

Radiation Exposure of the Anesthesiologist in the Neurointerventional Suite

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This article has been selected for the ANESTHESIOLOGY CME Program. Learning objectives and disclosure and ordering information can be found in the CME section at the front of this issue.

ABSTRACT

Background: Scatter radiation during interventional radiology procedures can produce cataracts in participating medical personnel. Standard safety equipment for the radiologist includes eye protection. The typical configuration of fluoroscopy equipment directs radiation scatter away from the radiologist and toward the anesthesiologist. This study analyzed facial radiation exposure of the anesthesiologist during interventional neuroradiology procedures.

Methods: Radiation exposure to the forehead of the anesthesiologist and radiologist was measured during 31 adult neuroradiologic procedures involving the head or neck. Variables hypothesized to affect anesthesiologist exposure were

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Received from the Department of Anesthesiology, Columbia University College of Physicians and Surgeons, New York, New York. Submitted for publication June 24, 2010. Accepted for publication November 3, 2010. Support was provided solely from institutional and/or departmental sources. Presented in part at the Society for NeuroInterventional Surgery Annual Meeting, July 27, 2009, Boca Raton, Florida; and the American Society of Anesthesiologists Annual Meeting, October 18, 2009, New Orleans, Louisiana. Figure 3 in this article was prepared by Annemarie B. Johnson, C.M.I., Medical Illustrator, Wake Forest University School of Medicine Creative Communications, Wake Forest University Medical Center, Winston-Salem, North Carolina.

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What We Already Know about This Topic

- Scatter radiation to the eye during radiologic procedures can cause cataracts, but eye and facial exposure to anesthesiologists in typical clinical settings has not been well studied.

What This Article Tells Us That Is New

- During neurointerventional angiographic procedures, radiation exposure to the anesthesiologist's face was six-fold greater than during angiography and three-fold greater than that of the radiologist.
- Anesthesiologists who spend significant time performing such procedures should wear protective eyewear.

recorded for each procedure. These included total radiation emitted by fluoroscopic equipment, radiologist exposure, number of pharmacologic interventions performed by the anesthesiologist, and other variables.

Results: Radiation exposure to the anesthesiologist's face averaged $6.5 \pm 5.4 \mu\text{Sv}$ per interventional procedure. This exposure was more than 6-fold greater ($P < 0.0005$) than for noninterventional angiographic procedures (1.0 ± 1.0) and averaged more than 3-fold the exposure of the radiologist (ratio, 3.2; 95% CI, 1.8–4.5). Multiple linear regression analysis showed that the exposure of the anesthesiologist was correlated with the number of pharmacologic interventions performed by the anesthesiologist and the total exposure of the radiologist.

Conclusions: Current guidelines for occupational radiation exposure to the eye are undergoing review and are likely to be

◇ This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 9A.

◆ This article is accompanied by an Editorial View. Please see: Amis ES Jr: Anesthesiologists in the neurointerventional suite: What is appropriate radiation protection? ANESTHESIOLOGY 2011; 114:477–8.

lowered below the current 100–150 mSv/yr limit. Anesthesiologists who spend significant time in neurointerventional radiology suites may have ocular radiation exposure approaching that of a radiologist. To ensure parity with safety standards adopted by radiologists, these anesthesiologists should wear protective eyewear.

WITH the rapid expansion of interventional radiology and radiologic imaging, the consequent radiation exposure has become a potential occupational hazard in the practice of anesthesiology.¹ Radiation exposure by the anesthesiologist has been measured in several previous studies^{2–4} using standard radiation badges. Most of these have measured exposure at the chest and/or neck level outside of any protective lead and were cumulative studies of radiation exposure over several months. These studies have reinforced the importance of wearing lead during radiologic procedures.

Radiation exposure to the human eye is known to cause cataracts.⁵ Exposure to radiologists from scatter radiation during angiography and interventional radiologic procedures has been measured and may exceed the threshold for long-term injury.⁶ Interventional radiologists and cardiologists should use eye protection, either leaded glasses or ceiling-suspended leaded shields,⁷ although leaded glasses are preferable.⁸ We hypothesized that radiation exposure to the unprotected eye of the anesthesiologist might be in the same range as that reaching the radiologist, thus warranting protective eyewear for the anesthesiologist; this exposure should be higher for interventional procedures than angiography.

In the current study, we measured radiation exposure on the face of both the anesthesiologist and the radiologist as a surrogate for eye exposure. We used sensitive electronic detectors that allow detection on a per-procedure basis. This method permitted us to analyze the relationship between medical interventions on the part of the anesthesiologist and to estimate his or her total eye exposure during a radiologic procedure.

Materials and Methods

Study Design

We studied the radiation exposure at the forehead of the radiologist and anesthesiologist in 31 adult neuroradiologic procedures involving the head and neck, performed at Columbia University Medical Center, New York, New York, from January 26, 2009, to October 30, 2009. The study was approved by the Institutional Review Board of Columbia University Medical Center. Our measurements involved the physicians, not the patients. The Institutional Review Board did not require written informed consent from our physicians because the study was passive and we were not altering physician behavior.

There was little preexisting information on which to power the study, and the duration and number of subjects were limited by external factors. The procedures were either cerebral angiography or interventional procedures consisting of cerebral vascular angioplasty and stent placement or em-

bolization of brain arteriovenous malformations, tumors, or cerebral aneurysms. For each procedure, the radiology fellow and the anesthesiology resident were equipped with electronic radiation detectors.

During the study, there was one radiology fellow and she participated in all 31 procedures, either alone or standing by the side of the radiology attending physician. Twenty-one anesthesiology residents participated. Sixteen residents were the primary clinician in only one procedure (defined as starting the procedure), and the remaining five residents were the primary clinician for two to four procedures (specifically, two residents were the primary clinicians for four procedures, one was the primary clinician for three procedures, and two were the primary clinician for two procedures each). When clinicians were replaced during a procedure, the detection equipment was moved to the new clinician and monitoring of radiation exposure was continued. These replacement clinicians included attending physicians and other residents in the anesthesia department. All clinicians had attended our medical center's training course on radiation safety as part of their general training for clinical appointment.

Radiation exposure was measured with two monitors (Unfors EDD30; Unfors Instruments, Billdal, Sweden). These devices have a small solid-state sensor ($6 \times 8 \times 25$ mm) connected to a pocket-sized meter at the end of a thin 1.5-m cable. To estimate the radiation exposure to the eye lens without obstructing the view and free movement of the participant, the sensor was positioned in the center of the forehead, 3 cm above eye level, and held in position with a head strap. Previous studies have used less sensitive cumulative dose radiation badges fixed at the eyebrow⁹ or estimates based on simulations and models of scatter radiation.¹⁰

The anesthesiologists and radiologist were instructed to continue their routine safety practices. Anesthesiologists were reminded to remain behind their portable leaded acrylic shield, to maximize their distance from the radiation source, and to wear a lead apron and thyroid shield (lead equivalent, 0.3–0.5-mm). For the interventional radiologists, standard equipment at our medical center also includes leaded glasses, with 0.75-mm lead equivalent main lenses and 0.25-mm lead equivalent side guards. Radiologists' sensors were located above their protective glasses. The study participants were blinded to their radiation exposure during the study by a piece of opaque tape that was placed over the unit display.

If either the anesthesiologist or the radiologist was unavailable to have the monitor placed before the procedure (11 procedures), data from the other clinician and from the fluoroscopy equipment were recorded; however, these procedures with partial data were not analyzed and are not part of the 31 procedures that compose our study. One anesthesiologist for a procedure early in the study for which paired radiologist exposure was not available had a radiation exposure 10 times higher than for similar previous procedures. For ethical reasons, the anesthesiologist was reminded of radiation safety techniques and not recruited for further studies.

There were two adult neuroradiology procedure rooms at Columbia University Medical Center during the current study (a Philips Integris V C-arm biplane system installed in 1998 [Philips Medical Systems, Amsterdam, The Netherlands] and a Siemens Axiom Artis dBA C-arm biplane system in service since 2006 [Siemens Medical Solutions, Erlangen, Germany]). Of the procedures, 7 were performed in the Philips room and 24 were performed in the Siemens room. In both rooms, the anesthesiologist was located along the patient's left side, with the anesthesia machine positioned across from the patient's hip. A 6-foot-high shield (0.5-mm lead equivalent) with a transparent acrylic upper half, 1.8 m wide in the Philips biplane room and 1.2 m wide in the Siemens biplane room, was positioned between the anesthesiologist and the fluoroscopy equipment. The radiologist stood at the patient's right side, at mid-thorax level, and had a 0.5-mm lead equivalent ceiling-mounted shield.

Both fluoroscopy systems had the anterior-posterior arm in a standard configuration, with the x-ray source pointing upward (image intensifier above the patient), thus minimizing backscatter to medical personnel.¹⁰ The Siemens system also had the standard arrangement for the lateral arm (*i.e.*, x-ray source facing the radiologist), thus directing scatter away from the radiologist. The Philips system had a modification to point the x-ray source away from the radiologist. Both fluoroscopy systems measured the total radiation produced during a procedure (Siemens in $\mu\text{Gy} \cdot \text{m}^2$ and Philips in $\text{Gy} \cdot \text{cm}^2$). Total radiation was converted arithmetically to the current standard, kerma-area-product in $\text{Gy} \cdot \text{cm}^2$.¹¹ The Philips equipment used older technology and generated more radiation than the Siemens equipment, approximately 20% more during standard diagnostic procedures.¹²

The international guidelines for radiation exposure of the human eye are given in Sv, the unit for equivalent dose, a measure of absorbed radiation that adjusts for the specific type of radiation exposure (x-rays, neutrons, electrons, or other).⁶ The Unfors monitors that were used in our study report radiation exposure in μSv . The Sv replaced the rem (roentgen equivalent man) in the official radiation nomenclature in the 1970s, with 1 Sv = 100 rem. The term rem appears in some publications referenced by our study. In addition, Gy is used as a more general term for the absorbed dose of energy imparted by ionizing radiation to any type of matter.¹¹ For x-rays, 1 Gy is equivalent to 1 Sv, because the radiation weighting factor assigned to x-rays is 1. This weighting factor reflects the relatively low transmission of energy from x-rays to biologic tissue, relative to other types of radiation, such as neutrons and protons.¹³

For each angiographic and interventional procedure, in addition to the radiation exposure of the anesthesiologist and radiologist, we measured several variables that clinical experience and existing literature had shown were relevant for radiation dosage to clinicians during fluoroscopy. These included overall duration of the procedure (defined as time spent in the procedure room), total fluoroscopy time (cumulative time [in minutes] that radiation is actually emitted from the fluoroscopy

equipment, as recorded by the fluoroscopy systems), total radiation emitted by the fluoroscopy equipment, and type of anesthesia (general anesthesia *vs.* sedation).

We also counted the number of pharmacologic interventions by the anesthesiologist in the care of the patient during the active fluoroscopy part of the procedure because this was hypothesized to relate to the anesthesiologist's exposure to radiation. We calculated the total number of drug boluses plus the total number of rate changes for continuous infusions after induction as a surrogate for the general level of activity by the anesthesiologist during the procedure. The actual number of medical interventions was understood to exceed the number that would be explicitly charted. For general anesthesia, we excluded interventions at the end of the procedure, starting with reversal of neuromuscular blockade, because blockade reversal is performed after fluoroscopy has ended. Interventions (drug boluses and changes in infusion rates) were counted using the anesthesia electronic medical record (CompuRecord; Philips Medical, Andover, MA).

Two types of analyses were pursued. We performed a general comparison of angiography *versus* interventional procedures (tables 1 and 2; fig. 1) for anesthesiologist and radiologist exposure, relative exposure (anesthesiologist relative to radiologist), procedure duration, and other related variables. We then performed a more detailed analysis of factors affecting anesthesiologist exposure for all procedures, angiography and interventional, using bivariate and multiple regression analysis (tables 3 and 4; fig. 2).

Statistical Analyses

For tables 1 and 2, comparisons between angiography and interventional procedures were first tested for equal variance. A two-sample *t* test with equal variance and a *t* test with unequal variance (both two tailed) were used as appropriate to test for overall differences between interventional procedures and those involving angiography. Results are shown as mean \pm SD and mean (95% CI) for ratio data. Bivariate analyses with simple linear regressions were used to detect

Table 1. Procedures Included in the Study

Procedure Type	No. of Procedures	Duration, Mean \pm SD, min*	General Anesthesia, No. (%)
Angiography	9	133 \pm 70	5 (56)
Interventional	22	231 \pm 72†	13 (59)
Aneurysm	9	275 \pm 60	9 (100)
Embolization			
AVM	8	200 \pm 43	2 (25)
Embolization			
Angioplasty	3	240 \pm 100	2 (67)
Tumor	2	147 \pm 85	0
Embolization			

* Interventional procedures had longer average durations than angiography. † $P < 0.005$.

AVM = arteriovenous malformation.

Table 2. Summary of Radiation Exposure for Anesthesiology and Radiology Personnel

Procedure Class, No. (%)	Total Radiation (KAP) from Fluoroscopy Equipment, Gy · cm ² *	Anesthesiologist Radiation Exposure, μSv*	Radiologist Radiation Exposure, μSv*	Ratio of Anesthesiologist Exposure to Radiologist Exposure for Each Procedure†	No. of Drug Interventions by Anesthesiologist during the Procedure*
Angiography Only, 9 (29)	82 ± 36	1.0 ± 1.0	2.1 ± 2.2	0.74 (0.12–1.4)	4 ± 1
Interventional Procedure, 22 (71)	147 ± 66‡	6.5 ± 5.4§	2.6 ± 1.6	3.2 (1.8–4.5)	14 ± 8§

Radiation exposure to personnel was measured on the forehead near eye level.

* Data are given as mean ± SD. † Data are given as mean (95% CI). ‡ $P < 0.05$. § $P < 0.0005$ for column-based comparisons between angiography and interventional procedures. || $P < 0.005$.

KAP = kerma-area-product.

associations between hypothesized explanatory variables and the radiation exposure of the anesthesiologist (table 3). $P < 0.05$ was considered significant. These variables were then tested for collinearity. Variance inflation factor scores ranged from 1.2 to 1.6 (average, 1.45), with a condition index of 6.5. With variance inflation factor scores far lower than 10, and a condition index value lower than 15, collinearity was judged not to be a problem for multiple regression analysis.¹⁴

The goal of the multiple regression analysis was to identify factors that contribute to the radiation exposure of the anesthesiologist, not to create a predictive model. Model selection with multiple linear regressions was performed using a stepwise approach, adding those variables from table 3 with significance in the order of decreasing explanatory power. Thus, variables were retained in the regression if their addition improved the adjusted R^2 value and if they reached a significance of 0.05. Interaction terms were not pursued.

Studentized residuals were plotted against predicted values to examine the homoscedasticity assumption. These are residuals that have been standardized to the SD of the predicted value (*i.e.*, divided by the SD) and in which the SD is calculated using the root mean square error of the regression while excluding the data point for that residual.¹⁵

As described previously, most anesthesiologists ($n = 16$) were the primary participant in only one procedure, but five were the primary clinician for multiple procedures. We were unable to model using the method for repeated measurements because of the limited sample size. In addition, staffing requirements required anesthesiologists to replace each other during the procedures; the radiation exposure measured during a specific procedure sometimes reflected a composite of clinician behavior, not of an individual physician.

Statistical analyses were performed using computer software (Stata/SE. V11.0 for Windows; StataCorp LP, College Station, TX).

Results

Radiation doses to the forehead of the radiologist and to the anesthesiologist were measured in 31 neuroradiologic procedures. As shown in table 1, 9 angiographic procedures and 22 interventional procedures were performed. The interventional procedures included cerebral angioplasty and embolization of cerebral aneurysms, arteriovenous malformations, and tumors. The type of anesthesia included both general anesthesia and sedation

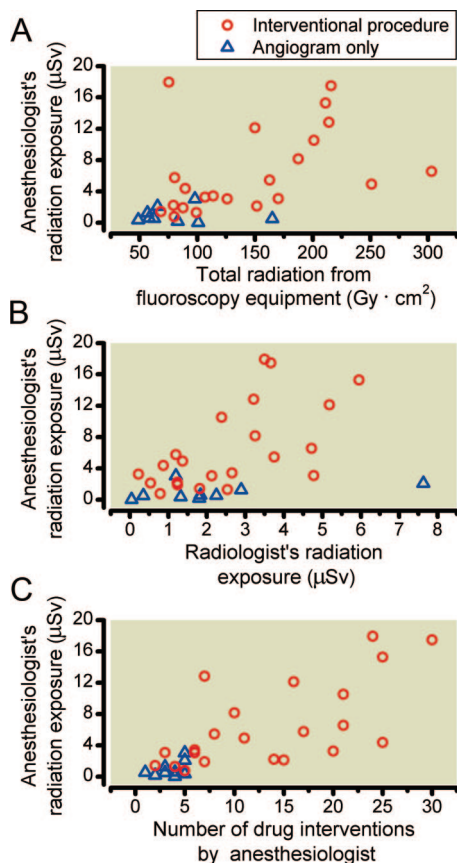


Fig. 1. Scattergrams of anesthesiologist's radiation exposure plotted against (A) total radiation exposure emitted by fluoroscopy equipment, (B) radiologist's radiation exposure, and (C) number of drug interventions by the anesthesiologist.

Table 3. Bivariate Analysis of Radiation Exposure of Anesthesiologists

Predictor	β Coefficient, Mean (95% CI)	R^2	P Value
No. of Drug Interventions	0.46 (0.31 to 0.62)	0.55	<0.001
Procedure Duration, min	0.036 (0.017 to 0.056)	0.33	0.001
Total Radiation (KAP) from Fluoroscopy Equipment, Gy · cm ²	0.041 (0.015 to 0.067)	0.27	0.003
Interventional Procedure (vs. Angiography Only)	5.6 (1.8 to 9.3)	0.24	0.005
Radiologist Total Exposure, μ Sv	1.4 (0.45 to 2.4)	0.24	0.006
Total Fluoroscopy Time, min	0.04 (−0.02 to 0.10)	0.06	0.19
General Anesthesia (vs. Sedation)	2.0 (−1.9 to 5.9)	0.04	0.30
Siemens vs. Philips Fluoroscopy Equipment	−1.6 (−6.2 to 3.1)	0.02	0.49

The coefficients are interpreted as the change (in μ Sv) of anesthesiologist exposure per unit increase of the tested variable. The analysis includes both angiography-only and interventional procedures.

CI = confidence interval; KAP = kerma-area-product.

administered by an anesthesiologist. Angiography averaged 133 ± 70 min; and interventional procedures, 231 ± 72 min ($P < 0.005$). Angiography and interventional procedures had similar rates of general anesthesia (*i.e.*, 56% and 59%, respectively).

Figure 1 shows the raw data for anesthesiologist's radiation exposure plotted against radiologist's exposure, total radiation emitted by fluoroscopy equipment, and drug interventions by the anesthesiologist. Table 2 summarizes the radiation exposure of the anesthesiologist and the radiologist during the 31 neuroradiologic procedures studied and compares exposure between interventional procedures and procedures in which only angiography was performed. As expected, total radiation emitted by the fluoroscopy equipment was greater during the interventional procedures than during angiography (147 ± 66 vs. 82 ± 36 Gy · cm²). The exposure of the anesthesiologist per interventional procedure was 6.5 ± 5.4 μ Sv, more than 6-fold greater than for noninterventional procedures ($P < 0.0005$); the exposure of the radiologist did not demonstrate a similar difference. For angiography, the average ratio of anesthesiologist exposure to that of the radiologist was 0.74, but the ratio was not significantly different from 1. However, for interventional procedures, the radiation exposure of the anesthesiologist was more than 3-fold that of the radiologist (ratio, 3.2; 95% CI, 1.8–4.5) and the ratio was significantly different from 1 ($P = 0.003$).

Table 4. Final Multiple Linear Regression Model of Radiation Exposure of the Anesthesiologist

Predictor	β Coefficient	P Value
No. of Drug Interventions	0.42 (0.29–0.56)	<0.001
Radiologist Total Exposure, μ Sv	1.1 (0.42–1.71)	0.002

For the final model, the anesthesiologist exposure increased by 0.42 μ Sv per bolus or change in infusion rate and tracked the radiologist total exposure, with a coefficient of 1.1 μ Sv per radiologist total exposure. Final $R^2 = 0.68$ (adjusted $R^2 = 0.66$).

In table 3, we show results from bivariate analyses using simple linear regressions with our hypothesized explanatory variables on anesthesiologist radiation exposure. The total number of drug boluses and infusion rate changes by the anesthesiologist (summarized as “drug interventions” for simplicity) was significantly related to anesthesiologist radiation exposure, with a correlation factor of 0.55. Procedure duration, total radiation emitted by the fluoroscopy equipment, radiation exposure of the radiologist, and angiography *versus* true interventional procedure were also correlated with anesthesiologist exposure.

In table 4, we show results from the final multiple linear regression. Only the number of drug interventions and the radiologist's exposure remained explanatory. For every drug intervention by the anesthesiologist, his or her radiation exposure increased by 0.42 μ Sv. In addition, the anesthesiolo-

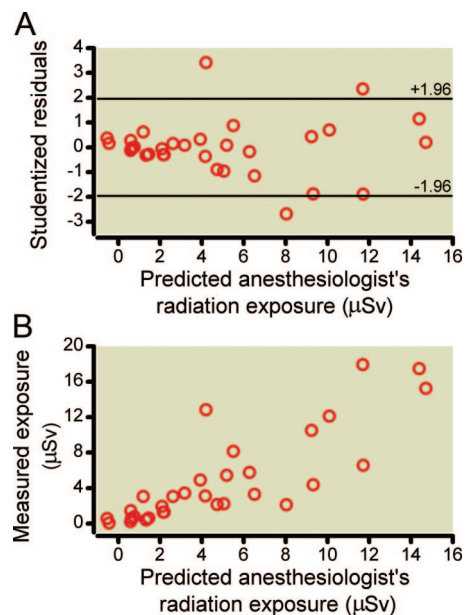


Fig. 2. Plot of final multiple regression and of studentized residuals. (A) Externally studentized residuals for regression *versus* predicted values. Residuals were normalized to unitary variance. (B) Measured ocular radiation exposure of anesthesiologist *versus* predicted value.

gist's radiation exposure increased by $1.1 \mu\text{Sv}$ for every $1.0\text{-}\mu\text{Sv}$ exposure of the radiologist. The significance of the overall model was $P < 0.001$, with $F_{2,28} = 30.27$ and adjusted $R^2 = 0.66$. Because the number of drug interventions might reasonably be considered as a surrogate for procedure duration, we attempted to force procedure duration into the final regression in two ways. When we replaced the number of drug interventions with procedure duration in the final regression, the adjusted R^2 value decreased to 0.44 . Forcibly adding procedure duration to the final regression while retaining the number of drug interventions minimally increased the R^2 value to 0.69 (from 0.68) but decreased the adjusted R^2 value to 0.65 . Thus, procedure duration was not included in the final regression.

In figure 2, we plotted measured anesthesiologist's exposure versus predicted and studentized residuals versus predicted exposure. The residuals appear to be randomly distributed around 0. Both interventional procedures and angiography were included in the described regression analyses.

Discussion

We present a prospective study that investigates radiation exposure of the eye for the anesthesiologist during neuroradiologic procedures. We used radiation dose at the forehead as a surrogate for eye exposure and showed that, during interventional procedures, the anesthesiologist is exposed to more radiation than the radiologist. The radiation exposure of the anesthesiologist during neuroradiologic procedures correlates with the number of interventions by the anesthesiologist, estimated by the number of boluses and infusion changes that are performed during the procedure.

The eye may be the organ most sensitive to radiation damage.¹⁶ Although anesthesiologists and radiologists both wear lead shielding to protect their bodies from the neck down, the standard of practice for interventional radiologists and others practicing interventional procedures also includes wearing leaded glasses or using ceiling-mounted leaded shields to protect the face.⁷ There is no similar standard for anesthesiologists involved in these procedures, and anesthesiologists may be unaware that they are leaving themselves partially unprotected.

It is remarkable, but not surprising, that the radiation dose to the anesthesiologist's eye can be greater than that to the radiologist. The radiation dose to medical personnel in interventional radiology is primarily the result of reflected scatter of x-rays from the patient.¹⁷ Modern interventional neuroradiology suites generally use biplane equipment with one C-arm in the anterior-posterior plane and one C-arm aimed laterally. The orientation of the arms is designed to minimize the cumulative exposure of the radiologist. The anterior-posterior arm is oriented with the x-ray source below the patient, so that scatter is directed back down to the floor. The anesthesiologist and radiologist would share equally in this source of scattered radiation. The lateral arm usually has the x-ray source on the side of the anesthesiolo-

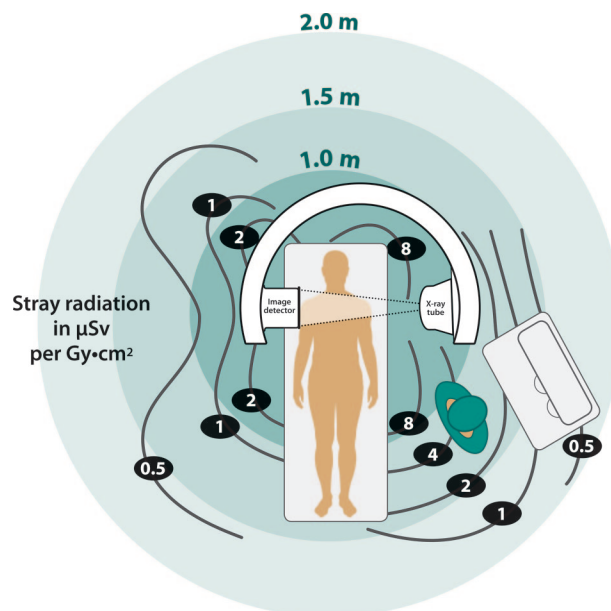


Fig. 3. Distribution of scatter radiation from a lateral x-ray source. Plan of interventional radiology procedure room showing distribution of scatter radiation from a lateral C-arm. There were higher concentrations of scatter on the side with an x-ray source, for each step increase of 0.5 m from the patient. Measurements were taken from a cardiac catheterization laboratory. Units are μSv radiation exposure to personnel per $\text{Gy} \cdot \text{cm}^2$ of total radiation emitted by the x-ray tube. This figure was modified and used with permission from page 64 of the following: Valentin J. Avoidance of radiation injuries from medical interventional procedures. *Ann ICRP* 2000; 30:7–67.

gist, pointing toward the radiologist and patient, so that scatter reflects away from the radiologist and, in this case, toward the anesthesia personnel.

As figure 3 shows, at a 1-m distance, the scattered radiation dose from a lateral C-arm can be four times greater on the side of the patient with the x-ray tube (generally, the side occupied by the anesthesiologist) than on the side with the image intensifier.¹⁸ In our own analysis, this effect was confounded by reversed orientation of the lateral tube in the older of our two fluoroscopy rooms (Philips equipment, see Study Design under Materials and Methods). This older-generation Philips equipment is known to generate more radiation,¹² but its orientation reflected lateral scatter toward the radiologist and away from the anesthesiologist. Our regression analysis did not detect an effect of procedure room on anesthesiologist radiation exposure, perhaps because of the few procedures (7 of 31) performed in this room.

In addition, we found that the number of drug interventions performed by the anesthesiologist during the procedure was highly correlated with his or her own radiation exposure. Anesthesia personnel were stationed across from the patient's hip behind a 1.8-m -high radiation shield, with a width of 1.2 or 1.8 m , depending on procedure room. To reach the patient's hands, all intravenous tubing looped forward toward the patient's head,

around the protective shield, and then back down toward the arms. Injections of drugs or alterations in pump settings would normally draw the anesthesiologist toward the intravenous tubing and, thus, toward the patient's head; closer to the source of scatter radiation; and closer to the front edge of the protective shield. Switching the anesthesia ventilator off temporarily, to create apneic movement-free periods for the radiologist, would do the same. Our analysis also demonstrates that the number of drug interventions is more than just a surrogate for duration of procedure. The bivariate association between number of drug interventions and anesthesiologist radiation exposure was stronger than for procedure duration and exposure; replacing the number of drug interventions with procedure duration in the final regression decreased the adjusted R^2 value by a third.

The layout of the interventional procedure room, the positioning of the anesthesia equipment, and the specifics of the fluoroscopy system will greatly affect the radiation exposure of the anesthesiologist.¹⁰ One drawback of our study is that we are describing a practice at a single university center involving two procedure rooms with similar designs. Even with the same configuration, personnel at different medical centers may be more or less precise in the positioning of protective screens and the care with which they avoid radiation; our results may not hold for other institutions.

There are also limitations to our statistical analysis, stemming primarily from our limited data set of 31 procedures. With a small data set and the evaluation of eight explanatory variables, it is possible that we are ascribing an effect to a variable that is actually related to random noise in our data. Thus, the correlations we found between the anesthesiologist's radiation exposure and the number of interventions he or she performed and the correlation to the radiologist's exposure need to be validated in an independent data set. In addition, the linear regression procedures we applied assumed that the results of each procedure were independent, although five of our anesthesiologists participated in two or more procedures. A larger data set with multiple procedures for each anesthesiologist would be preferable because statistical methods for repeated measurements would be able to allocate some of the variation in anesthesiologist radiation exposure to differences in behavior between anesthesiologists.

To gauge the clinical relevance of our results requires some background information concerning radiation safety. In current practice, the harmful effects of radiation to the eye may be more important than the carcinogenic or teratogenic effects of occupational exposure during interventional radiology.⁷ Radiation damage causes posterior lens opacification, a type of cataract associated with diabetes mellitus and steroid use.¹⁹ Most naturally occurring cataracts are more anteriorly located. Radiation damage to the eye (and skin) is considered a deterministic effect (*i.e.*, the amount of damage is directly related to the total radiation dose and resultant cell

injury or death). Deterministic effects are thought to have minimum thresholds for injury,²⁰ although some⁵ have argued that there is no threshold for cataract formation.

Cancer risk and other genetic damage (heritable risk) are stochastic effects and relate to the probability that an individual within an exposed population will develop a disease or genetic change.²¹ For the individual, the harmful stochastic effect is binary (*i.e.*, chance that he or she will or will not develop a cancer) and the intensity of the disease is not directly related to the radiation dose.¹¹ Stochastic effects do not have thresholds and are the basis for the concept of ALARA, reducing exposure to As Low As Reasonably Achievable.²⁰ For practitioners who follow the standard of practice and wear 0.3- to 0.5-mm lead-equivalent aprons or are positioned behind lead-equivalent shielding, levels of radiation reaching the torso and, thus, stochastic risk (cancer or other genetic damage) are probably small.

The existing recommendations for limiting radiation dose to the human lens during occupational exposure are based on research dating from the 1960s and 1970s.²² To avoid clinically significant cataracts in workers with long-term repeated exposure to x-rays over several years, a limit of 150 mSv/yr was recommended.²³ To prevent detectable, but nonsymptomatic, opacities, the guidelines suggest a lower limit (*i.e.*, 100 mSv/yr). Our results, 6.5- μ Sv ocular exposure per interventional procedure, are relatively low compared with these limits; and reflect the fact that our practitioners spend much of their time behind a lead shield.

However, current radiology and radiation physics literature suggests that these occupational limits on ocular exposure to radiation should be much lower. The threshold dose for cataract formation due to accumulated radiation exposure may be almost 10-fold lower than that on which the current standards were based.²⁴ One recent study²⁵ of 116 interventional cardiologists found that 38% had posterior lens opacities (including presymptomatic changes), whereas matched controls had a 12% prevalence. Given other recent data and uncertainties about the mechanism of cataract formation, the International Commission on Radiological Protection²³ has formed a new task force to evaluate the radiosensitivity of the lens of the eye.

Interventional radiology can produce relatively high exposure to the unprotected eye from scatter radiation.^{10,26} Embolization of cerebral aneurysms and arteriovenous malformations are considered high-dose radiation procedures, whereas angioplasty is classified as medium dose.²⁷ Estimates for the radiologist performing neuroembolization procedures are in the range from 1.4- to 5.6-mSv lens dose per procedure, if no movable shield or leaded glasses are worn, assuming a distance of 1 m from the patient.¹⁰ Few studies have looked specifically at the radiation exposure of anesthesia personnel during radiologic procedures. Most studies²⁻⁴ have used badge technology to record cumulative doses over intervals of one to several months. One study⁴ that targeted ocular damage found some anesthesia personnel involved

with cardiac catheterization accumulating the equivalent of 1.3–1.8 mSv per month. Based on the current radiation physics literature, this type of exposure could pose a risk for the development of cataracts.

For the anesthesiologist, the two most important factors in reducing radiation exposure are distance and shielding. Radiation intensity from a point source is inversely proportional to the square of the distance from the source.²⁸ The patient is the source of scatter radiation; thus, the anesthesiologist can greatly reduce his or her exposure by maximizing his or her distance from the patient. Unfortunately, the positioning of the radiologist on the patient's right, with the anesthesiologist along the left and on the side of the lateral x-ray beam's scatter, is commonly seen, although other arrangements undoubtedly exist.²⁹ This configuration is frequently dictated by ergonomic factors involving radiologists and their access to the patient's groin, the large footprint of the radiology equipment, the no-man's land created near the patient's head for the movements of the fluoroscopy C-arms, and the need for simultaneous access to the patient by two clinical services. Anesthesiologists can and should maximize their distance from the patient, but there are practical limits and this maneuver increases the dead space on intravenous tubing and forces the anesthesia machine and ventilator even farther from the patient's airway.

Appropriate radiation shielding is crucial. Standard lead aprons or transparent leaded acrylic shields, both with 0.5-mm lead-equivalent protection, reduce fluoroscopy levels of radiation by more than 98% each; combining the two devices multiplies the beneficial effect.³⁰ Prescription glasses made of optical glass offer modest protection (30–40% reduction), whereas lightweight plastic prescription glasses offer little protection (5% reduction).³¹ Lightweight leaded glasses worn by radiologists generally provide 0.5- or 0.75-mm lead-equivalent protection (98% or greater radiation reduction). Personnel in fluoroscopy suites should always wear their required radiation badges, but they need to be aware that badge dosimetry worn under lead aprons does not reflect eye exposure. Practitioners who are diligent about wearing lead aprons, but then peek around lead shields to examine a patient's airway or to inject medications, need to realize that they are leaving their eyes unprotected. Anesthesiologists interested in measuring their ocular exposure might contact their radiation safety office for a radiation badge to be worn near eye level on their surgical cap.

Predicting the side effects of work-related radiation exposure is complex and inexact. By using our results as a rough guideline, if the scattered radiation exposure to the eye of the anesthesiologist is three times that for the radiologist, anesthesiologists who find themselves spending significant time in fluoroscopy suites should wear leaded glasses. This would bring their radiation safety practice to the standard that has been adopted by many interventional radiologists. Portable transparent shields do afford some protection, but leaded glasses allow for the necessary movement of the anesthesiologist in caring for the patient.

Other anesthesiologists who choose to reduce their radiation exposure to as low as reasonably achievable will also adopt leaded glasses as a safety measure.

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