Ionizing radiation has detrimental effects on exposed human tissues. These effects are dose-related and include both tissue reactions, such as skin necrosis, and increased risk for stochastic events, such as radiation-induced cancer.

The development and refinement of advanced invasive cardiovascular procedures over the past 2 decades has led to increased exposure to both patients and to medical personnel. At the population level, between 1987 and 2006, exposure to medical radiation increased from 0.6 millisieverts (mSv) per year to 4 mSv per year. This exposure now exceeds that to medical radiation increased from 0.6 millisieverts (mSv) per procedure for femoral access and 2.3 μSv for radial access. Interventional operators receive an average effective dose of 1.2 microsieverts per procedure averages 8 to 10 mSv, with some complex procedures using substantially greater doses. Interventional operators receive an average effective dose of 1.2 microsieverts (μSv) per procedure for femoral access and 2.3 μSv for radial access. Consequently, a busy interventionalist performing 300 procedures a year with 80% radial access may accumulate 0.6 mSv occupational exposure in a year. Over a 30-year career, an operator would incur an exposure of 18 mSv. Exposures of these magnitudes for both patients and operators, while considered acceptable, are not trivial.

While the great clinical value of x-ray fluoroscopically guided invasive cardiovascular procedures is considered to justify the modest hazard conferred by the attendant radiation exposure, the hazard magnitude is directly related to dose with no known threshold for stochastic effects. The ALARA principle (As Low As Reasonably Achievable) states that it is axiomatic that exposure to both patients and medical personnel should be minimized. This principle fosters an ongoing endeavor to reduce patient and operator dose without importantly compromising study quality.

We congratulate the authors of the study entitled “Time-Course Reduction in Patient Exposure to Radiation From Coronary Interventional Procedures: The Greater Paris Area Percutaneous Coronary Intervention Registry” published in this issue of Circulation: Cardiovascular Interventions. In our view, this study’s findings clearly demonstrate that operator awareness and conduct can effectively reduce radiation exposure.

This study queried the CARDIO-ARSIF registry that required mandatory reporting of all invasive coronary diagnostic and therapeutic procedures performed in the Greater Paris region from 2009 to 2013. For each procedure, the data set recorded 2 x-ray exposure parameters: fluoroscopy time (FT) and cumulative kV*mA exposes product (KAP).

Cumulative KAP, which is the product of cumulative air kerma (a measure of dose intensity) and image entrance port area (reflecting the volume of exposed tissue), is the best measure of the total quantity of radiation that impinges on the patient during the procedure. It correlates directly with stochastic risk. It also correlates with the quantity of scattered radiation that exposes the operator and nearby medical personnel. Cumulative KAP would be expected to correlate roughly with FT as accumulated dose should be related to x-ray beam-on time but is also influenced by the fluoroscopy dose rate and image field size.

The authors demonstrated that over the 5-year observation period, FT decreased significantly. For coronary arteriography alone, FT (minutes) decreased from 4.1 (2.6–7.0) to 3.6 (2.3–6.0); P<0.0001. Cumulative KAP (Gy cm²) decreased from 33.5 (19.9–55.0) to 27.0 (16.1–44.0); P<0.0001. Similar findings occurred in patients undergoing percutaneous coronary intervention and combined coronary arteriography and percutaneous coronary intervention.

A decrease in KAP would be expected to accompany a decrease in FT. However, the authors observed (importantly) that the KAP decrease was disproportionately greater than the FT decrease. This is reflected in the KAP/FT ratio, which for coronary arteriography also decreased over time from 8.1 (4.9–12.7) to 6.8 (4.1–10.79); P<0.0001, with similar findings in the other procedure subsets. This means that, for a given amount of FT, patients (and medical personnel) were receiving smaller doses.

This observation prompted an extensive multivariate analysis to search for the cause of this desirable phenomenon. The KAP/FT relationship is affected by 3 groups of variables:

– Equipment-related variables: equipment quantum detection efficiency and calibration. This determines the image detector dose required to generate an acceptable image.
– Patient-related variables: patient body mass index. Heavier patients will require greater radiation input dose to produce the required detector dose.
– Operator behavior variables: X-ray system exposure parameter selection, image field size, and system positioning all affect the KAP/FT relationship.
It would be logical to conclude that the KAP/FT reduction might be because of installation of new x-ray equipment. However, multivariate adjustment demonstrated that although new or renovated x-ray equipment seems to have contributed to the decrease, a significant decrease persisted after adjustment for that variable. Patient-related variables actually trended opposite to the KAP/FT time course, with body mass index increasing slightly over the observation period.

This leaves operator behavior as the remaining independent variable to explain these findings. In our view, these data make a compelling argument for the importance and value of operator awareness of radiation minimization practices. It is noteworthy that this observation period follows passage of legislation in France that requires operators to undergo detailed training in patient radiation protection and dose optimization.

What tactics are currently available to operators to facilitate dose reduction? Many are made possible by progressive engineering refinement of x-ray cineradiographic systems.

- Enhanced image quality and quantum detection efficiency. This is because of engineering refinements throughout the imaging chain but particularly in improved image detector technology.
- Ergonomically improved operator control over imaging parameters. Current systems provide control over multiple determinants of x-ray dose and make these controls conveniently available tableside to the operator.

Operators can use several tactics to be able to decrease radiation exposure to the patients and to themselves. Many of these tactics are based on the concept that image resolution and temporal resolution may be modulated to select image quality (the ability to perceive sufficient detail for the imaging purpose) that, while not necessarily the best possible, is sufficient for a particular procedure’s requirements.

Image quality is directly related to the image detector dose, which is linked to KAP. Overall, cumulative KAP will be determined by the combination of the following:
- Image detector dose per frame (pulse)
- Image field size
- Image framing rate

Current x-ray cineradiographic units can provide magnificent image quality and detail compared with systems used in earlier times. Today’s best image quality frequently exceeds that needed for the purpose of a particular portion of a study. Consequently, operators can decrease radiation dose to the patient (and to themselves) by choosing to use an image quality that is less than best available but is adequate for the purpose of the study.

The operator has 4 radiation-sparing tactics available:
- Minimize FT and cine acquisition times
- Modulate the fluoroscopy dose per frame to the minimum that provides adequate image detail for the study’s purpose
- Decrease the radiation detector magnification and reduce field size by collimation
- Decrease framing rate

Shortening FT and cine acquisition times has direct and obvious effects on radiation exposure per procedure.

Modulation of fluoroscopy dose requires the operator to be aware of the equipment settings that affect dose. Most x-ray systems have 4 exposure modes that deliver different detector doses. Representative detector doses of the different modes at 22 cm magnification include low-dose fluoroscopy (typically 20 μGy/frame), standard-dose fluoroscopy (40 μGy/frame), cine acquisition (200 μGy/frame), and digital subtraction (1200 μGy/frame). As dose increases, the image signal to noise ratio improves, thus, increasing perceptible image detail. Different degrees of image detail are necessary for different functions during a procedure. Consequently, an operator should consciously select the lowest level of image detail needed for a particular procedure, thereby, minimizing the associated radiation dose.

The radiation detector magnification mode has direct effects on KAP. Current x-ray cineradiographic systems use detector panels \( \approx 30 \times 40 \) cm with pixel matrices of 2480×1920. Magnification (zoom) modes (typically 32, 22, and 16 cm) achieve greater image magnification by stretching a smaller number of pixels. Greater magnification modes require greater detector dose (roughly inversely proportional to image area) to achieve an

Figure. A single-frame image comparison between 2 different detector zoom modes both acquired in the low dose fluoroscopy mode. A, Acquired at 32 cm magnification. B, Acquired at 48 cm magnification with collimation to limit the exposed image field size.
acceptable image signal to noise ratio. KAP for full-field exposure is roughly uniform over the range of magnification modes, but KAP can be decreased at larger magnification modes if the full field is not used. Consequently, if an operator does not require the full image resolution available, he/she can decrease dose by using less image magnification and collimating to a smaller field size. An example of this concept is seen in the Figure.

In the example shown in the Figure, the lower dose image is smaller, has greater noise, and has less perceptible image detail. However, the lower dose images are adequate for certain purposes (in this example, right heart catheterization). Accepting lower image quality means a smaller dose both to the patient and to the operator.

The dose for a given exposure duration is directly related to the framing rate. Consequently, decreasing the framing rate will proportionately decrease KAP. Current x-ray cineradiographic systems provide a range of framing rates ranging from 4 to 30 fps. Improved detector image detail facilitates the use of slower frame rates with the tradeoff that temporal resolution and the ability to resolve motion detail will decrease. This tradeoff can be acceptable for less demanding procedures, such as basic catheter placement, but not for complex interventional procedures. Although historically 15 fps has been the standard framing rate for fluoroscopy and cine acquisition, 10 fps has been shown to be adequate for diagnostic coronary angiography, and even 4 to 7.5 fps have been shown to be sufficient for catheter placement.4 6

These findings are particularly significant in the context that radial access frequency is increasing. As radial access, compared with the femoral approach, has been shown to expose the operator to a higher radiation dose (normalized to KAP), radiation-sparing tactics, while obviously beneficial to the patient, also protect the operator and attendant medical personnel.2

This study’s findings demonstrate the importance of operator awareness and adoption of radiation-sparing practices. It shows that these practices can substantially decrease radiation exposure not only to patients but also to the operators and their support personnel. The French experience validates the value of their required operator education.

Disclosures

None.

References


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