3‖	4
Superior hypophyseal artery	1	1	1
Postpetrous carotid artery	1	1	1
Cavernous carotid artery	1	1	1
Total	30	30	31

* Included anteroposterior, lateral, and one oblique view; injection at 6 mL/s for 9 mL.

† Missed on DSA because of vascular loop.

‡ Missed on rotational angiogram because of FOV.

§ Overcall on DSA because of vascular loop; missed on DSA because of aneurysm clip.

‖ Missed on DSA because of vascular loop.

gle injection. The precise definition of the aneurysmal neck is simplified as compared with the standard trial-and-error approach.

With our method, the C-arm gantry rotates around the operator-defined isocenter at 30°/s. A full 180° rotation (−90° to +90°) requires approximately 6 seconds. Full speed is reached in 1 to 2 seconds. For each rotational angiogram, two separate 60-exposure rotations were obtained to achieve the subtracted image. Our line-pair resolution quantification of the rotational angiogram at all FOVs revealed no inherent anatomic degradation at full rotational speed. Therefore, theoretically, identification of 1-mm lenticulostriate arteries is limited not by the ultrashort (<15 millisecond) exposures but by patient motion. As expected, patient motion substantially degrades subtracted images.

A greater quantum mottle of each rotational image resulted from the less than 15-millisecond exposure time and low-milliampere tube loading of the rotational angiography technique compared with a standard head DSA exposure. Individual standard head DSA exposure times were 200 milliseconds. Although the shorter exposure times, or the large number of images generated in both standard and nonstandard projections, caused decreased signal to noise (increased quantum mottle), rotational angiography was better than DSA at delineating aneurysmal necks and at differentiating aneurysmal neck from surrounding vessels. These additional images offer two advantages. First, the rotational angiograms are obtained from multiple angles and, second, when displayed rapidly in a continuous cine loop, the eye integrates the successive images and suppresses the effective, observed noise. Conventional DSA, on the other hand, provides static projections that are selected largely from operator experience.

X-ray delays are important in rotational angiography. To achieve arterial detail at the initiation of gantry movement and maximal arterial opacification throughout the 6-second exposure, the arrival of contrast material should be synchronous with initial gantry movement. A lengthy X-ray delay resulted in early termination of the injection with concomitant superimposition of venous obscuration. A 1-second delay was optimal.

Artificial restrictions were placed on this study. To facilitate comparisons among patients, only three standard views were used for DSA evaluations. In clinical situations, multiple projections are used; however, use of a variable number of injections per patient would have complicated data analysis. In addition, we hoped to ascertain whether rotational angiography would provide detailed information about the aneurysms' vascular anatomy, thereby reducing the need for countless angiographic projections.

Prolonged injection angiography has been used safely in the neuroangiographic setting (5–7, 16, 17). Rotational angiographic injections are prolonged to achieve arterial opacification during the entire C-arm movement. With a 3-mL/s injection rate, a total volume of 18 mL was injected over 6 seconds at 4 to 24 mL total volume and at 5 to 30 mL total volume. Although 3-mL/s, 4-mL/s, and 5-mL/s injections were equivalent for aneurysm detection, characterization, and small-vessel identification, the rate of 4 mL/s achieved satisfactory vascular detail with minimal postprocessing adjustments. Images acquired at 3 mL/s required multiple adjustments for contrast, brightness, and edge enhancement. Neither vascular detail nor aneurysm identification increased at 5 mL/s.

Technical problems may result from the small FOV of the rotational angiography run, incorrect choice of X-ray delay time, and insufficient memory space (Fig 9). A large FOV decreased resolution, as evidenced by our phantom studies (Figure 2C). In one clinical case, the angiographer injected contrast medium on the first run, and the second run became the mask. As a result, obscuring venous opacification was superimposed on the arterial phase (Fig 2D) of the subtracted rotational angiogram. For clean subtracted arterial detail, the mask should be the first rotational angiography run.

Subject problems include motion and overlying tubes and lines that may collide with the rotating C-arm. Patient motion markedly hampers identification of small vessels. Vascular shifts were not clearly seen on rotational angiograms obtained with small FOVs. The FOV limits visibility of conventional landmarks (Table 3).

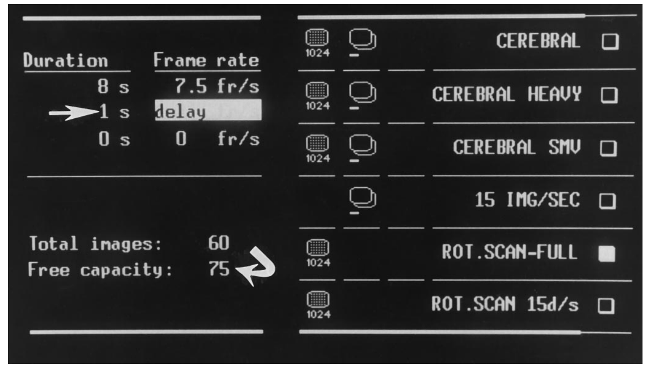


Fig. 9. Example of control panel after the mask rotational angiography. Sixty images are in memory. For the injection rotational angiography, 60 more exposures will be acquired. The technologist should check for adequate storage space (*curved arrow*). Note the X-ray delay setting of 1 second (*straight arrow*).

Application

The subjective advantages of rotational angiography are intuitive. Since rotational views remove the shortcomings of single-view standard DSA injections, the entire FOV can be imaged in a single injection. This factor is expected to expedite differentiation between vascular loops and aneurysms, improve the definition of an aneurysmal neck, and potentially increase sensitivity to the identification of vascular abnormalities and variability. The latter benefit was not manifested in our preliminary

TABLE 3: Pitfalls of rotational angiography

Problem	Comment
Technical	
FOV too small	Limits full vascular detail
FOV too large	Decreases resolution
X-ray delay too short	Causes superimposition of venous and arterial structures
X-ray delay too long	Causes loss of true lateral arterial detail
Insufficient memory space	Makes rotational feature inoperable
Reversed mask/injection	Causes superimposition of venous and arterial structures
Patient	
Motion	Causes loss of subtraction and small vascular detail
Overlying tubes and lines	Creates overlying artifacts
Vascular shifts	Not clearly seen with small FOV, causes loss of conventional landmarks

study. When facial bones obscure vascular detail, subtracted rotational angiograms are useful. The disadvantage of this technique is increased image noise, usually caused by patient motion.

A potential limitation of rotational angiography is the increased volume of contrast material. Rotational angiography has the potential to reduce total contrast load in the further evaluation of an aneurysm on routine views, since the need for multiple trial-and-error projections may be reduced. This technique could therefore reduce the total radiation burden, as demonstrated by our dosimetry data. No adverse effects occurred among our patients, but potential problems remain a possibility in patients with decreased renal function. Another limitation of rotational angiography is venous superimposition. Late in the rotation injection, all arterial vessels are opacified, although, theoretically, the rotation offsets this effect. An additional benefit is the way the eye integrates the cine loop images, which helps delineate the aneurysm in relation to surrounding vessels.

Prolonged Injection Angiography and Patient Tolerance

In the past, the amount of contrast medium that could be injected safely into the internal carotid artery was limited by the risk of pain, seizures, and neurotoxicity. The physiological effects were due to contrast-induced dilatation of the external carotid artery. Today, modern nonionic contrast agents have reduced osmolarity and decreased neurotoxicity and are tolerated better (18, 19).

Prolonged injection angiography was used by Numaguchi et al in 1979 during polytomographic evaluation of intracranial masses. These authors reported that total injection volumes of 14 mL of ionic contrast material over 4 seconds were well tolerated during the evaluation of cerebral hemangiomas (5) and brain tumors (6). They reported no complications in their study of 70 cases of histologically verified tumors and 36 cases of pituitary adenomas, meningiomas, and craniopharyngiomas with prolonged injection angiography. In our study, patients received nonionic contrast medium and the injection duration was extended 2 seconds to accommodate total volumes of 30 mL. No patient reported discomfort, and none had a change in vital signs or physical or laboratory measurements.

In conclusion, rotational angiography is a valuable technique in the work-up of aneurysms of the anterior circulation. Vascular anatomy and detail are best elucidated with an injection rate of 4 mL/s, a 1-second X-ray delay, and the smallest FOV. This technique was helpful in elucidating aneurysmal necks, particularly those of the anterior communicating artery. Prolonged injection rates of 3 to 5 mL/s over 6 seconds were well tolerated without complications.

Acknowledgments

We are grateful to Brent Stewart and Michael Graham of the University of Washington Medical Center, and to Nina Skrobecki, Matthew Harrington, Patrick Willis, Victoria Rios, and Scott Canaday of the Department of Radiology, Harborview Medical Center, for their expert technical support.

References

1. Cornelius G, Bellet A, Van Eygen B, Roisin PH, Libon E. Rotational multiple sequence roentgenography of intracranial aneurysms. *Acta Radiol* 1972;13:74–76
2. Thron A, Voigt K. Rotational cerebral angiography: procedure and value. *AJNR Am J Neuroradiol* 1983;4:289–291
3. Schumacher M, Cultic K, Ott D. Digital rotational radiography in neuroradiology. *AJNR Am J Neuroradiol* 1989;10:644–649
4. Hoff DJ, Wallace C, terBrugge KG, Gentili F. Rotational angiography assessment of cerebral aneurysms. *AJNR Am J Neuroradiol* 1994;15:1945–1948
5. Numaguchi Y, Kishikawa T, Sawada K, Kitamura K, Matssura K, Russel WJ. Prolonged injection angiography for diagnosing intracranial cavernous hemangiomas. *Radiology* 1979;131:137–138
6. Numaguchi Y, Kishawaka T, Ikeda J, et al. Prolonged injection angiography for diagnosing intracranial neoplasm. *Radiology* 1980;136:387–393
7. Numaguchi Y, Kishikawa T, Ikeda J, et al. Neuroradiological manifestations of suprasellar pituitary adenomas, meningiomas, and craniopharyngiomas. *Neuroradiology* 1981;21:67–74
8. Brendler SJ, Hayes GJ. Hypaque intracerebral angiography: report of complications in 617 angiograms. *J Neurosurg* 1959;454: 454–460
9. Osborne AG. *Introduction to Cerebral Angiography*. New York, NY: Harper & Row; 1980: 18
10. Ahlgren P. Iohexol compared to urografin meglumine in cerebral angiography: a randomized, double blind cross-over study. *Neuroradiology* 1982;23:195–198
11. Thron A, Ratzka M, Voigt K, Nadjmi M. Iohexol and ioxaglate in cerebral angiography. In: Tawnzer V, Zeitler E, eds. *Contrast Media in Urography, Angiography and Computerized Tomography*. New York, NY: Thieme-Stratton; 1983:115–119
12. Holtas S, Cronquise S, Raena T. Cerebral angiography with iohexol: a comparison with metrizamide in man. *Neuroradiology* 1983;24:201–204

13. Amundsen P, Dugstas G, Presthus J, Sveen K. Randomized double-blind cross-over study of iohexol and amipaque in cerebral angiography. *AJNR Am J Neuroradiol* 1983;4:342–343
14. Voigt K, Stoeter P, Petersen D. Rotational cerebral roentgenography: evaluation of the technical procedure and diagnostic application with model studies. *Neuroradiology* 1975;10:95–100
15. Voigt K, Stoeter P. Experimental basis and clinical results of an isocentric rotational roentgenographic technique in diagnostic neuroradiology. *Medicamundi* 1975;21:7–20
16. Acker JD, Kline LB, Vitek JJ. Computed tomographic sellar and parasellar evaluation: use of high-dose continuous contrast infusion. *J Clin Neuroopthalmol* 1981;1:141–152
17. Hayman LA, Evans RA, Basion FO, Hinck VC. Delayed high dose contrast CT: identifying patients at risk of massive hemorrhagic infarction. *AJNR Am J Neuroradiol* 1981;2:139–147
18. Swanson DP. *Pharmaceuticals in Medical Imaging: Radio Opaque Contrast Media, Radiopharmaceuticals, Enhancement Agents for Magnetic Resonance Imaging and Ultrasound*. New York, NY: Macmillan; 1990:27–62
19. Bush WH, Swanson DP. Acute reactions to intravascular contrast media: types, risk factors, recognition and specific treatment. *AJR Am J Roentgenol* 1991;157:1153–1161