Ionizing radiation absorption of vascular surgeons during endovascular procedures

Pei Ho, MBBS, FRCS(Edin),[a] Stephen W. K. Cheng, MS, FRCS(Edin), FACS,[a] P. M. Wu, MSc, MSocS, PhD,[b] Albert C. W. Ting, MS, FRCS(Edin),[a] Jensen T. C. Poon, MBBS, FRCS(Edin),[a] Clement K. M. Cheng, MSc, MInstP, CPhys, CSci,[c] Joseph H. M. Mok, BSc(Hons),[c] and **M. S. Tsang, BSc(Hons), Mphil,[c]** *Hong Kong, China*

Objective: **Endovascular procedures have become an integral part of a vascular surgeon's practice. The exposure of surgeons to ionizing radiation and other safety issues have not been well studied. We investigated the radiation exposure of a team of vascular surgeons in an active endovascular unit and compared yearly dosages absorbed by various body parts among different surgeons. Patients' radiation exposure was also assessed.**

Methods: **The radiation absorption of a team of vascular surgeons was prospectively monitored in a 12-month period. During each endovascular procedure, the effective body, eye, and hand radiation doses of all participating surgeons were measured by mini-thermoluminescent dosimeters (TLD) attached at the chest level under a lead apron, at the forehead at eye level, and at the hand. The type of procedure, fluoroscopy machine, fluoroscopy time, and personal and operating theatre radiation protection devices used in each procedure were also recorded. One TLD was attached to the patient's body near the operative site to measure the patient's dose. The yearly effective body, eye, and hand dose were compared with the safety limits of radiation for occupational exposure recommended by the International Commission on Radiation Protection (ICRP). The radiation absorption of various body parts per minute of fluoroscopy was compared among different surgeons.**

Results: **A total of 149 consecutive endovascular procedures were performed, including 30 endovascular aortic repairs (EVAR), 58 arteriograms with and without embolization (AGM), and 61 percutaneous transluminal angioplasty and stent (PTA/S) procedures. The cumulative fluoroscopy time was 1132 minutes. The median yearly effective body, eye, and hand dose for the surgeons were 0.20 mSv (range, 0.13 to 0.27 mSv), 0.19 mSv (range, 0.10 to 0.33 mSv) and 0.99 mSv (0.29 to 1.84 mSv) respectively, which were well below the safety limits of the ICRP. The mean body, eye, and hand dose of the chief surgeon per procedure were highest for EVAR. A significant discrepancy was observed for the average hand dose per minute of fluoroscopy among different surgeons. The mean radiation absorption of patients who underwent EVAR, AGM, and PTA/S was 12.7 mSv, 13.6 mSv, and 3.4 mSv, respectively.**

Conclusion: **With current radiation protection practice, the radiation absorbed by vascular surgeons with a high endovascular workload did not exceed the safety limits recommended by ICRP. Variations in practice, however, can result in significant discrepancy of radiation absorption between surgeons. (J Vasc Surg 2007;46:455-9.)**

The development of endovascular intervention has been a major advancement in vascular surgery in the last two decades.[1-3] Fluoroscopy is essential to provide image guidance for endovascular procedures. Vascular surgeons performing significant numbers of endovascular procedures, as well as their patients, are at risk of exposure to potentially hazardous ionizing radiation, but radiation safety data have seldom been documented quantitatively. This study aims to determine the cumulative amount of radiation absorbed by surgeons performing various types of endovascular procedures and the differential absorption by body regions. The patients' exposure to ionizing radiation during these procedures was also investigated.

From the Division of Vascular Surgery, Department of Surgery,[a] and Department of Clinical Oncology,[b] Queen Mary Hospital; and Radiation Health Unit, Department of Health.[c]

This study was funded by a research grant from The Occupational Safety and Health Council.

Competition of interest: none.

Reprint requests: Prof Stephen W. K. Cheng, Division of Vascular Surgery, Department of Surgery, University of Hong Kong Medical Centre, Queen Mary Hospital, K14S, 102 Pokfulam Rd, Hong Kong SAR, China (e-mail: wkcheng@hku.hk).

0741-5214/$32.00

doi:10.1016/j.jvs.2007.04.034

METHODS

We prospectively record the radiation absorption of all surgeons and patients during all fluoroscopy-guided endovascular procedures in a tertiary vascular surgery unit during a 12-month period from July 2004 to June 2005. The surgical staff consisted of four specialist vascular surgeons (VS 1-4) and one rotating trainee (TR) of a 6-month term.

Fluoroscopy equipment and radiation protection. All endovascular procedures were performed in the operating room under mobile fluoroscopy guidance, using the OEC 9800 (GE Medical Systems, Salt Lake City, Utah) or BV 29 (Philips, Best, the Netherlands) image intensifier systems on a carbon-fiber interventional operating table (US Imaging Tables, New York, NY) equipped with side lead shields (model 311/DS-004, Kenex, Haelow, Essex, UK). Additional mobile lead shields (model 326/05, Kenex) were routinely used above the table for added protection.

The usual fluoroscopic frame rates used were 8 to 12 frames per second with digital subtraction angiography, where appropriate. Both pulsed and nonpulsed radiation beams were used during screening and acquisition runs according to the image quality requirement in different circumstances. High-level fluoroscopy was not used. Collimation was applied whenever possible, and its application was decided by the chief surgeon performing the procedure. Personal radiation protection devices included 0.3-mm and 0.5-mm lead aprons, a lead thyroid shield, and lead eyeglasses.

Role of surgeons. The chief surgeon is responsible for decision-making as well as manipulating guidewires and catheters, contrast injection (if hand injection is used), and delivery of stents or stent grafts. The first and second assistants (or the supervisor) stand on the side of the chief surgeon and are responsible for preparation of catheters or devices, stabilizing the guidewires, and exchange of catheters or devices. The chief surgeon occupies a position closest to the fluoroscopy field compared with the assistants.

Radiation absorption measurement. The radiation absorption of vascular surgeons was measured by the dose equivalent of the absorbed radiation, which is calculated as absorbed dose times the quality factor of the radiation beam. The special unit is rem. The sievert (Sv) is the International System of Units of dose equivalent (1 rem = 0.01 Sv).

Multiple radiation sensitive mini-thermoluminescent dosimeters (TLDs) were worn by the chief and assistant surgeons during all endovascular procedures. The dosimeter used was the LiF:Mg,Ti Bicron/Harshaw TLD-100 chips (Harshaw/Bicron, Solon, Ohio). All the TLDs were calibrated in the laboratory of the Radiation Health Unit, Department of Health, with a minimal detectable level of 10 μSv. Standard badge TLDs were attached to the chest level beneath the lead apron for measurement of the effective body dose under lead. A TLD model EXT-RAD was applied to the forehead or within lead eyeglasses to measure the effective dose to the eyes. A third ring-type TLD (DXT-RAD) was worn on the left index finger to measure the hand dose. One EXT-RAD TLD was attached to the main exposure area of each patient for measurement of their surface entrance dose.

All the TLDs were processed by automated TLD readers Harshaw 6600E or 6600CCD. The type of procedure, fluoroscopy machine, total fluoroscopy time, types of personal radiation protection device applied, and the use of extra radiation shield were recorded.

Data analysis. The cumulative effective dose of all the surgeons was compared with the safety dose limit recommended by the International Commission on Radiation Protection (ICRP; Table I) for occupational and public exposure with respect to different body areas.[4] The mean radiation absorption per procedure and the mean patient dose for different types of endovascular procedures was determined. The radiation absorption per minute of fluoroscopy time of various body areas was compared among the different surgeons when they were chief operator to determine the relationship between practice and exposure.

Table I. The safety dose limits for occupational and public exposure with respect to different body areas recommended by the International Commission on Radiation Protection ICRP

Tissue or organ	*Dose limit for occupational worker*	*Time period*
Whole body	20 mSv/year*	Averaged over 5 years
Lens of the eye	150 mSv/year	In any calendar year
Extremities outside lead apron	500 mSv/year	In any calendar year

*Maximal 50 mSv in any one single year.

RESULTS

A total of 149 endovascular procedures were performed in the studied period. These included 30 endovascular aortic aneurysm repairs (EVARs), 58 angiographic examinations with or without embolization (AGM), and 61 percutaneous artery angioplasty and stenting (PTA/S) procedures. The operation time, fluoroscopy time, fluoroscopy machine, and the application of radiation protection devices for different types of endovascular procedures are summarized in Table II.

The median yearly effective body dose (under lead apron) of the surgeons was 0.20 mSv (range, 0.13 to 0.27 mSv). The median yearly effective doses were 0.19 mSv (range, 0.10 to 0.33 mSv) for the eyes and 0.99 mSv (range, 0.29 to 1.84 mSv) for the hands (Table III). All surgeons' annual body, eye, and hand effective doses were well below the limit of occupational and public radiation exposure recommended by the ICRP. The median yearly effective body dose of the surgeons measured was only 1% of the recommended limit. The respective mean body, eye, and hand doses of the chief surgeon were 7.7 μSv, 9.7 μSv, and 34.3 μSv per EVAR, 2.9 μSv, 2.4 μSv, and 11.4 μSv for AGM, and 3.1 μSv, 2.0 μSv, and 20.8 μSv for PTA/S. Vascular surgeons performing EVAR had the highest radiation exposure to the body, eye, and hand. The average radiation absorption of the patients who underwent EVAR, AGM, and PTA/S were 12.7 mSv, 13.6 mSv, and 3.4 mSv, respectively.

The average dose absorbed by the body and eye per minute of fluoroscopy time of the four vascular surgeons as chief operator in EVAR, AGM, and PTA/S were similar (Tables IV, V, and VI); however, there was a greater discrepancy on the average hand-absorbed dose among the surgeons. When surgeon 1 was the chief operator, the average hand dose per minute of fluoroscopy for PTA/S was 2.5 μSv/min, whereas it was 8.43 mSv/min for surgeon 3. The similar discrepancy was observed between surgeon 1 and 3 on the average hand-absorbed dose during EVAR and AGM.

DISCUSSION

The number and variety of fluoroscopy-guided endovascular procedures are ever increasing in many specialized vascular surgery centers.[5] Radiation exposure of surgeons,

Table II. Operative details and protective devices applied in different types of endovascular procedures

	EVAR (n = 30)	*AMG (n = 58)*	*PTA/S (n = 61)*
Operating table	96.7% US Imaging*	94.4% US Imaging*	91.1% US Imaging*
	3.3% conventional	5.6% conventional	8.9% conventional
Fluoroscopy machine	96.7% OEC 9800†	98.1% OEC 9800†	91.7% OEC 9800†
	3.3% BV 29‡	1.9% BV 29‡	8.3% BV 29‡
Mobile lead shield	100%	98.1%	95.0%
Mean operation time (min)	234 ± 8	78 ± 63	98 ± 44
Mean fluoroscopy time (min)	13.0 ± 7.5	6.0 ± 4.6	6.3 ± 3.9
Cumulative fluoroscopy time (min)	390	356	386

EVAR, Endovascular aneurysm repair; *AMG,* arteriogram with or with embolization; *PTA/S,* percutaneous angioplasty with stenting.
*US Imaging Tables, New York, NY.
†GE Medical Systems, Salt Lake City, Utah.
‡Philips, Best, the Netherlands.

Table III. Summary of the application of personal radiation protective devices and the annual body, eye and hand effective dose of all vascular surgeons

	VS 1	*VS 2*	*VS 3*	*VS 4*	*TR*
No. of operations	71	78	70	66	76
Lead apron (%)					
0.3 mm					1.3
0.5 mm	100	100	100	100	98.7
Thyroid shield (%)	100	100	98.6	100	97.4
Lead eyeglasses (%)	100	9.0	0	10.6	0
Role in operations (%)					
Chief	64.8	30.8	41.4	37.9	32.9
Supervisor	32.4	44.9	14.3		
First assistant	2.8	23.1	38.6	40.9	32.9
Second assistant		1.2	5.7	21.2	34.2
Cumulative fluoroscopy time (min)	684	620	544	528	598
Cumulative body absorbed dose (mSv)	0.20	0.27	0.27	0.13	0.14
Cumulative eye absorbed dose (mSv)	0.19	0.33	0.20	0.10	0.10
Cumulative hand absorbed dose (mSv)	1.18	0.99	1.84	0.72	0.29

VS, Vascular surgeons; *TR,* trainee.

Table IV. The average radiation absorbed dose per minute fluoroscopy for individual surgeon performing as chief operator during endovascular aneurysm repair

EVAR	*VS 1*	*VS 2*	*VS 3*	*VS 4*
Total fluoroscopy time	235	116	50	NA
Average dose absorbed (μSv/min)*				
Body	0.21	1.55	0	NA
Eye	0.64	0.76	1.00	NA
Hand	1.96†	2.50	5.60†	NA

EVAR, Endovascular aneurysm repair; *VS,* Vascular surgeons; *NA,* not applicable.
*Dose per minute of fluoroscopy time.
†The greatest difference between various surgeons.

Table V. The average radiation dose absorbed per minute of fluoroscopy for individual surgeon performing arteriograms as chief operator

AGM	*VS 1*	*VS 2*	*VS 3*	*VS 4*
Total fluoroscopy time	154	37	54	58
Average dose absorbed (μSv/min)*				
Body	0.26	0	1.73	0.36
Eye	0.06	0.57	1.15	1.07
Hand	0.79†	3.14	5.00†	2.14

AGM, Arteriogram; *VS,* vascular surgeon.
*Dose per minute of fluoroscopy.
†The greatest difference between various surgeons.

especially in high-case-load centers, has not been well studied. The finding of this study assured us that with proper radiation protection, the yearly effective body, eye and hand doses of vascular surgeons are within the safety dose limit recommended by the ICRP.[4] Although the method of measurement of radiation exposure is not exactly the same, the annual effective dose of vascular surgeons is relatively low compared with cardiologists and interventional radiologists, who respectively received annual body doses of 1.9 to 37 mSv[6,7] and 0.37 to 10.1 mSv,[8,9] The median annual body effective dose of vascular surgeons in

Table VI. The average radiation dose absorbed per minute fluoroscopy for individual surgeon performing percutaneous angioplasty and stenting as chief operator

PTA/S	*VS 1*	*VS 2*	*VS 3*	*VS 4*
Total fluoroscopy time	49	35	71	82
Average dose absorbed (μSv/min)*				
Body	0.42	2.06	0.57	0.25
Eye	0	2.06	0.71	0
Hand	2.50†	5.59	8.43†	3.83

PTA/S, Percutaneous angioplasty and stenting; *VS,* vascular surgeon.
*Dose per minute of fluoroscopy.
†The greatest difference between various surgeons.

this study of 0.20 μSv will be approximately equivalent to the dose a frequent flyer absorbed with two to three round trip trans-Atlantic flights.

From these results, we can extrapolate that a vascular surgeon can use fluoroscopy for 113,200 minutes or 49.4 days per year before reaching the dose limit recommended by ICRP. Assuming similar fluoroscopy setting and radiation protection devices were applied and calculated from the mean body dose per procedure, a vascular surgeon would have to perform 2597 EVAR, 6897 AGM, or 6451 PTA/S before reaching the dose limit; therefore, vascular surgeons are unlikely to receive radiation exceeding the limit, even with an increased workload.

This study found the patients' average radiation dose was 3.4 to 13.6 mSv, which is comparable to that of percutaneous coronary angioplasty and stenting (range, 5.7 to 15.3 mSv)[10] and embolization of intracranial arteriovenous malformations (range, 6 to 43 mSv).[11] Aneurysm patients will require further surveillance computed tomography assessment at intervals after EVAR, however, and thus their cumulative radiation exposure will therefore increase.[12] Patients' radiation dose will be further increased with the development of more complicated fenestrated stent graft devices that will require longer fluoroscopy time for placement. Radiation exposure of this group of patients should be monitored to ensure their safety.

High-dose ionizing radiation (≥10 Sv) can cause death when given within a short period of time. At sublethal doses, it can induce deterministic (skin burn, marrow suppression, subfertility, cataract) and stochastic effects (hair loss, carcinogenesis, teratogenesis). These adverse effects of ionizing radiation were based on studies of high-dose exposure in the range of tens to hundreds of microsieverts.[13-15] In real life medical practice with protection devices, the radiation exposure is usually much lower. Whether low-dose radiation will give rise to these adverse effects is uncertain, but there is a concern that a stochastic event may occur after long-term exposure. Even knowing a surgeon's annual effective dose is within the limits recommended by the ICRP, one should still pursue additional means to further reduce the radiation dose exposure, if possible.

Fig. Photograph shows a mobile lead shield being applied to shield operating surgeons from scattered radiation from the fluoroscopy machine.

Lipsitz et al[16] reported three vascular surgeons performing EVAR during a 1-year interval (47 total procedures, 1852 minutes of cumulative fluoroscopy time) had an effective eye and hand dose of 2.04 to 7.77 mSv and 5.44 to 18.69 mSv, respectively. These dosages were higher than those recorded for the surgeons of the current study, who performed 30 EVAR, 58 AGM, and 61 PTA/S (yearly cumulative fluoroscopy time, 1132 minutes), even after adjusted for the longer fluoroscopy time. This might be related to the use of extra protective device, including a table-side lead shield and a mobile lead shield, which would reduce scattered radiation (Fig).

We observed a relatively large difference in the hand radiation absorption per minute of fluoroscopy (range, 2.50 to 8.43 μSv/min) among the four surgeons. This discrepancy was in evidence even for different types of endovascular procedure, and therefore is likely a reflection of their catheter and guidewire handling. It would be interesting in future study to perform practice analysis by recording the surgeon's hand position with photographs or video compared with the dose measurement. Surgeons who had a high hand dose per minute of fluoroscopy time could try to reduce excessive screening while maneuvering. Alternatively, radiation protection gloves could be used, which could effectively reduce half of the radiation.[17]

Vascular surgeon 1 applied lead eyeglasses in 100% of his endovascular procedures, and surgeons 2 and 4 used eye protection intermittently (9.0% and 10.6% of the time). Surgeon 3 did not use lead eyeglasses at all and had higher eye radiation absorption per minute of fluoroscopy than surgeon 1 in the three types of endovascular procedures. The averaged eye dose per minute fluoroscopy for all procedures of surgeons 1 to 4 was 0.34, 0.96, 0.93, and 0.44 μSv/min, respectively. Thus, we believe lead eyeglasses are beneficial to shield off radiation to the eye, but other factors, including positioning of the mobile lead shield, may contribute to reduce radiation exposure to surgeon's eye.

Vascular surgeons are exploring new image modalities for guidance of endovascular procedures, including ultrasound-guided peripheral artery angioplasty[18] and MRI-guided EVAR.[19] As these new image modalities become more popular, the absorption of ionizing radiation will be further reduced.

CONCLUSION

With the proper application of radiation protection devices, the annual effective body, eye, and hand dose of vascular surgeons who perform endovascular procedures does not exceed the safety limits recommended by the ICRP. There is a large variation in individual hand doses that is likely related to individual endovascular techniques. Patients who underwent endovascular procedures received radiation doses similar to other fluoroscopically guided procedures.

We thank Ms Wing M Tam and Ms Ada Ko of the operating theatre, Ms Grace Cheung, Dr Ka C. Ng, Dr Wai K. Yiu and Dr Tan T. Cheung for their help during the study.

AUTHOR CONTRIBUTIONS

Conception and design: PH, WK, PW, KM
Analysis and interpretation: PH, PW, AT, JP, MT
Data collection: PH, WK, PW, AT, JP, KM, JM, MT
Writing the article: PH
Critical revision of the article: PH, WK, PW, AT
Final approval of the article: WK
Statistical analysis: PH, JP, KM, JM
Obtained funding: PH, WK
Overall responsibility: PH, WK

REFERNECES

1. Bates MC, AbuRahma AF. An update on endovascular therapy of the lower extremeities. J Endovasc Ther 2004;11(suppl 2):II107-27.
2. Chuter TA, Parodi JC, Lawrence-Brown M. Management of abdominal aortic aneurysm: a decade of progress. J Endovasc Ther 2004;11(suppl 2): II82-95.
3. Mozes G, Sullivan TM, Torres-Russotto DR, Bower TC, Hoskin TL, Sampaio SM, et al. Carotid endarterectomy in SAPPHIRE-eligible high-risk patients: implications for selecting patients for carotid angioplasty and stenting. J Vasc Surg 2004;39:958-66.
4. International Commission on Radiological Protection, 1990. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann ICRP 1991;21:1-3.
5. Arko FR, Lee WA, Hill BB, Olcott C 4th, Harris EJ, Dalman RL, et al. Impact of endovascular repair on open aortic aneurysm surgical training. J Vasc Surg 2001;34:885-91.
6. Delichas M, Psarrakos K, Molyvda-Athanassopoulou E, Giannoglou G, Sioundas A, Hatziioannou K, et al. Radiation exposure to cardiologist performing interventional cardiology procedures. Eur J Radiol 2003; 48:268-73.
7. Chong NS, Yin WS, Chan P, Cheng MC, Ko HL, Jeng SC, et al. Evaluation of absorbed radiation dose to working staff during cardiac catheterization procedures. Zhonghua Yi Xue Za Zhi (Taipei) 2000;63: 816-21.
8. William JR. The interdependence of staff and patient doses in interventional radiology. Br J Radiol 1997;70:498-503.
9. Niklason LT, Marx MV, Chan HP. Interventional radiologists: occupational radiation doses and risks. Radiology 1993;187:729-33.
10. Stisova V. Effective dose to patient during cardiac interventional procedures (Prague workplaces). Radiat Prot Dosimetry 2004;111:271-4.
11. Berthelsen B, Cederblad A. Radiation doses to patients and personnel involved in embolization of intracerebral arteriovenous malformations. Acta Radiol 1991;32:492-7.
12. Aldrich JE, Bilawich AM, Mayo JR. Radiation doses to patients receiving computed tomography examinations in British Columbia. Can Assoc Radiol J 2006;57:79-85.
13. Yiin JH, Schubauer-Berigan MK, Silver SR, Daniels RD, Kinnes GM, Zaebst DD, et al. Risk of lung cancer and leukemia from exposure to ionizing radiation and potential confounders among workers at the Portsmouth Naval Shipyard. Radiat Res 2005;163:603-13.
14. Zhang W, Muirhead CR, Hunter N. Age-at-exposure effects on risk estimates for non-cancer mortality in the Japanese atomic bomb survivors. J Radiol Prot 2005;25:393-404.
15. Preston DL, Shimizu Y, Pierce DA, Suyama A, Mabuchi K. Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiat Res 2003;160:381-407.
16. Lipsitz EC, Veith FJ, Ohki T, Heller S, Wain RA, Suggs WD, et al. Does the endovascular repair of aortoiliac aneurysms impose a radiation safety hazard to vascular surgeons. J Vasc Surg 2000;32:704-10.
17. Stoeckelhuber BM, Schulz E, Melcher UH, Blobel J, Gellissen J, Gehl H, et al. Procedures, spectrum and radiation exposure in CT-fluoroscopy. Rontgenpraxis 2003;55:51-7.
18. Ascher E, Marks NA, Schutzer RW, Hingorani AP. Duplex-guided balloon angioplasty and stenting for femoropopliteal arterial occlusive disease: an alternative in patients with renal insufficiency. J Vasc Surg 2005;42:1108-13.
19. Raman VK, Karmarkar PV, Guttman MA, Dick AJ, Peters DC, Ozturk C, et al. Real-time magnetic resonance-guided endovascular repair of experimental abdominal aortic aneurysm in swine. J Am Coll Cardiol 2005;45:2069-77.

Submitted Jan 20, 2007; accepted Apr 10, 2007.