Does the endovascular repair of aortoiliac aneurysms pose a radiation safety hazard to vascular surgeons?

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Objectives: **Endovascular aortoiliac aneurysm (EAIA) repair uses substantial fluoroscopic guidance that requires considerable radiation exposure. Doses were determined for a team of three vascular surgeons performing 47 consecutive EAIA repairs over a 1-year period to determine whether this exposure constitutes a radiation hazard.**

Methods: **Twenty-nine surgeon-made aortounifemoral devices and 18 bifurcated devices were used. Three surgeons wore dosimeters (1) on the waist, under a lead apron; (2) on the waist, outside a lead apron; (3) on the collar; and (4) on the left ring finger. Dosimeters were also placed around the operating table and room to evaluate the patient, other personnel, and ambient doses. Exposures were compared with standards of the International Commission on Radiological Protection (ICRP).**

Results: **Total fluoroscopy time was 30.9 hours (1852 minutes; mean, 39.4 minutes per case). Yearly total effective body doses for all surgeons (under lead) were below the 20 mSv/y occupational exposure limit of the ICRP. Outside lead doses for two surgeons approximated recommended limits. Lead aprons attenuated 85% to 91% of the dose. Ring doses and calculated eye doses were within the ICRP exposure limits. Patient skin doses averaged 360 mSv per case (range, 120-860 mSv). The ambient (> 3 m from the source) operating room dose was 1.06 mSv/y.**

Conclusions: **Although the total effective body doses under lead fell within established ICRP occupational exposure limits, they are not negligible. Because radiation exposure is cumulative and endovascular procedures are becoming more common, individuals performing these procedures must carefully monitor their exposure. Our results indicate that a team of surgeons can perform 386 hours of fluoroscopy per year or 587 EAIA repairs per year and remain within occupational exposure limits. Individuals who perform these procedures should actively monitor their effective doses and educate personnel in methods for reducing exposure. (J Vasc Surg 2000;32:704-10.)**

Endovascular aortoiliac aneurysm (EAIA) repair has recently become a procedure approved by the Food and Drug Administration. Endovascular treatments for other vascular processes are also being more widely used. It has been estimated that up to 80% of all abdominal aortic aneurysms can be treated with an endovascular graft, and that in the near future, 40% to 70% of all vascular interventions will be performed with an endovascular method.[1] These procedures require the use of digital cinefluoroscopy, which exposes both the patient and staff to ionizing radiation.

Comprehensive training in radiation safety and radiation physics is not a part of general or vascular surgical residency training programs. Additionally, radiation safety issues are significantly underrepresented in the vascular surgery literature compared with that of other specialties. To determine whether the endovascular repair of aortoiliac aneurysms con-

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Competition of interest: FJV and TO are consultants for the OEC Corporation.

Presented at the Twenty-eighth Annual Symposium on Vascular Surgery, Society for Clinical Vascular Surgery, Rancho Mirage, Calif, Mar 15-19, 2000.

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0741-5214/2000/$12.00 + 0 **24/6/110053**
doi:10.1067/mva.2000.110053

stitutes a radiation hazard to the vascular surgeons performing them, we evaluated the exposure to three vascular surgeons over a 1-year period. Radiation exposure to the patients and operating room staff was also evaluated.

METHODS

Forty-seven endovascular repairs of aortic or iliac aneurysms that were performed over a 1-year period beginning in July 1998 were included in the study. Other fluoroscopic procedures such as diagnostic or completion angiography, iliac or renal artery angioplasty and stenting, fluoroscopically assisted thromboembolectomy, and inferior vena cava filter placement were not included. A surgeon-made aortounifemoral device, Montefiore Endovascular Graft System, was used in 29 cases. Bifurcated devices, including Talent (World Medical Manufacturing Corp, Sunrise, Fla), Excluder (W. L. Gore, Flagstaff, Ariz), and Vanguard (Boston Scientific Corp, Natick, Mass), were used in 18 cases. Fluoroscopy was performed with a Philips BV212 (Philips, Medical Systems, Shelton, Conn) in 18 cases, an OEC 9800 (OEC Medical Systems, Salt Lake City, Utah) in two cases, and a Philips BV312 in 28 cases. Image intensifier sizes were 31, 23, and 17 cm for the Philips and 31, 23, and 15 cm for the OEC. Digital subtraction and high-level fluoroscopic aquisitions were performed with manual contrast injections.

Each of the three surgeons participating in the procedures wore three radiation dosimeters (Landauer, Inc, Glenwood, Ill); they were worn (1) on the waist under the lead apron, (2) on the waist outside the lead apron, and (3) on the collar outside the thyroid shield. A ring dosimeter was worn on the ring finger of the left hand by each surgeon. Additional badges were placed on the operating table at the patients' right shoulder (20-30 cm from source), at the foot of the operating table (120-140 cm from source), and in the corner of the operating room (> 3 m from source). These badges were used to estimate the exposure to the patient, scrub nurse, and circulating nurse. The minimum detectable radiation dose for these badges is 10 mrem, which is equal to 0.1 mSv. In cases where the badges read "minimal" (ie < 10 mrem), a value of 5 mrem or 0.05 mSv was arbitrarily assigned. Patient entrance doses were calculated with the fluoroscopic energies and positions recorded during each case. Badge readings were performed independently (Landauer, Inc) on a monthly basis and forwarded to the Department of Nuclear Medicine. Total effective doses (TEDs) were calculated according to the formula TED = (y dose [under lead] × 1.5) + (y dose [collar] × 0.04). They were then compared with standards established by the International Commission on Radiological Protection (ICRP).[2] Deep dose readings were used rather than shallow dose readings because these are thought to more closely approximate risk.

RESULTS

Total fluoroscopy time for the 47 EAIA repairs was 30.9 hours (1852 minutes; mean, 39.4 minutes per case). The time spent using high-level fluoroscopy varied between 5% and 37%, although in one case it was as high as 60%. The milliampere ranged from 2.1 to 4.7 and the kilovolt from 65 to 105.

Yearly TEDs for the surgeons (under lead) were 1.52 mSv, 1.64 mSv, and 0.92 mSv (Table). All were below the 20 mSv/y ICRP occupational exposure limit, and one was below the 1 mSv/y civilian limit. Outside lead doses for all surgeons exceeded civilian limits and in two cases approximated the recommended occupational limits. Lead aprons attenuated 85% to 91% of the dose.

Ring doses were 18.69 mSv/y, 16.00 mSv/y, and 5.44 mSv/y (Table). Calculated eye doses were 7.77 mSv/y, 5.67 mSv/y, and 2.04 mSv/y. These were within ICRP occupational exposure limits.

Patient entrance doses averaged 360 mSv per case (range, 120-860 mSv). Yearly doses measured at the patient's right shoulder were 40 mSv. The yearly dose measured at the foot of the operating table was 2.59 mSv. The ambient (> 3 m from the source) operating room dose was 1.06 mSv/y.

DISCUSSION

Radiation effects. The biologic effects of radiation can be divided into two types, deterministic and stochastic.[2] Deterministic effects are observed only when many cells in an organ or tissue are killed by virtue of a dose above a given threshold. Stochastic effects are due to radiation-induced injury to the DNA of a single cell and have no threshold. However, the probability of an effect is small. Stochastic effects may be either somatic or hereditary. It is these stochastic effects that are of concern because there is no low threshold.

There are many sources of background radiation within the environment, both naturally occurring and man-made. Radon gas constitutes the single most important source of naturally occurring external background radiation, followed closely by solar, cosmic, and galactic radiation. Natural atmospheric radiation, radionuclides, terrestrial nuclides, nuclear

Yearly exposure in TED for each of the three surgeons

Surgeon	*TED under lead (mSv/y)*	*TED outside lead (mSv/y)*	*Eye (mSv/y)*	*Hand (mSv/y)*
Primary	1.52 (8%)	13.77 (69%)	7.77 (5%)	18.69 (4%)
First assistant	1.64 (8%)	12.57 (63%)	5.67 (4%)	16.00 (3%)
Second assistant	0.92 (5%)	5.23 (26%)	2.04 (1%)	5.44 (1%)

Percentages are ICRP occupational dose limit.

reactors, and the testing of nuclear weapons all contribute to background radiation.

Radiation exposure is cumulative, and effects are permanent. The total exposure for an individual performing fluoroscopic procedures is the sum of the individual's exposure during these procedures plus background exposure and any incidental medical exposure (eg, diagnostic chest radiograph) that are incurred. In the United States, the average person receives approximately 3.5 mSv per year in background exposure. This dose increases with altitude and other local factors, such as radionuclides, in the soil.

There are several different measures of radiation exposure. *Absorbed dose* is the energy delivered to an organ divided by the mass of the organ, in grays. *Equivalent dose* is the average absorbed dose in an organ or tissue multiplied by a radiation weighting factor, in sieverts. Because, in general, radiation used in medicine has a weighting factor of one, the absorbed dose and the equivalent dose are considered equal. The TED is the sum of the equivalent doses to all tissues and organs multiplied by a tissue-weighting factor for each organ or tissue.[2]

Endovascular procedures. The long fluoroscopy times observed in this study reflect both the complexity of cases seen at our institution and the presence of a training program. In a study of radiation exposure during cardiology fellowship training, Watson et al[3] found a statistically significant increase in exposure for cases done in the first versus the second year of fellowship. This difference was largely accounted for by an increased time for the less experienced operators to position the catheters. The needs of training must therefore be balanced against the increased fluoroscopy times for patients and staff alike.

Methods to reduce exposure. Radiation exposure is proportional to total fluoroscopy time. Therefore, the most effective way to reduce exposure to both the patient and staff is to reduce the total fluoroscopy time. Several steps can be taken toward this end. Catheter-guidewire exchanges with a stable wire position do not need to be visualized in their entirety. When the field of interest is repositioned by moving either the table or the C-arm, the desired position should be estimated and then fine-tuned under fluoroscopy, rather than imaged along the entire course. This is also true when obtaining oblique or angled projections. When cine-acquisition is performed, each screening should be carefully planned and have a specific objective. Poorly planned runs add no information to the procedure and increase exposure, contrast load, and operative time. The most important factor is to be conscious of when the fluoroscope is on and whether necessary information is being gathered. Simply measuring the fluoroscopic time may be enough to increase awareness and reduce overall time. Hough et al[4] found that the use of audible radiation monitors, which were dose sensitive, led to a significant reduction in exposure to the staff who wore them.

The next most effective way to reduce exposure is to increase the distance from the source. The exposure of the operator is largely due to scattered radiation that results from dispersion of the beam from its intended path by the subject. Scatter decreases with the square of the distance from the source, which is known as the *inverse square law*. There is a substantial drop in scattered radiation once one moves to between 30 and 50 cm from the scatter source.[5,6] For most endovascular interventions, the working distance from the source is largely fixed by the distance between the area of interest and the arterial access site. The radiation dose to the operator during cardiac interventions has been shown to increase by 1.5 to 2.6 times when the operator moves from the femoral to the subclavian position.[7] Kuwayama et al[8] found that radiation to the operator was increased by approximately two to three times and hand exposure increased 10-fold when a transcarotid versus a transfemoral route was used for neuroradiologic procedures. EAIA repair requires prolonged imaging over the abdomen and pelvis. Penetration of these tissues requires more energy and results in a significantly higher exposure than imaging the periphery.[9]

The beam source should be positioned under the patient (ie, posteroanterior imaging). This will

decrease scatter and hand exposure of the operator. Placing the beam in the anteroposterior position (source anterior to patient, image intensifier posterior to patient, patient supine) results in an exposure approximately four times greater to the operator's head, neck, and upper extremities.[5] Additionally, these areas are far more difficult to shield than the area below the waist. Obtaining oblique views will also have an impact on the scattered radiation dose. The right anterior oblique view will result in significantly more scatter to an operator standing on the patient's left than the left anterior oblique view.[10]

The image intensifier should be positioned as close as possible to the patient. This reduces scatter by allowing for a lower entrance exposure and also results in a sharper image. Pulse mode fluoroscopy at rates of 15 to 30 frames per second or lower greatly reduces exposure, compared with continuous mode.

A larger image intensifier mode requires less radiation than a smaller one. The radiation dose approximately doubles with each successively smaller image intensifier setting.[11] Large image intensifier sizes should be used whenever possible. The excessive use of high level or cineacquisition mode should be avoided.

The amount of radiation produced by the fluoroscope depends on the energy used to generate the beam as determined by the milliamperes and kilovolts. The milliampere setting controls the number of photons produced.[11] Low milliamperes produce a mottled image that can be eliminated by increasing the milliamperes at the cost of higher radiation. The kilovolt control determines the penetration of the beam and image contrast. For most fluoroscopic units the milliampere and kilovolt settings are determined by an automatic brightness control, which sets the values using feedback from the image obtained. However, where these are not set, the use of higher kilovolt and lower milliampere techniques will reduce exposure while not greatly affecting image quality. Increasing the fluoroscopy voltage from 75 to 96 kV can decrease the entrance dose by 50%.[12]

A heavier patient will require greater radiation energy to penetrate the tissues with a consequent increase in radiation exposure to the patient and staff. We found increased doses in heavier patients, although the amount is difficult to quantify because of variability in the amount of high-level fluoroscopy used in each case.

Although collimation of fluoroscopic units is regulated by federal law, the ratio of the field of view to the total exposed area is not 1:1. Granger et al[13] evaluated 18 fluoroscopic units from different manufacturers and of different ages and found that only 67% of the units met federal compliance standards. The measured difference between the total exposed area and the field of view ranged from 22% to 48% for units not in compliance and from 5% to 32% for units in compliance. This excess-exposed area increases the radiation dose and reduces image contrast and quality. After the units were serviced, a 40% average reduction in beam area was achieved, and 100% of the units met compliance standards. All fluoroscopes should undergo at least biannual inspection and calibration as required by law.

Although automatic collimation is part of all current systems, reducing the field size by means of manual collimation will greatly decrease exposure and has the added benefit of enhancing image quality by reducing stray radiation. Lindsay et al[7] found that by collimating the field of image during radiofrequency catheter-ablation procedures, the radiation dose to the patient and staff was reduced by 40%.

Antiscatter grids mounted in front of the input screen decrease the amount of scatter reaching the image intensifier and improve image quality. They also greatly increase both the required radiation to obtain a satisfactory image and the backscatter to the patient and staff.[14] Removal of these grids can reduce the radiation dose by a factor of 2 to 4, but with some loss of resolution. For pediatric procedures the grids can and should be removed without loss of image quality.[14]

Protective barriers should be readily available and used liberally. The most important of these is the lead apron. These are generally available in 0.5- and 0.25-mm thicknesses. In optimal circumstances, the 0.5-mm thickness will attenuate 98% to 99.5% of the radiation dose, whereas the 0.25-mm thickness attenuates approximately 96% of the dose.[11,15] Deterioration of the apron's lead lining occurs with use and is increased by rough handling or improper storage. Aprons should undergo periodic screening and replacement if inadequate protection is found. The protection afforded by the lead aprons in this study was less than expected and may have been due to fatigue. Alternatively, many of the aprons used were not wraparound and do not provide circumferential protection. Scattered radiation from the sides can thereby expose the underlead badge. A thyroid collar and "protective" glasses are essential. Protective eyewear is highly variable in the amount of protection afforded and allows anywhere from 3% to 98% transmission of the radioactive beam.[16] The greatest protection is obtained with glasses contain-

ing lead. Some glasses may provide UV, but not ionizing radiation protection. A significant amount of the ocular exposure, up to 21%, is the result of scatter from the operator's head, which suggests that side shields or wraparound configurations are necessary to provide adequate protection.[16] A lead acrylic shield, which can be either mounted on a ceiling or put on a mobile floor stand, can be placed between the operator and patient and has been shown to reduce eye radiation by a factor of 20 to 35.[7,10] Lead-lined gloves also help to reduce exposure, but can be cumbersome. Because backscattered radiation is more intense than forward-scattered radiation[17] and because with the C-arm in the posteroanterior orientation the greatest exposure due to scatter occurs from under the table, we place a lead drape suspended from the operating table on the operator's side.[5]

The use of radiation badges by all persons working with fluoroscopy is mandatory and required by law. The position of the badges is important. A badge must be worn at waist level under the lead apron. Additional badges should also be worn on the collar to monitor the head dose and to aid in calculating the TED because there is a large and variable difference between the overlead and underlead doses.[18] Ring badges are also advisable. Waist and collar badges should be worn on the operator's left side when working on the patient's right side and on the operator's right side when working on the patient's left side (ie, the badge should face the source directly). Ring badges should be worn on the hand most likely to be exposed. We monitored the left hand because it is frequently used to stabilize sheaths and is therefore close to the beam. A self-retaining device to stabilize the sheaths may also reduce exposure. The monitoring of all body positions at risk is essential because dominant hand finger doses were shown not to correlate with doses estimated by shoulder badges in interventionalists performing percutaneous drainage procedures.[19] Although it is mandated, it is the responsibility of the individual to wear monitoring badges and of the institution to have a program with feedback to the exposed individuals in place.

In one large prospective study of interventional radiologists Marx et al[18] found that the only variable correlating with overlead collar dose was the number of procedures performed per year, and the only variable correlating with waist underlead dose was the thickness of the lead apron (0.5 mm vs 1 mm). This study also included a questionnaire in which nearly one half of the respondents reported rarely or never wearing their radiation badges. One half of the respondents either had exceeded or did not know whether they had exceeded monthly or quarterly occupational dose limits at some time within the past year. Regarding protection, 30% rarely or never wore a thyroid shield, 73% rarely or never wore lead glasses, 70% rarely or never used a ceiling-mounted lead shield, and 83% rarely or never wore leaded gloves. These results indicate that there can be significant complacency even among the population of physicians who are at the most risk and who have substantial training in radiation safety and physics.

In general, the patient is exposed only once. Most of our patients are in an older age range and are therefore less likely to have malignancies. However, because of the long screening times, patients should be evaluated for transient skin erythema, which may present up to several weeks after the procedure, and other skin conditions.

Several available devices can help reduce total exposure. A floating table simplifies positional changes and reduces the need for fluoroscopic adjustments. A power injector ensures that an adequate volume of contrast is delivered that maximizes image quality and reduces the need for multiple screening runs. This is especially important when imaging the thoracic or abdominal aorta and its branches. Most important, a power injector allows operators to increase their distance from the source. The same effect can be achieved by adding extension tubing to the catheter injection port during manual injection technique. The tabletop should be maximally radiolucent, and the equipment (stent grafts, guidewires, catheters) should be well marked with radiopaque indicators that are easily visualized.

Noninvasive vascular imaging techniques such as duplex Doppler scan and intravascular ultrasound scan do not provide the same anatomic detail as angiography and currently have a limited role in the performance of endovascular procedures. Marking appropriate landmarks on the screen with an erasable pen allows one to work under regular fluoroscopy rather than "road mapping," which may increase exposure.

Summary of results and conclusions. Although the exposures measured in our study fall within the ICRP limits established for occupational exposure, they are nonetheless significant, and exposure is cumulative. Factors that increase exposure include increased fluoroscopy time required for the aortounifemoral grafts and the proximity of the surgeon to the operative field of the abdomen and pelvis.

Our results indicate that a team of surgeons can perform 386 hours of fluoroscopy per year or 587 EAIA repairs per year and remain within occupa-

tional exposure limits. This does not include other endovascular procedures, the performance of which would lower these figures.

The maximum allowable occupational and civilian radiation exposure doses have been lowered with time. It is likely that with increasing knowledge about the effects of radiation, this trend will continue. We recommend keeping exposure to within, at most, 10% to 20% of established occupational limits. Those performing these procedures should actively monitor their effective doses and educate personnel on methods for reducing exposure.

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Submitted Mar 9, 2000; accepted Jun 28, 2000.

DISCUSSION

Dr Samuel S. Ahn (Los Angeles, Calif). Thank you for the floor. I think Dr Lipsitz and his colleagues at Montefiore deserve many congratulations for bringing this important topic of radiation safety to our attention, and I think the Society program committee also deserves praise for allowing this paper to be presented on the main program. I wish it had been presented in front of a larger audience actually. Without question, this topic is important to the surgeon, to staff, and the patient. Yet this topic receives very little attention in the literature, at our meetings, in our training, and, I suspect, in our daily practice. Although this study described here is quite simple, they just basically measured the dosimetry on the three surgeons, and although there is not a whole lot of science behind this, I believe this paper nevertheless is very important. It certainly shows that the annual radiation dose to each of the three surgeons fell within the recommended exposure limits and therefore, we can go ahead and do these procedures relatively safely. However, it was interesting to note that the calculated radiation exposure to the eyes and to the areas external to the lead shields were not that insignificant. I did some calculations and your average millisievert radiation dose to the eye was 5 per year, and you have to remember that we're going to be practicing for approximately 20 to 30 years so if you multiply that then you get over 100 to 120 over your career plus you have the ambient daily exposure from the environment, the sun, the cosmic rays, etc, which is another 3 to 5 per year so that during your career lifetime, you can easily get over 200 mSv and that is certainly enough to cause cataracts and other eye disorders. Remember that the radiation effects are cumulative and they are permanent as Dr Lipsitz pointed out. So I would urge all of you to take great caution. Read the manuscript. It is very well written. It gives some very good pearls on what to do to try to minimize your radiation exposure.

I really only have one question to the authors. I noted that one of your surgeons had much less radiation exposure than the other two. What did he do differently because I want to know?

Dr Evan C. Lipsitz. The surgeon with the least exposure tended to be the fellow who did less of the procedure. We generally have two attendings involved in all of these cases and a fellow. If you're going to be doing these procedures with two surgeons, I don't think you can necessarily add the doses of the three surgeons here, but the dose of two surgeons performing these procedures would certainly be higher than the doses of the two out of the three surgeons that we presented. Thank you for your comments Dr Ahn.