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EDITORIAL COMMENT

Important Strategies to Reduce Occupational Radiation Exposure in the Cardiac Catheterization Laboratory

No Lower Limit*

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It is well-established that even low levels of exposure to ionizing radiation cause molecular injury in tissues with potentially detrimental consequences (1,2). Radiation-induced stochastic effects are believed to be linearly dose-related with no threshold below which there is zero risk. The evolution of the radiation biology and safety knowledge base led to the formulation of the ALARA principle that states that radiation exposure should always be kept "As Low As Reasonably Achievable." As understanding of the health implications of radiation exposure has accumulated, standards for exposure limits of occupationally exposed workers have become more restrictive. The current standard, from the 2007 recommendations of the International Commission on Radiological Protection specifies a maximum permissible dose of 20 mSv/year averaged over a 5-year period with no one year exceeding 50 mSv (3). This is a decrease from the prior standard of 50 mSv/year. As further experience with occupational exposure accumulates, it is likely that future standards will specify lower limits.

Invasive and interventional cardiologists constitute a group of physicians, with careers potentially lasting >4 decades, who incur among the largest career occupational exposures. There is uncertainty with respect to what detrimental effects these physicians may experience as a consequence of their exposure. Accordingly, what dose levels may be considered "safe" is not completely clear.

This reinforces the importance of the ALARA principle. Consequently, it is important that this group of physicians employ *all* available tactics to minimize their occupational radiation exposure. Physician operator knowledge of radiation physics, biology, and safety is the foundation of protective strategies because physicians need to understand the theoretical basis of the tactics to protect themselves. Clinical competency statements in regard to physician knowledge of the subject have been developed and published (4).

Although invasive cardiologists have a long history of dealing with the occupational exposure issue, a new constituency of exposed physicians is emerging. Structural interventional cardiology frequently requires transesophageal echocardiography (TEE) guidance, often employs general anesthesia, and may involve collaboration with cardiovascular surgeons. Consequently, these physician groups, who may not have training in radiation protection, now frequently work in a potentially high-radiation environment and may be subject to considerable radiation exposure.

FINDINGS AND THE EFFECT OF SHIELDING

The Crowhurst et al. study (5), in this issue of the *Journal*, measures the scattered x-radiation exposure received by TEE operators, anesthesiologists, and interventional operators during structural cardiac interventions. It relates exposure magnitude to procedural characteristics and examines the value of protective shielding (5). The authors used instantly downloadable dosimeters to measure the radiation

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exposure received by all members of the structural interventional team. In the initial 98 procedures, the TEE operator and the anesthesiologist wore protective lead garments but did not have any portable radiation shielding. In this group of procedures, the unshielded TEE operator mean per-procedure exposure (2.62 μSv) was somewhat greater than the first operator's mean exposure (1.91 μSv; $p = 0.101$) and substantially higher than the second operator's (0.48 μSv; $p < 0.001$), both of whom benefitted from portable shielding. The anesthesiologist, who could be located farther from the radiation source than the other operators, received less exposure (mean 0.48 μSv).

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In the subsequent 50 procedures, the investigators utilized a second ceiling-mounted shield for the TEE operator. This resulted in an 82% reduction in the TEE operator mean exposure (2.62 μSv to 0.48 μSv; $p < 0.001$). Through multivariate linear regression analysis, the authors found that the type of procedure (left atrial device implantation) and fluoroscopic projection (procedures utilizing predominantly right anterior oblique and steep right anterior oblique projections) was independently associated with greater doses to the TEE operator. These findings are consistent with previous measurements of the effect of radiologic projection on the intensity of scattered radiation at a particular location (6).

We congratulate the authors on this important effort toward reducing radiation exposure to TEE operators. Their findings, although documenting the value of additional shielding protection for the TEE operator, have implications for the entire structural heart team. Practices aimed at reducing radiation exposure should be adopted and championed by all members of the structural heart interventional team and by all operators who conduct any sort of x-ray fluoroscopy-guided procedure.

EXPOSURE OF STRUCTURAL INTERVENTIONAL TEAM MEMBERS

The operator exposures measured in the Crowhurst et al. study (5) are consistent with other studies' findings (7). These values indicate that current operator exposure rates are well below the current International Commission on Radiological Protection maximum permissible dose of 20 mSv per year. In the Crowhurst et al. study, the first interventional operator received a mean dose of 1.91 μSv per procedure (5). A highly active operator performing 500 procedures (of all types) per year would likely accumulate a total annual exposure of approximately 1 mSv—well below the International Commission on Radiological Protection maximum. Nonetheless, as outlined in the preceding text, these values do not justify lack of attention to efforts to reduce occupational exposure further.

DETERMINANTS OF OPERATOR EXPOSURE

To identify opportunities to reduce radiation exposure, it is important to consider determinants of exposure in an x-ray fluoroscopic environment, which fall into 3 main categories:

1. Magnitude of total x-ray exposure used (determined by equipment calibration, operating mode, and beam-on time). This parameter is best measured by the Kerma area product, which reflects the total amount of radiation released.
2. Distance from the radiation source (radiation intensity decreases as the square of the distance from the source).
3. Shielding (0.5-mm lead-equivalent shielding intercepts 90% to 95% of incident radiation in the diagnostic energy range).

SHIELDING TO DECREASE OPERATOR EXPOSURE. Previous studies have also demonstrated that TEE operators receive substantial radiation exposures during fluoroscopic procedures (8). Several unique issues arise with respect to protecting the TEE operator. By necessity, the TEE operator must stand in close proximity to the x-ray source. In addition, the TEE operator generally stands with his or her back to the x-ray source, and the back of the lead apron typically has a thinner layer of lead for protection (typically 0.5 mm on the front and 0.25 mm on the back). Lastly, mounted shields can pose a challenge to the TEE operator's ability to access the patient and manipulate the TEE probe effectively. Given these challenges, the American Society of Echocardiography recommends that echocardiographers participating in fluoroscopically guided procedures should wear personal protective equipment when exposed, wear radiation dosimetry badges, and use radiation shields whenever possible (9).

Ceiling-suspended adjunctive portable shields for the physician interventional operators are now standard practice and designed into most invasive cardiovascular procedure rooms. Crowhurst et al. (5) clearly demonstrate that incorporating an additional ceiling-mounted shield (similar to that used by the interventional operators) for the TEE operator can decrease his or her exposure approximately 5-fold.