

Radiation Safety for the Cardiac Sonographer: Recommendations of the Radiation Safety Writing Group for the Council on Cardiovascular Sonography of the American Society of Echocardiography

Elizabeth F. McIlwain, MHS, RCS, FASE (Chair), Patrick D. Coon, RCCS, RDCS, FASE, Andrew J. Einstein, MD, PhD, Carol K. C. Mitchell, PhD, RDMS, RDCS, RVT, RT(R), FASE, Gregory W. Natello, DO, FASE, Richard A. Palma, BS, RDCS, RCS, FASE, Margaret M. Park, BS, RDCS, RVT, FASE, Frank Ranallo, PhD, and Marsha L. Roberts, RCS, FASE, *New Orleans, Louisiana; Philadelphia, Pennsylvania; New York, New York; Milwaukee and Madison, Wisconsin; Morristown, New Jersey; Hartford, Connecticut; Cleveland, Ohio; Grand Prairie, Texas*

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From the Louisiana State University Health Sciences Center, New Orleans, Louisiana (E.F.M.); St Christopher's Hospital for Children, Philadelphia, Pennsylvania (P.D.C.); Columbia University Medical Center and New York-Presbyterian Hospital, New York, New York (A.J.E.); University of Wisconsin Hospital, Milwaukee, Wisconsin (C.K.C.M.); Cardiovascular Core Lab at Morristown Medical Center, Morristown, New Jersey (G.W.N.); St Francis Medical Center, Hartford, Connecticut (R.A.P.); The Cleveland Clinic, Cleveland, Ohio (M.M.P.); University of Wisconsin–Madison, Madison, Wisconsin (F.R.); Inside Echo, LLC, Grand Prairie, Texas (M.L.R.).

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Dramatic advances in the practice of cardiovascular medicine have been paralleled by and made possible in part through similarly dramatic advances in the field of cardiac ultrasound. Cardiac ultrasound maintains a paramount role in daily practice essential for diagnosis and management. Echocardiography offers high sensitivity, portability, and lower cost compared with other imaging modalities, without the potential risks associated with ionizing radiation. Cardiac sonographers are increasingly requested to perform examinations on patients undergoing multiple procedures in rapid succession while hospitalized or in outpatient facilities. It is increasingly common that sonographers are exposed to radiation through participation in transesophageal echocardiography–assisted fluoroscopically guided procedures (TEEFPs) in the cardiac catheterization and

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Abbreviations**PPD** = Personal protective device**RSO** = Radiation safety officer**TEEFP** = Transesophageal echocardiography–assisted fluoroscopically guided procedure**TTE** = Transthoracic echocardiography

electrophysiology laboratories and hybrid cardiac surgical suites, especially while performing studies on patients who were very recently injected with radioisotopes for myocardial perfusion imaging or other radionuclide studies.

The radiation dose absorption and possible associated risks for sonographers performing transthoracic echocardiography (TTE) on patients made transiently radioactive shortly after

retains most of its energy and may scatter in any direction. These scattered photons may exit the patient and become an exposure risk to those near the patient.

SOURCES OF RADIATION FOR SONOGRAPHERS

Two sources of radiation exist for sonographers: patients and procedures. Sonographers sit very close to their patients and frequently drape their arms and bodies over patients who have recently received radioactive agents for diagnostic nuclear studies, thereby rendering the patients transiently radioactive. Proximity to this radioactive source and the relatively long duration of the exposure are two important determinants of potential radiation dose absorption by sonographers.^{3,9} This may be even more significant for novice and in-training sonographers, who may require more time to complete a study.

Over the past 10 years, there has also been a significant increase in demand for TEEFPs.¹⁰ Sonographers who assist with transesophageal echocardiography during transcatheter aortic valve replacement, percutaneous mitral valve repair, left atrial occluder device implantation, and atrial septal defect or patent foramen ovale device closure spend significant time in cardiac catheterization and electrophysiology laboratories and hybrid cardiac surgical suites in close proximity to x-ray sources while they are emitting radiation.

Chronic exposure to ionizing radiation is known to cause cataracts, leukemia, and several other types of cancer.^{2,5} Potential sources of radiation for a cardiac sonographer are participating in TEEFPs and performing TTE on patients who recently received ionizing radiation with agents that continue to emit radiation (“hot” patients). A basic understanding of personal protection techniques can greatly reduce radiation dose absorption by a cardiac sonographer from both the x-ray photons from x-ray units and gamma rays produced by the decay of radioisotopes given to patients as diagnostic tracers or part of the therapeutic regimen. Exposure to patient sources of radiation has been reported as being within what is considered acceptable limits for nurses and radiologic technologists,^{3,11} whereas prolonged close exposure of cardiac sonographers to the radioactive sources has not been adequately investigated.

It is imperative that sonographers be aware of their radiation exposure and take necessary steps to protect and monitor themselves. All sources of ionizing radiation in the clinical setting need to be acknowledged.

PERSONAL PROTECTION TECHNIQUES

Cardiac sonographers can significantly reduce radiation exposure from patients receiving radioisotopes and from patients undergoing TEEFPs by applying the cardinal principles of radiation safety: time, distance, and shielding¹² (Figure 1). Application of these principles incorporates methods for (1) decreasing exposure time, (2) increasing the distance from the radiation source, (3) increasing the time from isotope administration to the cardiac ultrasound procedure, and (4) using personal protective devices (PPD) and laboratory shielding (Table 1). In this section we address each of these areas.

Decreasing Exposure Time

Sonographers traditionally have not been considered as being “exposed to radiation” while performing TTE on “hot” patients despite having close contact with the patients (the radiation source)

undergoing myocardial perfusion imaging studies (nuclear stress tests) or participating with TEEFPs are inadequately addressed in the literature and unknown. There is conclusive evidence that the risk from exposure to high levels of radiation is quite real and can produce tissue reactions such as skin burns and cataracts, as well as stochastic effects such as cancers and damage to a fetus.¹⁻³ The best current evidence suggests that there is no safe level of exposure to radiation, that even low doses can cause cancer, and that risks are generally proportional to dose.⁴⁻⁶ These guidelines address the issues faced by sonographers, define the usual circumstances of radiation exposure for sonographers, define how sonographers can minimize their radiation exposure, and offer a pathway to clarify for administrative leaders the risks sonographers face regarding their exposure to ionizing radiation.

TYPES OF RADIATION AND BASIC RADIATION PRINCIPLES

Wilhelm Röntgen discovered x-rays in 1895 and created the first x-ray image (of his wife’s hand).⁷ The first practical and commercially available fluoroscope was developed by Thomas Edison in 1896.⁸ Other than skin burns, few adverse effects from ionizing radiation were understood until Edison’s assistant, Clarence Dally, succumbed in 1904 to the cumulative effects of repeated exposure.⁸ Since that time, the understanding of ionizing radiation has mandated its safe and effective use in medical imaging.

When x-rays pass through the human body to produce a radiographic image, the x-ray photons interact with human tissue in three ways: photoelectric absorption, coherent scattering, and Compton scattering. The photons that escape interaction travel on to the image receptor to produce the radiographic image.⁹ The principal interaction responsible for creating this image is photoelectric absorption. In photoelectric absorption, an x-ray photon transfers all its energy to an electron in an atom, and the photon disappears (it is totally absorbed).⁹ The electron is ejected from the atom and deposits its energy in the nearby tissue. In coherent scattering, an x-ray photon interacts with an entire atom, and changes its direction, but loses no energy in the process.⁹ When scattered photons reach the image receptor at random locations, they cause some image degradation by producing an overall haze in the image. Only a very trivial amount of coherent scatter exits the patient in a direction other than toward the image receptor, and it is not a significant concern for radiation exposure to those near the patient during the x-ray exposure. Compton scattering presents the greatest potential danger to a cardiac sonographer. This type of scatter is produced when an x-ray photon interacts with an electron in an atom and transfers some of its energy to the electron, ejecting it from the atom.⁹ The photon, however,

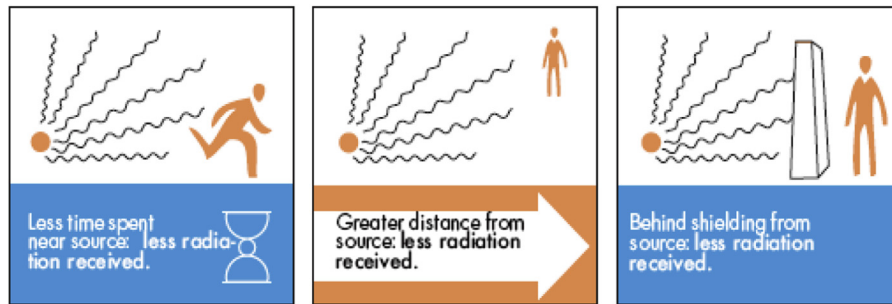


Figure 1 Protection principles to minimize radiation exposure. Effects of time, distance, and shielding on radiation exposure and dose absorption. Exposure can be minimized by limiting the time of exposure to the radioactive source, maximizing distance from the source (increasing distance exponentially reduces exposure) and using shielding. From the Nuclear Regulatory Commission.¹²

for prolonged periods of time. Because the volume of patients receiving radioisotopes for nuclear scans shortly preceding the performance of TTE has increased, this exposure, along with the exposure during TEEFPs, merits consideration. Scheduling should include rotation of the cardiac sonography staff through these areas to minimize or dilute the risk for exposure. These patients and procedures should ideally be avoided by pregnant sonographers. However, if circumstances necessitate participation by a pregnant sonographer, she must strictly adhere to radiation safety regulations.¹³⁻¹⁵

Increasing the Distance from the Radiation Source

Increasing the distance from the radiation source markedly reduces radiation exposure. Doubling the distance from a radiation source reduces the radiation exposure to one-fourth of the original dose.¹⁶ Therefore, small increases in distance very significantly reduce exposure. It is important to be mindful that the source of radiation is the patient, as a radioactive source if the patient has recently received a radioisotope or as a source of x-ray scatter if the patient is undergoing a TEEFP. In the latter case, radiation to the sonographer directly from the x-ray tube should be negligible. However, close proximity to the patient along with table and x-ray tube positioning and associated spatial limitations to the optimal use of shielding during TEEFPs potentially place the TEE operator and sonographer at increased risk for significant radiation exposure. It is important in positioning oneself and shielding to realize that scattered radiation intensity is greatest on the x-ray beam entrance side of the patient. Optimal operator and sonographer positioning to reduce radiation exposure is ideally on the side opposite to the x-ray tube. Positioning should be considered in advance of the procedure.

Exposure can be calculated by the inverse square law: $I_1/I_2 = (D_2/D_1)^2$, where I denotes the intensity of the beam and D denotes the distance from the source, wherein the x-ray beam intensity is inversely proportional to the distance squared. Therefore, and worthy of emphasis, small increases in distance from the radiation source substantially reduce radiation exposure. This principle applies to patients who have been injected with radioisotopes, those undergoing TEEFP, and brachytherapy (internal radiotherapy) patients.

Increasing the Time between Isotope Administration and the Ultrasound Procedure

Performing TTE on a patient before the administration of a radioisotope or delaying TTE in a patient who recently received a radioisotope can eliminate and reduce radiation exposure, respectively. Delaying echocardiography in a patient who has very recently received a radioisotope for nuclear medicine imaging will enable

some radioactive decay, thereby reducing the potential dose to the sonographer. Therefore, as is possible, an ultrasound examination of a patient who has very recently received a radioisotope for nuclear medicine imaging should be delayed. Technetium-99m is used for the vast majority of cardiac nuclear studies (Table 2). The far less frequently used isotope ²⁰¹Tl, although having a much longer half-life compared with ^{99m}Tc, has a lower exposure rate constant and thereby less potential dose to the sonographer (by at least an order of magnitude).

Shielding

Shielding can decrease the x-ray exposure from scatter or primary radiation and the gamma and x-rays from radioisotopes. Shielding includes both PPDs and procedure room mobile (rolling) or equipment-mounted transparent leaded plastic shields.^{3,9,17} PPDs include radiation protective garments (one-piece, two-piece vest/skirt and pregnancy aprons that can accommodate the enlarging abdomen), thyroid collars, and protective eyewear.^{3,9} Radiation protective garments have traditionally been referred to as “lead aprons.” Until recently, lead was the exclusive radiation-attenuating material used in protective garments. Currently, many vendors offer protective apparel with options for lead, composite, or lead-free materials, and as such the use of the term “radiation protective apparel” is now more correct than the term “lead aprons.” Lead-alternative radiation-attenuating materials include bismuth oxide and barium sulfate, rare-earth materials, and composites including lead, tin, tungsten, and barium.^{18,19} Such materials can provide the same protection as lead while having the advantages of being lighter weight and obviating the issue of end-of-life toxic material disposal. However, lead alternatives may be less durable and may provide less protection from energies > 100 keV, which are typical in exposure to patients who have received ^{99m}Tc-based radiopharmaceuticals (140 keV) (i.e., most nuclear stress testing patients).¹⁵

Radiation protective aprons are typically available with a lead equivalency of 0.25 to 0.5 mm.⁹ Those with a lead equivalency of 0.25 mm will allow about 10% of the radiation from x-rays to pass through the shielding⁹ and may be suitable for those individuals exposed to a minimal amount of radiation from x-rays.

Much greater attenuation is achieved by materials with a lead equivalency of 0.5 mm, which will allow only about 2% of the radiation from x-rays to pass through.⁹ This higher level of attenuation is recommended for those individuals who may receive more than minimal amounts of radiation as well as for pregnant workers.

Exposure to the primary unattenuated x-ray beam, which is incident on the patient, must be avoided or extremely minimized if

Table 1 Personal protection techniques: methods to minimize radiation exposure

1. Decrease exposure time
2. Increase time from isotope administration to cardiac ultrasound procedure
3. Increase distance from the radiation source
4. Use personal and laboratory shielding

Adapted with modification from the Nuclear Regulatory Commission.¹²

absolutely essential. If a practitioner's hands will be in the primary beam, highly attenuating gloves or radioprotective bismuth oxide-containing lotion should ideally be worn. The need for and use of protective gloves by sonographers performing TTE on a radioactive patient has not been studied. Sonographers performing TEEFP should wear protective eyewear, to prevent cataracts.

In addition to PPDs, procedure room rolling and mounted shields have an important role for radiation protection. Equipment-mounted shielding includes ceiling-mounted shields, lateral table-mounted shields, and table-side drapes.^{9,17}

When performing TTE on a patient having recently received a radioisotope, PPDs may be useful to reduce radiation exposure. However, their use has not been described in this setting and may be limited by ergonomic and musculoskeletal factors,^{20,21} and aprons may be less efficacious depending on the specific radioisotope. Radioisotopes differ in the energies and penetration of their emitted particles. Some radioisotopes, such as positron emission tomographic tracers, emit photons that are much higher energy than those found in diagnostic x-ray beams. These high-energy gamma-ray photons are poorly stopped by 0.25- to 0.5-mm lead-equivalent radiation protective apparel, in contrast with lower energy gamma rays, which are effectively attenuated. Consider two common single-photon emission computed tomographic radioisotopes, ^{99m}Tc and ²⁰¹Tl. The radiation from ²⁰¹Tl contains primarily rather low energy photons, so the attenuation of radiation protective garments is much the same as quoted above for x-rays. The radiation from ^{99m}Tc contains somewhat higher energy photons, which are attenuated less effectively. When working around a patient who has received ^{99m}Tc, a 0.25-mm lead-equivalent garment will let about 40% of the radiation to pass through, while a 0.5-mm lead-equivalent garment will allow about 15% of the radiation to pass through. Therefore, the higher lead equivalency (0.5 mm) would more effectively attenuate radiation originating from a patient injected with ^{99m}Tc.

REGULATORY AND ADMINISTRATIVE ISSUES

Typically, safeguards exist within the hospital setting to reduce and monitor radiation exposure for health care workers. The medical use of radiation is regulated at the state, federal, and local levels. State radiation protection programs, which regulate cyclotron- and accelerator-produced radionuclides, provide much of the basis for local hospital policy regarding radiation safety. The use of reactor-produced radionuclides in nuclear medicine and radiation therapy is regulated by the US Nuclear Regulatory Commission in nonagreement states and by the individual states in the 37 agreement states.²²⁻²⁴ In addition, machine-produced radiation is regulated by the federal Center for Devices and Radiological Health of the US Food and Drug Administration in conjunction with individual state ra-

Table 2 Radioisotopes characterized by half-life and usual cardiac indications

Isotope (radiopharmaceutical)	Physical half-life	Procedure
^{99m} Tc-labeled agent (e.g., ^{99m} Tc-sestamibi)	6 h	SPECT MPI (for myocardial perfusion, function, viability)
²⁰¹ Tl	73 h	SPECT MPI (for myocardial perfusion, viability, function)
^{99m} Tc-pertechnetate	6 h	Radionuclide ventriculography, also referred to as a MUGA scan (for myocardial function)
¹⁸ F-FDG	110 min	PET (for myocardial metabolism, viability, inflammation)
⁸² Rb	75 sec	PET (for myocardial perfusion, blood flow, function)
Ammonia ¹³ N	10 min	PET (for myocardial perfusion, blood flow, function)

FDG, Fluorodeoxyglucose; *MPI*, myocardial perfusion imaging study; *MUGA*, multiple-gated acquisition; *PET*, positron emission tomography; *SPECT*, single-photon emission computed tomography.

diation protection programs. All machines used with humans, as well as the rooms in which ionizing radiation is used for either diagnosis or therapeutics, must meet design and use standards approved by the Food and Drug Administration and the individual state radiation protection programs. All medical facilities using radionuclides are mandated to have dedicated radiation safety officers (RSOs) and radiation safety committees. The RSO is the resource for any radiation safety related issue as it pertains to all health care workers.⁴ Administrators should work with the RSO to ensure that exposure to cardiac sonographers is as low as reasonably achievable.

Radiation safety training and monitoring specific to the area of exposure (such as at the bedside, nuclear medicine, etc.) reduces the risk for stochastic effects. Personal exposure badges or dosimetry monitors are typically used to monitor exposure. These badges include x-ray film badges, thermoluminescent dosimeter badges, optically stimulated luminescent dosimeter badges, and self-reading dosimeters; they may take the form of flat badges typically worn on the torso or ring badges that can be worn on the finger for workers injecting radiopharmaceuticals.^{11,15,25} These badges are measured over a period of time (usually once a month) and provide important information concerning chronic exposure. Film badges, although inexpensive, are the least accurate. Thermoluminescent dosimeter badges typically use lithium fluoride crystals to measure radiation exposure. This technology, which is commonly used in today's ring badges, is single-use and cannot be reread. Single-use optically stimulated luminescent badges, which use aluminum oxide to measure radiation, are more sensitive than film badges and thermoluminescent dosimeter badges and are the most widely used approach for personal dosimetry monitoring in health care workers today. Self-reading dosimeters such as pocket radiation detection and measurement devices may be read immediately and are useful for monitoring

exposure during a single procedure or series of procedures. Although practices vary across the United States, some users exposed to significant amounts of radiation may wear two badges, one on the collar to measure direct exposure and one on the waist under the apron to measure attenuated exposure.¹¹ Federal law requires the wearing of at least a single badge for those likely to receive an amount of radiation >10% of occupational exposure limits.²³

POLICY DEVELOPMENT

Administrators should acknowledge sonographers as a group of health care workers potentially exposed to medical radiation. Echocardiography departments should add radiation safety to their orientation and provide radiation badges to appropriate employees, in accordance with legal regulations and institutional policies.²³ Ongoing education should be provided to staff members potentially exposed to radiation and a safety culture fostered. Cardiac sonography schools should adopt educational curricula to address occupational risks and safety practices for sonographers in the clinical setting, not limited to radiation, while creating a personal awareness of the risk for radiation exposure from “hot” patients and radiation-emitting procedures. Schools as well as accrediting and certification organizations should also foster a safety culture for the profession. Radiation safety training should include training specific to circumstances wherein sonographers may be exposed to radiation.

Radiation exposure is of further concern with respect to embryos and fetuses. A consensus document offering recommendations for pregnant physicians and personnel working in cardiac catheterization laboratories has been published by the Women in Innovations group of cardiologists, with endorsement from the Society for Cardiovascular Angiography and Interventions.¹⁴ Pregnant cardiac sonographers should promptly notify their supervisors to help ensure fetal protection. A declaration of pregnancy, filed with the employer, is legally necessary to initiate the recommended dose monitoring and to be granted a lower exposure limit.^{13,14,26} In addition to vigorously adhering to principles of radiation safety and recommended monitoring, considerations may include using PPDs when performing TTE on patients recently injected with radionuclides and limiting or possibly removing a pregnant sonographer from studying such patients as well as participating with TEEFPs.

Cardiovascular ultrasound laboratories should give consideration to the radiation exposure of personnel who have direct and prolonged patient contact. The laboratory supervisor should periodically meet with the RSO to discuss and identify the exposure, create relevant educational and monitoring plans, and develop policies specific to the needs of the individual laboratory. These policies should include education upon hire and annually, awareness of the circumstances of exposure unique to sonographers, methods to minimize exposure, scheduling to facilitate rotation of sonographers to reduce exposure, special attention to pregnant sonographers, and monitoring radiation exposure. Special attention should be directed to those individuals who may require additional time scanning, such as novice sonographers, including students and fellows.

RECOMMENDATIONS

1. Echocardiography laboratory and facility administrations should recognize sonographers as another group within the health care environment who are potentially exposed to radiation and its associated risks.

2. Sonographers should self-educate with respect to the basic principles of radiation safety and take personal responsibility to ensure their own safety.
3. Cardiac sonography schools should include radiation fundamentals and relevant radiation safety in their curricula.
4. Organizations that accredit cardiac sonography schools should require that education about radiation fundamentals and relevant radiation safety be part of the educational programs of accredited programs.
5. Organizations that offer certification in cardiac sonography should include radiation fundamentals and relevant radiation safety as topics in certification examinations.
6. Echocardiography laboratories, in conjunction with the RSO, should develop radiation safety policies and procedures specific to sonographers.
7. Insofar as possible, sonographers should strive to minimize the amount of time they are close to radiation sources while attempting to optimize study quality.
8. Insofar as possible, sonographers should strive to maximize their distance from radiation sources while attempting to optimize study quality. Sonographers should be mindful of the circumstances in which radiation exposure occurs and the radiation source (which is typically the patient or scattered x-rays from the patient).
9. Sonographers participating in TEEFPs must wear PPDs as routinely worn by other health care workers in the same setting and directed by the RSO. Radiation shields should be used routinely as is possible.
10. When performing TTE on a patient recently injected with a radioisotope, a sonographer may consider using PPDs. However, the use of PPDs has not been described in this setting and may be limited by ergonomic and musculoskeletal factors, and apron efficacy may be reduced depending on the specific radioisotope.
11. Sonographers participating in TEEFPs must wear radiation-monitoring badges as typically worn by other health care workers in the same setting.
12. Radiation absorption by sonographers performing TTE on patients recently injected with radioactive isotopes is inadequately studied. Pending the availability of adequate published data, it is prudent for sonographers, who more than rarely study such patients, to wear radiation-monitoring badges, as is typically done by other health care personnel working with radioactive sources.
13. A patient's medical record must document the administration of a radioisotope including the agent, dose, date, and time injected. This must be reviewed by the sonographer or echocardiography staff member in advance of performing TTE, to allow possible adjustments (e.g., the need for re-scheduling, targeted expedited procedure, PPDs, and possibly to substitute for a pregnant sonographer).
14. Elective TTE should be performed before the injection of a radioisotope. If practical, an ultrasound examination of a patient who has very recently received a radioisotope for nuclear medicine imaging should be delayed.
15. Echocardiography laboratories should recognize pregnant sonographers as being at additional risk due to potential radiation exposure to their embryos or fetuses. Steps should be taken to minimize embryonic and fetal radiation exposure. Acknowledging the absence of data specific to sonographers, in addition to vigorously adhering to radiation safety practices and recommended monitoring, considerations may include using PPDs when performing TTE on patients recently injected with radionuclides and limiting or possibly removing pregnant sonographers from studying such patients as well as participating with TEEFPs.
16. Research regarding cardiac sonographers' radiation dose absorption while performing studies on patients after radioisotope administration is warranted.

SUMMARY

The exposure of cardiac sonographers to ionizing radiation has to date been inadequately addressed. Because the clinical workloads of cardiac sonographers are increasingly combined with patients undergoing procedures using ionizing radiation, recommendations for cardiac sonographers to minimize their radiation exposure are

appropriate. Although this report is written from the sonographer's perspective, the writing group recognizes that much of the information and recommendations presented here apply to physicians, nurses, technologists, and all other providers of cardiac ultrasound. These guidelines provide a basis to develop policies and protocols specific to radiation safety for echocardiography laboratories in addition to providing cardiac sonographers with guidance and awareness of safety principles to minimize radiation exposure.

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