Radiation exposure of vascular surgery patients beyond endovascular procedures

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Background: **Medical imaging evaluations provide valuable information and are often imperative in the care of our patients. Radiation exposure in patients who undergo medical imaging procedures is not routinely monitored and the associated risks are often underestimated.**
Methods: **Radiation exposure associated with computed tomography (CT) angiography and coronary intervention is reviewed.**
Results: **Vascular surgeons are often involved in the decision-making process in roughly 30% of CT scans performed that are believed to be unnecessary. Society for Vascular Surgery (SVS) practice guidelines for patients with abdominal aortic aneurysms recommended eliminating a 6-month contrast surveillance CT if no endoleak was observed at 1 month after endovascular aneurysm repair (EVAR). Ultrasound and aortic duplex can help eliminate some of the CT scans.**
Conclusion: **Vascular surgeons must remain vigilant in monitoring radiation exposure for their patients who have potential for coronary and vascular imaging with radiation. Judicious use of alternative imaging modalities when possible and maintaining the dose as low as reasonably achievable (ALARA) is the responsibility of vascular surgeons. (J Vasc Surg 2011;53:39S-43S.)**

High-dose ionizing radiation has been shown to be associated with predictable deterministic effects, namely hematologic disorders, gastrointestinal symptoms, skin injuries, and central nervous system syndrome.[1,2] Chronic low-dose radiation exposure, on the other hand, is often related to unpredictable stochastic effects, particularly cancer inductions.[1] In addition to background radiation and radiation exposure during endovascular procedures, patients with vascular diseases are frequently subjected to additional radiation from several common sources of medical imaging, particularly plain x-rays, computed tomography (CT) scans, nuclear stress tests, and coronary angiographies.

A common scenario we encounter as vascular surgeons is described here: An elderly patient with multiple medical problems presents to the clinic for evaluation of an aortic aneurysm or peripheral vascular disease. This patient then undergoes several diagnostic tests prior to vascular interventional procedures. For example, a CT angiogram is obtained for this patient with an aortic aneurysm or lower extremity occlusive disease; a preoperative nuclear cardiac stress study may be required because of his history of coronary artery disease; and then a coronary angiogram and coronary angioplasty/stent is prescribed for him due to the abnormal cardiac stress test. Following the vascular procedure, this patient may receive multiple CT scans for routine follow-up surveillance of an aneurysm repair or necessary secondary endovascular interventions to maintain patency of the revascularized lower extremity vessels. These medical imaging evaluations provide valuable information and are often imperative in the care of our patients. However, radiation exposure in patients who undergo medical imaging procedures is not routinely monitored and the associated risks are often underestimated.

Plain x-rays are commonly performed imaging studies. Despite its low radiation dose, a single chest x-ray, for example, is equivalent to the amount of radiation exposure one experiences from our natural surroundings in 10 days.[3] Like plain x-rays, CT scans also utilize x-rays passing through the body to generate images. CT scans have gained immense popularity in medical imaging since its introduction in the 1970s, but radiation risks are often under recognized. The exposure from a chest CT scan is equivalent to the amount of radiation exposure one experiences from natural sources in 2 years, and an abdominal CT scan is equivalent to that of 3 years.[3,4] Unlike x-rays and CT scans, the small amount of radioactive material inhaled, injected, or swallowed during nuclear medicine procedures is the main source of radiation, and the amount of radiation exposure is associated with the type of radioactive material.[3]

CT SCANS AND RADIATION EXPOSURE

CT scanning is considered the greatest advancement in modern medicine with remarkably versatile imaging applications. It is the standard imaging modality used for preoperative planning in patients with aortic aneurysms and the most common follow-up imaging modality postoperatively.[5] It is also often used as a diagnostic test by many vascular surgeons for patients with peripheral vascular diseases. Over the last several decades, the usage of CT scans has increased dramatically. The rise in the volume of imaging services per Medicare beneficiary was reported to have outstripped the growth of all other services physicians provided.[6] The total number of CT examinations per-

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formed annually in the United States has risen from approximately three million in 1980 to nearly 70 million in 2007.[7] The dramatic rise in imaging raises both health care costs and patient radiation exposures.[6] The exposure to radiation levels from a CT scan is considerable and variable. An abdominal CT scan delivers 500 times the radiation than a routine anterior-posterior (AP) chest x-ray, while a multiphase abdominal and pelvic CT angiogram routinely doubles that amount of radiation.[7]

Utilization patterns of CT scans and radiation exposure. Multiple studies have evaluated radiation exposure for patients who have undergone CT scans. A recent study evaluated nearly one million adults less than 65 years of age across the United States and found that approximately 70% of the study population underwent at least one imaging procedure associated with radiation exposure over a 3-year period.[8] CT scans and nuclear imaging accounted for 21% of the total number of procedures and 75% of the total effective doses. Although most subjects received relatively low doses of radiation, 20% of the total population received either moderate (>3 mSv), high (>20 mSv), or very high (>50 mSv) annual effective doses. Elderly subjects and women had higher rates of high and very high effective doses.[8] A retrospective cross-sectional study conducted by Smith-Bindman and colleagues included 1119 consecutive adult patients in the San Francisco Bay area during a 5-month period.[7] The author examined the 11 most common types of diagnostic CT studies and documented higher and more variable doses than what was typically quoted from the most common types of diagnostic CT studies performed in clinical practices. For example, the median effective dose varied from 2 mSv for a routine head CT to 14 mSv for a suspected stroke CT. A routine noncontrast abdominal and pelvic CT scan had a much lower median effective dose (15 mSv) than a multiphase abdominal and pelvic CT scan (31 mSv). Interestingly, there was also a substantial variation in doses within and across institutions, with a mean 13-fold variation between the highest and lowest doses for each CT study type included. The investigators found no specific pattern to the variation. Significant variation in radiation dose across the facilities has also been documented from other studies as well.[9] This considerable dose variation reflects the lack of standardization in administration of CT scans.

CT scan-associated radiation injuries. Significant radiation exposure associated with the increased usage of CT scans has raised the concern of future cancer risks in the population. Radiation is one of the most extensively studied carcinogens, and its direct relationship to the risks of cancer has been demonstrated from studies of the Japanese atomic bomb survivors and radiation workers.[10,11] There was a significant increase in the risk of cancer even in the subgroup of atomic bomb survivors who received low doses of radiation, doses that are approximately equivalent to two or three CT scans in adults. Similarly, significant risks of cancers have also been observed among 400,000 radiation workers in the nuclear industry who were exposed to an average dose of radiation equivalent to that of a single CT scan for an adult.[12,13] Although the risk of CT-associated cancers to an individual is small, the cumulative exposure in the population likely leads to considerable public health issues due to the large number of people exposed annually. In a review article in the *New England Journal of Medicine*, Brenner and Hall estimated that 1.5% to 2% of all cancers in the United States may be attributable to the radiation from CT studies.[12] In another large-scale study, the investigators conducted a detailed modeling of the future cancer risks for current CT scan usage in the US and estimated that approximately 29,000 future cases of cancer could be related to CT scans performed in the US in 2007.[14] Based on the author's assumption of a 50% mortality rate, these cancer cases would translate into about 14,500 cancer deaths.

Physician awareness. Unfortunately, the majority of physicians underestimate the amount of radiation exposure associated with CT scans and a significant number of physicians including many vascular surgeons are not aware of CT-associated lifetime risks of cancers. A survey conducted in the emergency room (ER) of an academic medical center showed that only 47% of radiologists, 9% of ER physicians, and 3% of patients believed that there was an increased cancer risk.[15] All patients and most physicians were unable to accurately estimate the radiation dose for one CT scan compared with that of one chest x-ray.[15]

Admittedly, most cancers and noncancer health risks due to radiation exposure are derived from Japanese atomic bomb survivors and radiation workers.[10-13] There is minimal direct evidence of radiation injury actually related to CT scans. It is also very difficult to estimate the risk of malignancies associated with ionizing radiation generated by medical imaging. Malignancies induced by radiation from CT and other medical imaging are often indistinguishable from malignancies induced by other carcinogens or background radiation.[4] As CT scans become commercially available, thousands of people have undergone a total body scan without an appropriate medical indication despite limited insurance coverage. Together with ever-increasing medical imaging, the cumulative dose of ionizing radiation in the general population is alarming and measures should be taken to reduce radiation exposure.

In addition to standardizing CT scan guidelines and carefully tracking the dosage information of patients, the most effective measure in decreasing radiation exposure is to reduce the amount of CT scans prescribed. It is reported that over 30% of CT examinations currently performed may be unnecessary.[7] Vascular surgeons are often part of the decision-making process to contribute to this effort. It is our responsibility to help reduce radiation exposure of our patients. In fact, a recent Society for Vascular Surgery (SVS) practice guideline for patients with an abdominal aortic aneurysm recommended eliminating a 6-month contrast CT surveillance if no endoleak or other abnormality of concern was observed on contrast-enhanced CT scan performed 1 month after EVAR.[5] Alternatively, magnetic resonance imaging (MRI) and ultrasounds could be used to replace some CT scans.

Although MRI is sophisticated and noninvasive without exposing patients to radiation, the use of MRI for vascular evaluations has not been widely adopted largely due to the higher cost and unfamiliarity with the technology among vascular surgeons.[3] Ultrasound, on the other hand, has been a successful screening tool for abdominal aortic aneurysms, but its utilization for preoperative planning is limited. Moreover, for postoperative follow-up evaluations, it is often dependent upon the comfort of the physicians and consistency of the technicians. With increasing familiarity and consistency, MRIs and ultrasounds are promising diagnostic tools for vascular patients. Utilization of these alternatives can decrease the demand for contrast-enhanced CT angiograms and potentially reduce radiation exposure to our patients.

CORONARY ANGIOGRAPHY/INTERVENTION AND RADIATION EXPOSURE

Coronary catheterization is another diagnostic modality frequently required for vascular patients, as moderate-to-severe coronary artery diseases are common in this patient population. Unlike CT scans, complicated coronary artery interventions can result in high enough radiation dosages to cause deterministic effects of radiation exposure.[16-19] Similar to endovascular procedures, the radiation dosage during coronary interventions depends on the lengths of fluoroscopy and cineangiography (cine), procedure indications, positions of the x-ray tube, and clinical conditions of the patients. Several studies have compared radiation exposure between peripheral vascular interventions and coronary interventions. Not surprising, it was found that patients received similar amounts of radiation and the doses correlated to total procedure time.[19] During a coronary artery intervention, the effective dose a patient receives varies greatly from approximately 5 mSv (moderate) to 60 mSv (very high). In other words, one single coronary angioplasty can deliver radiation up to the amount of radiation exposure one experiences from the natural surroundings in 15 years and equivalent to 3000 times more radiation than a routine AP chest x-ray.

Coronary intervention and radiation measurement. There has been increased evidence in the cardiology literature examining radiation exposure during coronary angiographies and angioplasties. Faulkner and colleagues showed a significant increase in the coronary interventional procedures with the average number of coronary angioplasties increasing by 6.7% per year across 29 European countries since 1990.[17,18] Growing numbers of interventional procedures lead to growing incidences of deterministic and stochastic effects of radiation to a single patient, to the population, and to health care providers. Clinical awareness of radiation exposure to patients and staff has been heightened in recent years. However, due to nonuniform exposure and dose variations during coronary interventions, the cumulative dose of radiation is often difficult to measure. The dosimeter, a commonly worn badge by a fluoroscopy operator to measure radiation exposures, may underestimate the radiation exposure of the medical personnel. The measurement often varies based on location and angulation of dosimeters. Studies have shown that the greater angulation and rotation away from the x-ray tube, the less the measurement of actual radiation exposure.[20,21] While the average operator dose is quantitatively related to the average patient dose, it is not surprising that Kim and coauthors observed greater variations in operator doses than in patient doses in a retrospective review.[22] In their review, the authors also found that for the same patient dose-area product, occupational doses varied widely, which suggested variations in the usages of radiation protection devices and management of radiation scattering. To decrease radiation exposure to health care providers, various protective devices are available such as leaded aprons, thyroid shields, leaded glasses, leaded gloves, and lead screens. However, the protection for patients is often minimal. Fixed fluoroscopy units often have an integrated component that outputs the kinetic energy released in dose-area product. This automatic feature provides valuable information about estimated radiation exposure of our patients.

Risk factors for radiation exposure during coronary interventions. Radiation exposure during coronary artery intervention varies significantly. Total fluoroscopy time and number of frames recorded have shown to be the major factors in determining the radiation delivered during interventional procedures.[20, 23] Studies have shown that anatomical and technical factors significantly influence the total fluoroscopy time.[19,20,24] Complex lesions, multiple lesions, prior history of bypass surgery, and the number of digital cines performed are associated with higher total fluoroscopy times.[20,25] Patient radiation exposures in cine are much higher than static image recordings, and the dose is directly proportional to the framing frequency. Cine was reported to contribute 66% of the total radiation dose while only occupying 23% of the total exposure time.[21] A recent Canadian study including approximately 2000 patients confirmed that multiple lesions, complex lesions, bifurcation lesions, and radial access were significantly associated with increased radiation exposure.[26] Studies have also shown that despite a modest reduction in average operator doses over time for diagnostic coronary angiography and ablation, occupational doses have not been reduced for therapeutic coronary angioplasty. In addition, radiation exposure during an angioplasty was strongly correlated with procedure complexity.[22] These lessons learned from coronary interventions can be easily translated into the vascular surgical field where increasingly complex endovascular interventions are being performed.

Radiation-related injuries during coronary interventions. Radiation-induced skin injuries, such as erythema, pigmentation, desquamation, ulceration, and hair loss, have been reported as early as 1897.[16] Even with appropriate dose-saving techniques, complicated interventional procedures and prolonged use of fluoroscopy can deliver a very high dose of radiation that places the skin at risk for injury.[16] Using an automatic build-in dose monitoring system, den Boer and colleagues calculated the skin radiation dose for 322 consecutive adult patients during coronary interventions. The authors found that the radiation-exposed skin was restricted to a size of 50 cm × 50 cm in 95% of all procedures. The high-dose areas occurred when fluoroscopy time was >60 minutes; gantry positioning unchanged throughout the procedure; the irradiation occurred through a thick body mass; and high radiation quality was required during fluoroscopy and cine. Dose values >1 Gy occurred in the majority of the patients, and 1.2% of the patients received a dose >4 Gy at some parts of the skin, even with aggressive dose-saving techniques and real-time monitoring systems.[16] Other studies also confirmed that certain projections of gantry accounted for a disproportionally high amount of radiation exposure.[21]

In addition to the deterministic effects, radiation exposure during coronary interventions can also contribute to risks of cancers. It is estimated that there is a 2.5% per Sv lifetime risk of fatal cancer for a population between the age of 40 and 60 years.[27] A study examined diagnostic and interventional cardiology procedures in 29 European countries and estimated that the population doses from these procedures alone were 27,000 man Sv in 2006.[17]

SUMMARY

The advancement of medical imaging has undeniable benefits for our patients. Commonly prescribed imaging modalities for vascular patients, such as CT scans, nuclear imaging, and coronary angioplasty, can help to establish an accurate diagnosis, stratify operative risk, aid in preoperative planning and postoperative evaluations, and potentially reduce the risk of vascular interventions. Benefits from the medical procedures may greatly outweigh any potential minimal risk of harm from the amount of radiation when appropriately used. However, modern medicine is increasingly dependent on technology, and the growing use of imaging procedures has raised significant concerns regarding radiation exposure in the general population. Many of these procedures are frequently performed on multiple occasions in the same patient. An extensive body of literature has clearly demonstrated that excessive utilization of medical imaging beyond what is appropriate increases radiation exposure. Literature also revealed that radiation doses vary significantly for each procedure among institutions and even within the same institution. Furthermore, radiation exposure in patients who undergo medical imaging is not routinely monitored, and there are significant inconsistencies in the reported values of radiation doses. Standardizing protocols for medical imaging, limiting unnecessary imaging studies, and utilizing alternative imaging modalities can help to reduce radiation exposure in our patients.

Although there is no direct evidence that ionizing radiation from medical imaging can induce cancer, radiation is one of the most extensively studied carcinogens. The consensus from experts and researchers advocates a conservative approach of "linear no threshold hypothesis" to radiation dose and risk of malignancies.[2, 4] Physicians and technologists performing these procedures should be trained to use the minimum amount of radiation necessary for the procedure. Certain states, such as California, require all physicians who perform fluoroscopic procedures to hold Supervisor and Operator Fluoroscopy Permits. The licensee is to use qualified judgment in deciding whether fluoroscopy of a patient is essential and adhere strictly to good practices during fluoroscopic examinations. Appropriate utilization of imaging modalities to maintain the dose as low as reasonably achievable (ALARA) is the responsibility of all operators.

REFERENCES

1. International Commission on Radiological Protection. Avoidance of radiation injuries from medical interventional procedures. ICRP Report 85. Ann ICRP 2000;30:1-70.
2. International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Report 103. Ann ICRP 2007;37:1-332.
3. Radiation Exposure From Medical Diagnostic Imaging Procedures - Health Physics Society Fact Sheet.
4. Gerber TC, Carr JJ, Arai AE, Dixon RL, Ferrari VA, Gomes AS, et al. Ionizing radiation in cardiac imaging: a science advisory from the American Heart Association Committee on Cardiac Imaging of the Council on Clinical Cardiology and Committee on Cardiovascular Imaging and Intervention of the Council on Cardiovascular Radiology and Intervention. Circulation 2009;119:1056-65.
5. Chaikof EL, Brewster DC, Dalman RL, Makaroun MS, Illig KA, Sicard GA, et al. The care of patients with an abdominal aortic aneurysm: the Society for Vascular Surgery practice guidelines. J Vasc Surg 2009;50(4 Suppl):S2-49.
6. Smith-Bindman R, Miglioretti DL, Larson EB. Rising use of diagnostic medical imaging in a large integrated health system. Health Aff (Millwood) 2008;27:1491-502.
7. Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 2009;169:2078-86.
8. Fazel R, Krumholz HM, Wang Y, Ross JS, Chen J, Ting HH, et al. Exposure to low-dose ionizing radiation from medical imaging procedures. N Engl J Med 2009;361:849-57.
9. Hausleiter J, Meyer T, Hermann F, Hadamitzky M, Krebs M, Gerber TC, et al. Estimated radiation dose associated with cardiac CT angiography. JAMA 2009;301:500-7.
10. Little MP. Heterogeneity of variation of relative risk by age at exposure in the Japanese atomic bomb survivors. Radiat Environ Biophys 2009; 48:253-62.
11. Little MP. Cancer and non-cancer effects in Japanese atomic bomb survivors. J Radiol Prot 2009;29:A43-59.
12. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. N Engl J Med 2007;357:2277-84.
13. Cardis E, Vrijheid M, Blettner M, Gilbert E, Hakama M, Hill C, et al. The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: estimates of radiation-related cancer risks. Radiat Res 2007;167:396-416.
14. Berrington de Gonzalez A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009;169:2071-7.
15. Lee CI, Haims AH, Monico EP, Brink JA, Forman HP. Diagnostic CT scans: assessment of patient, physician, and radiologist awareness of radiation dose and possible risks. Radiology 2004;231:393-8.
16. den Boer A, de Feijter PJ, Serruys PW, Roelandt JR. Real-time quantification and display of skin radiation during coronary angiography and intervention. Circulation 2001;104:1779-84.
17. Faulkner K, Werduch A. An estimate of the collective dose to the European population from cardiac X-ray procedures. Br J Radiol 2008; 81:955-62.
18. Faulkner K, Werduch A. Analysis of the frequency of interventional cardiology in various European countries. Radiat Prot Dosimetry 2008; 129:74-6.

19. Kocinaj D, Cioppa A, Ambrosini G, Tesorio T, Salemme L, Sorropago G, et al. Radiation dose exposure during cardiac and peripheral arteries catheterisation. Int J Cardiol 2006;113:283-4.
20. Brasselet C, Blanpain T, Tassan-Mangina S, Deschildre A, Duval S, Vitry F, et al. Comparison of operator radiation exposure with optimized radiation protection devices during coronary angiograms and ad hoc percutaneous coronary interventions by radial and femoral routes. Eur Heart J 2008;29:63-70.
21. Efstathopoulos EP, Makrygiannis SS, Kottou S, Karvouni E, Giazitzoglou E, Korovesis S, et al. Medical personnel and patient dosimetry during coronary angiography and intervention. Phys Med Biol 2003;48:3059-68.
22. Kim KP, Miller DL, Balter S, Kleinerman RA, Linet MS, Kwon D, et al. Occupational radiation doses to operators performing cardiac catheterization procedures. Health Phys 2008;94:211-27.
23. Geijer H, Beckman KW, Andersson T, Persliden J. Radiation dose optimization in coronary angiography and percutaneous coronary intervention (PCI). II. Clinical evaluation. Eur Radiol 2002;12:2813-9.
24. Bernardi G, Padovani R, Morocutti G, Vano E, Malisan MR, Rinuncini M, et al. Clinical and technical determinants of the complexity of percutaneous transluminal coronary angioplasty procedures: analysis in relation to radiation exposure parameters. Catheter Cardiovasc Interv 2000;51:1-9; discussion 10.
25. Bakalyar DM, Castellani MD, Safian RD. Radiation exposure to patients undergoing diagnostic and interventional cardiac catheterization procedures. Cathet Cardiovasc Diagn 1997;42:121-5.
26. Mercuri M, Xie C, Levy M, Valettas N, Natarajan MK. Predictors of increased radiation dose during percutaneous coronary intervention. Am J Cardiol 2009;104:1241-4.
27. Coulden RA, Readman LP. Coronary angiography: an analysis of radiographic practice in the UK. Br J Radiol 1993;66:327-31.

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