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Radiation Dose to Patients and Personnel during Intraoperative Digital Subtraction Angiography

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BACKGROUND AND PURPOSE: **The use of intraoperative angiography to assess the results of neurovascular surgery is increasing. The purpose of this study was to measure the radiation dose to patients and personnel during intraoperative angiography and to determine the effect of experience.**

METHODS: **Fifty consecutive intraoperative angiographic studies were performed during aneurysmal clipping or arteriovenous malformation resection from June 1993 to December 1993 and another 50 from December 1994 to June 1995. Data collected prospectively included fluoroscopy time, digital angiography time, number of views, and amount of time the radiologist spent in the room. Student's *t*-test was used to assess statistical significance. Effective doses were calculated from radiation exposure measurements using adult thoracic and head phantoms.**

RESULTS: **The overall median examination required 5.2 minutes of fluoroscopy, 55 minutes of operating room use, 40 seconds of digital angiographic series time, and four views and runs. The mean room time and the number of views and runs increased in the second group of patients. A trend toward reduced fluoroscopy time was noted. Calculated effective doses for median values were as follows: patient, 76.7 millirems (mrems); radiologist, 0.028 mrems; radiology technologist, 0.044 mrems; and anesthesiologist, 0.016 mrems.**

CONCLUSION: **Intraoperative angiography is performed with a reasonable radiation dose to the patient and personnel. The number of angiographic views and the radiologist's time in the room increase with experience.**

Intraoperative angiography is gaining acceptance as a useful tool in the surgical treatment of intracranial neurovascular disease. The first report of this technique was by Luessenhop and Spence in 1960 (1), in which they describe their use of intraoperative angiography in monitoring embolization of arteriovenous malformations (AVMs). Although supported by several later studies (2–6), the procedure did not become widely used, perhaps because of the technical difficulties in performing these procedures. Recently, considerable improvements in portable angiographic technology have facilitated real-time fluoroscopy and digital subtraction angiography (DSA) (7, 8). Using this modern equipment, several authors have described their experience with intraoperative angiography and its impact on surgical management (9–14). Many of these investigators advocate the routine use of intraoperative angiography in surgery for aneurysms and AVMs (11–13), although there is some recent evidence that it is not necessary for aneurysms of the supraclinoid segment of the internal carotid artery (14, 15).

Although intraoperative angiography has demonstrated usefulness, many radiologists may be hesitant to employ this new technology because of concerns about the radiation dose to patients and operating room personnel, as well as the time and effort involved in performing these procedures. The purpose of this study was to measure the radiation exposure and to discern any differences that increased experience might bring.

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Methods

Procedures

Fifty consecutive examinations of 47 patients referred for intraoperative angiography were monitored prospectively from June 1, 1993, to December 31, 1993. As use of intraoperative angiography became routine at our institution, another 50 consecutive examinations of 48 patients were studied prospectively from December 1, 1994, to June 30, 1995. Several secondyear neuroradiology fellows, assisted and supervised by the same two staff neuroradiologists during both time periods, were responsible for selective catheterizations and injections. The radiology technologist involved in the procedure recorded the following data at the time of the study on a standardized data collection sheet: type and location of vascular lesion, total fluoroscopic and angiographic series time, number of angiographic views and runs, and total time in the operating room for the radiologist and radiology technologist. Operating room time was defined as the time from which either the technologist or radiologist arrived in the operating room (whoever arrived first) to the time the technologist left the room. Operating room time did not include time taken to place the femoral sheath. Medical records were reviewed retrospectively for all patients in the study in order to confirm the location and type of vascular lesion and to determine if the findings on the initial examination resulted in changes in surgical therapy.

A 5F femoral sheath was introduced in all patients. Sheaths either were placed while the patient was in the operating room, usually after the induction of anesthesia and before surgery, or had been placed during previous diagnostic angiography. Fluoroscopy was not used to assist sheath placement in the operating room, nor was it routinely used for sheath placement before diagnostic angiography in the angiography suite. The sheath was continuously flushed with arterially pressurized saline while not in use.

Once in the operating room, the patient was positioned on a radiolucent operating table (Skytron, Grand Rapids, MI) with the head immobilized in a carbon fiber head-holder (Mayfield radiolucent skull clamp, Ohio Medical, Cincinnati, OH). Five patients were placed in the prone position and the others were supine. In these five, the sheath was placed while the patient was supine just after the induction of anesthesia. The patients were then carefully turned prone and bolsters were placed above and below the sheath sites to allow access for the arteriogram. The left femoral artery, rather than the right, was catheterized in these patients for better access to the groin during arteriography, owing to the configuration of the operating room. The femoral sheath was covered and draped to allow access during the angiogram. Care was taken to avoid placing radiopaque materials over the patient's head, neck, or chest. The operating room table was positioned to allow room for the portable angiography unit.

Catheterization of the desired vessel was performed through the 5F arterial sheath in the standard fashion immediately before the angiogram was obtained, rather than preoperatively. Injections were done by hand in all studies. Either ionic or nonionic contrast medium was injected at the discretion of the angiographer.

A portable digital subtraction unit (OEC Diasonics, Salt Lake City, UT), consisting of a C-arm fluoroscope, a digital image processor, a storage unit, and a video monitor, was used in all cases. This unit allows routine fluoroscopy and real-time DSA. The distance between the X-ray source and the image intensifier was fixed at 36.07 inches. A tri-mode image intensifier allowed the use of three field sizes (9, 6, and 4 inches) for the purposes of magnification. Fluoroscopy was performed during selective catheterization without magnification or the use of a boost mode (with a higher mA). The range of technique factors during fluoroscopy was 66 kVp and 0.2 to 5.0 mA. All DSA runs were performed in the boost mode with magnification. The range of technique factors during DSA in the boost mode was 69 kVp and 100 to 300 mAs. Field size used during DSA was typically 4 inches. The frame rate selected for the arteriogram was four per second.

Permanent hard-copy images were made for the X-ray jacket with a photography unit. The most recent preoperative angiograms, either conventional diagnostic studies or, in most AVMs, studies obtained at the completion of embolization, were in the operating room for comparison in all cases. All examinations were interpreted by the attending neuroradiologist and discussed with the neurosurgeon before leaving the operating room. In cases in which the initial examination detected residual aneurysm or parent or branch vessel compromise, a repeat study was performed after replacing or repositioning the aneurysmal clip. The additional time spent in the room, as well as the fluoroscopic and angiographic time data, was added to the initial data: repeat studies during the same surgical procedure were not treated as separate examinations.

Data Analysis

Differences in time spent in the room, fluoroscopic and angiographic run time, and number of views and runs between the initial 50 procedures and the subsequent 50 procedures were assessed with a Student's *t*-test ($P < .05$ accepted for statistical significance). A similar analysis for the initial and subsequent aneurysmal and AVM subgroups was performed.

Radiation Exposure

Radiation exposure measurements to the patient and to personnel were obtained during a simulated examination using anthropomorphic head and chest/thorax phantoms of an adult. Both fluoroscopy and DSA were performed in an identical manner as in an actual intraoperative study, using the same positioning and technique. Exposure measurements to the patient were obtained by using an X-ray monitor (Radcal Corp, model 2025, Monrovia, CA) with an electrometer/ion chamber (Radcal Corp model 20 X 5–3) for primary beam measurements. The entrance exposure rates for the patient, including back-scattered radiation, were obtained during nonmagnification posteroanterior fluoroscopy of the chest/thorax phantom and during a digital-subtraction run of the head phantom in an oblique orientation. The DSA run was performed with magnification (4-inch field) in the boost mode.

Radiation levels due to secondary radiation (primarily scattered radiation) were measured at selected locations during identical fluoroscopic and angiographic simulations with the head and chest phantom as above. These measurements were obtained with a pressurized ionization chamber (Victoreen, model 450P SN 2393, Cleveland, OH) at the positions typically occupied by the radiologist performing the procedures, the radiology technologist, and the anesthesiologist (Fig 1). Distances from the beam to the personnel were measured with a measuring tape from the edge of the image intensifier.

Effective Doses

Measurements of radiation exposure were used to compute the effective doses imparted to the patient and the medical personnel during a typical intraoperative procedure, based on median values of fluoroscopic and angiographic study times.

The effective dose, formerly referred to as the effective dose equivalent, is a concept recommended by the International Commission on Radiological Protection (ICRP) (16, 17). The concept is popular for the specification of radiation dose whenever a nonuniform pattern of exposure exists. The effective dose concept explicitly takes into account the nonuniform irradiation of organs and tissues of the body and yields a single computed value that permits direct comparison with effective dose estimates associated with other situations. The computed effective dose represents the uniform whole-body dose that suggests the same harm or biological detriment as the actual nonuniform dose situation. It should be noted that the effective dose is only an estimate of the uniform whole-body dose and is not an accurate measurement of the actual energy imparted (20). The effective dose concept relies on assumptions regarding uniform patient size and organ weighting factors, which may vary significantly among individuals. These assumptions introduce errors in the calculation of effective dose in individual patients when going from measurements of exposure to organ dose and effective dose.

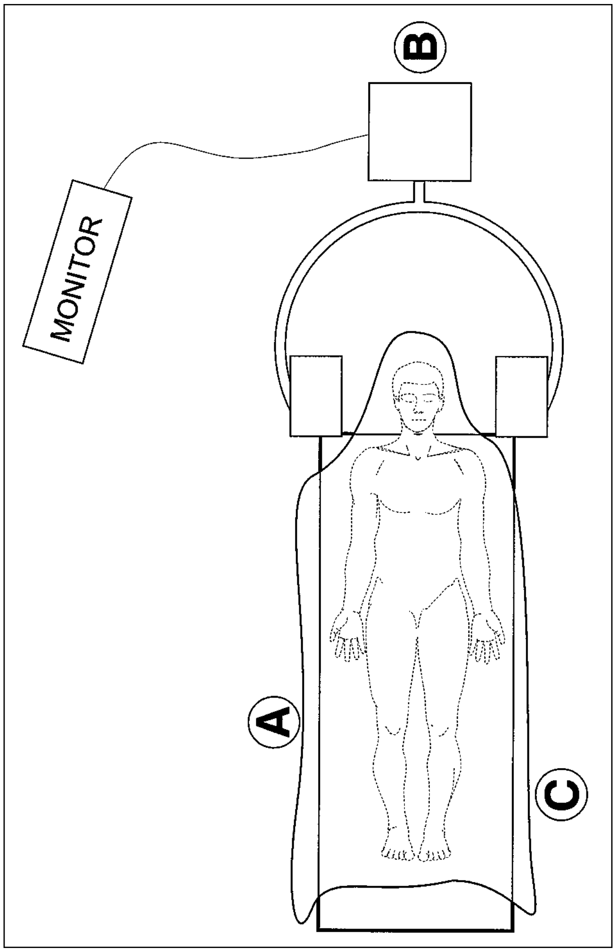

FIG 1. Schematic of operating room layout. The radiologist typically stands at point A and the anesthesiologist sits at point C. The radiology technologist operates the C-arm at point B. The monitor is positioned to allow both the radiologist and the technologist good visibility of the screen.

The method of Huda and Bissessur (18) was used to determine the effective dose equivalents, the older concept based on the organ and tissue weighting factors recommended in ICRP publication 26 (19), for both the fluoroscopic and angiographic portions of the intraoperative procedure. The effective dose equivalents of Huda and Bissessur were then converted to estimates of effective doses, based on the most recent organ and tissue recommendations of ICRP publication 60 (16), by using an interpolated conversion ratio of the two values obtained from Huda et al (20).

The effective doses for the medical personnel were obtained using the results of Faulkner and Marshall (21) to convert upper-chest exposure values to effective doses for individuals wearing 0.5-mm lead-equivalent protective aprons.

Results

Procedures

A total of 100 procedures were performed in 95 patients. In 77 patients, 81 arteriograms were obtained to evaluate aneurysmal clip placement; in 18 patients, 19 procedures were performed to assess residual AVM nidus or to determine the remaining vascular anatomy of an AVM. Sixty-seven patients were female and 28 were male; the median age was 49.5 years (range, 10 to 78 years). A total of 90 aneurysms were clipped in the 81 procedures performed to evaluate clip placement. These aneurysms included 17 at the middle cerebral bifurcation, 17 at the posterior communicating artery, 14 at the anterior communicating artery, 12 at the internal carotid artery bifurcation, nine at the basilar tip, nine at the pericallosal or anterior cerebral artery, four at the ophthalmic artery, three at the superior hypophyseal artery, two at the posterior cerebral artery, two at the superior cerebellar artery, and one at the posterior-inferior cerebellar artery. Among the 18 AVMs, five were located in the temporal lobe, three in the frontal lobe, three in the cerebellar hemisphere, two in the frontal parietal region, and one each in the occipital lobe, the parietal lobe, the temporoparietooccipital region, the parietooccipital region, and the temporoparietal region.

The first group of patients had 40 procedures for aneurysmal clippings and 10 procedures for AVM resections. Four of the 40 intraoperative aneurysmal studies were performed after clipping of two intracranial aneurysms. One study for aneurysmal assessment detected a residual neck and was repeated after the clip position was changed. One study performed after AVM resection revealed a residual nidus and was repeated after further resection. The second group of patients had 41 procedures for aneurysmal clippings and nine for AVM resections. In this group, five aneurysmal studies followed clipping of two aneurysms and one followed clipping of three aneurysms. Eight studies were repeated after replacing or repositioning the clip. No studies after AVM resection were repeated in the second group of patients.

The femoral artery was successfully catheterized with a 5F sheath in all studies. The right common femoral artery was used in 92 of 100 procedures. The left common femoral artery was used in the other eight procedures. Four of these were in the prone position for AVM resection. Use of the left common femoral artery in the prone position was divided evenly in both groups. More arterial sheaths were placed in the operating room than remained from the diagnostic angiogram (49 versus 41). Sheath placement was uncomplicated in all patients and no complications attributable to the sheath were observed.

Catheterization of the desired common carotid, internal carotid, or vertebral artery was successful in all procedures. Sixty-nine of the 100 procedures required catheterization of one vessel (a carotid or vertebral), and 31 required catheterization of two vessels (a carotid and a vertebral or both carotids). No significant difficulty in selective catheterization was encountered in the four procedures performed in the prone position. All studies were technically adequate.

Mean and median values for all recorded parameters are summarized in Tables 1 and 2, respectively. A trend toward reduced fluoroscopy time be-

TABLE 1: Mean values for 100 intraoperative studies

	Room Time (min)	Fluoroscopy Time (min)	Run Time (s)	No. of Views	No. of Runs
All procedures	62.4	6.9	50.6	4.1	4.5
First 50	54.8	7.5	39.5	3.4	3.6
Second 50	76.1*	6.4	65.5*	5.0*	5.5*
Aneurysms					
Total	62.4	6.7	50.6	4.1	4.5
First group (n = 40)	52.1	7.3	36.7	3.3	3.4
Second group (n = 41)	76.6*	6.1	65.2*	4.9*	5.6*
AVMs					
Total	69.2	8.0	60.8	4.6	4.9
First group (n = 10)	65.7	8.5	55.0	3.9	4.5
Second group (n = 9)	74.3	7.5	67.3	5.3	5.3

* $P < .05$

TABLE 2: Median values for 100 intraoperative studies

	Room Time (min)	Fluoroscopy Time (min)	Run Time (s)	No. of Views	No. of Runs
All procedures	55	5.2	40	4	4
First 50	49	5	37.4	3	3
Second 50	67.5	5.3	55	4	4
Aneurysms					
Total	50	5	37.8	4	4
First group (n = 40)	45	4.4	36	3	3
Second group (n = 41)	65	5.3	49	4	5
AVMs					
Total	60	6.2	60	4	4
First group (n = 10)	55	7.9	59.5	4	4
Second group (n = 9)	70	5.3	72	4	4

tween the first and second groups of 50 examinations was observed but was not statistically significantly ($P = .34$). Several statistically significant differences were detected. Overall mean room time for the radiologist and technologist was longer with the second 50 procedures ($P = .01$). The number of angiographic views and runs obtained increased ($P = .002$ and $P = .001$, respectively). These differences remained statistically significant within the aneurysm subgroup but not for the AVM subgroup. Excluding patients who had multiple aneurysms and repeat intraoperative studies, the increase in the number of runs and views remained statistically significant ($P = .002$ and $P = .006$, respectively). The reduction in fluoroscopy time again was reduced but was not statistically significant ($P = .142$).

Total operating room time for the radiologist and technologist ranged from 32 to 120 minutes for AVMs and from 20 to 120 minutes for aneurysms. Fluoroscopy time ranged from 3.5 to 20 minutes for AVMs and from 1 to 25 minutes for aneurysms. Angiographic run time ranged from 34 to 73 seconds for AVMs and from 6 to 72 seconds for aneurysms.

TABLE 3: Measured radiation exposures during intraoperative angiography

	Entrance Exposure	
	Fluoroscopy	Angiography
Patient	0.74 R/min	120 mR/s
Radiologist	0.045 mR/min (@ 36 in.)	8.2 uR/s (@ 44 in.)
Technologist	0.050 mR/min (@ 60 in.)	15.4 uR/s (@ 60 in.)
Anesthesiologist	0.033 mR/min (@ 84 in.)	3.4 uR/s (@ 96 in.)

Note.—Exposure rates in roentgens (R) or milliroentgens (mR). The distances for fluoroscopy and angiography are different for the radiologist and the anesthesiologist because the tube has moved cranially.

Radiation Exposure and Dose

The measured radiation exposure rates are summarized in Table 3. Using the longest recorded times for fluoroscopy and DSA, the maximum skin exposures were 0.24 Gy for the patient, 0.01 Gy for the technologist and the radiologist, and 0.004 Gy for the anesthesiologist. Mean fluoroscopic and angiographic run times were greater than median times for all recorded categories, indicating a skew of the data (Tables 1 and 2). For this reason, effective doses were calculated using median exposure

TABLE 4: Representative effective doses for intraoperative angiography

		Effective Dose (mrem/case)			
	Median Time	Patient	Radiologist*	Technologist*	Anesthesiologist*
Fluoroscopy	5.2 min	50.0	0.012	0.013	0.009
Antiography	40 s	26.7	0.016	0.031	0.007
Total		76.7	0.028	0.044	0.016

* Medical personnel with 0.5-mm lead-equivalent protective aprons.

times. The effective doses for the patient and operating room personnel for median procedure values can be found in Table 4. Using the measured radiation exposure rate data to calculate the effective doses for the range of observed fluoroscopy and DSA times produced values of 13 to 280 mrems for the patient, 0.005 to 0.086 mrems for the radiologist, 0.007 to 0.12 mrems for the radiology technologist, and 0.003 to 0.054 mrems for the anesthesiologist.

TABLE 5: Effective dose equivalent from other common diagnostic radiology procedures

Examination	Effective Dose (mrem)
Standard head CT (25)	170
Standard abdomen CT (25)	680
Chest X-ray (24)	8
Barium enema (24)	406

Discussion

Intraoperative angiography has the potential to improve patient outcome in neurovascular surgical procedures through identification of such abnormalities as residual aneurysm, branch vessel occlusion by the aneurysmal clip, and residual AVM nidus. The intraoperative information obtained allows surgical correction of these findings while the patient is still in the operating room. In determining the relative benefit of any new procedure, one must consider its risk and cost, among other factors. The purpose of this study was to assess some of the practical aspects of performing these examinations, including the time required and the radiation dose incurred during intraoperative angiography.

The time required to perform intraoperative angiography is comparable to that for conventional studies, with examinations for AVMs tending to be longer than those for aneurysms. The time required for the procedures in our study was similar to that reported by Martin et al (10), who found the average procedure time was 45 to 60 minutes, with a range of 25 to 120 minutes. We believe that preoperative sheath placement greatly facilitated catheterization. This practice allows femoral arterial puncture to be performed in a standard supine position and eliminates the time required to gain vascular access during the angiographic procedure. Prone positioning of the patient is challenging but does not make intraoperative angiography impossible. With the correct positioning and support, the access area can be properly draped and the procedure performed as aseptically as possible. No infections were observed in this small group of patients with AVMs (n = 4). Fluoroscopy, DSA series time, number of views, and angiographer time were similar to those for the patients examined in nonprone positions.

Although the time demand is not great, a hidden cost of intraoperative angiography is that the examinations cannot be scheduled precisely, and therefore require the radiologist to be available regardless of any other responsibilities.

A portion of the fear of excessive radiation exposure is overcome by experience with the portable equipment. High-dose (or ‘‘boost’’) fluoroscopy requires activation of a second fluoroscopy switch in some newer models or maximal depression of the fluoroscopy switch in older models. When these switches activate the boost fluoroscopy mode, the audio pulsing accompanying the fluoroscopy noticeably increases in frequency. The fluoroscopy boost mode was not necessary in this series, as the increased exposure did not increase the ease of the procedure. However, the boost mode improves the digital subtraction image and was used for all DSA acquisitions. As in most angiographic procedures, anatomy, catheters and guidewires used, positioning, and experience are the determining factors in technical performance (22).

Radiation doses were well within the guidelines established by the National Council on Radiation Protection and Measurements (NCRP) governing medical radiation (23). The recommended annual occupational exposure of personnel is 50 mSv (5 rem), which is approximately 40,000 times the effective dose calculated for the operating room personnel who received the highest dose (the radiology technologist) from the longest observed procedure. In addition, the dose to the patient was not excessive and is comparable to the dose received from several other diagnostic radiologic procedures (Table 5) (24, 25). The maximum calculated effective dose of 280 mrem for the patient and maximum occupational effective doses of 0.086 and 0.12 mrems for the radiologist and the technologist, respectively, were also within these guidelines. The maximum calculated skin exposures observed in this study were well below those expected to cause cataracts or temporary epilation (26).

In separating the two groups of patients, we expected to find a reduced operating room time for the radiologist resulting from increased experience with the technique. Correspondingly, we assumed that the fluoroscopy time and angiography run time would also be decreased. Despite the increased experience with additional procedures, only the fluoroscopy time was reduced. It is even more impressive that the fluoroscopy time was reduced, as additional angiographic series were obtained in the second group of patients, both for aneurysms and for AVMs. These differences remained statistically significant when patients who had multiple clipped aneurysms and repeated studies were excluded from the analysis. One possible explanation for the significant increase in angiographic runs and views is an increased awareness of the false-negative rate for residual aneurysm with intraoperative angiography. The second group of patients was studied after analysis of our initial experience in which an 8% rate for missed residual aneurysm was identified (13). This most likely resulted in the acquisition of additional views in an attempt to better evaluate the aneurysms intraoperatively.

Conclusion

Intraoperative angiography can be efficiently performed in an amount of time comparable to that required for conventional studies. Radiation doses to patient and operating room personnel are reasonable.

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