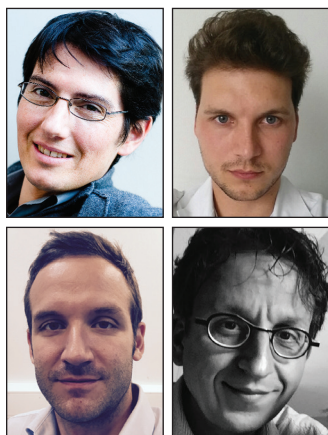


How to Reduce Radiation Exposure During EVAR

Tips and tricks to minimize radiation exposure during EVAR procedures.

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During the last 2 decades, technical improvements in biomaterials have enabled minimally invasive treatment of most vascular diseases. Endovascular aneurysm repair (EVAR) is now a large part of vascular surgeons' daily practice. Initially reserved for high-risk patients and expert centers, EVAR is now commonly performed as the first-line treatment

in most hospitals. However, these procedures require x-ray guidance, which is associated with biological risks for both physicians and patients. Potential consequences range from skin burns to the development of solid cancers and leukemia. When following good practices, it is possible to achieve excellent clinical outcomes with a simple workflow and a low x-ray exposure level.¹ This article suggests various strategies—from room setup to good radiological practices—to reduce radiation dose during endovascular aortic procedures.

RADIATION FUNDAMENTALS

X-ray imaging is based on the seemingly simple physics of the interaction of x-rays with matter. X-rays are both electromagnetic waves and particles (photons) that move along straight lines in a vacuum. They are powerful enough to deeply penetrate in matter and are able to cross it in certain conditions. A shadow image is seen because certain parts of the body are more transparent to x-rays than others. In all cases, some x-rays are absorbed (entirely or partially) by the body. This absorption effect is called the *radiation dose*, and therefore, it is inherent to x-ray imaging to supply a radiation dose to the patient.

Air kerma (AK, in Gy; *kerma* refers to the kinetic energy released per unit mass) is the absorbed dose and is computed at the interventional reference point, defined as 15 cm from the system isocenter toward the anode, which is a good estimation of the patient skin entrance position. It is well correlated to the peak skin dose (in Gy), which is

defined as the highest dose delivered to any portion of the patient's skin, including backscattered radiation during a procedure, and is used to assess the risk of deterministic effects, such as skin injuries. A threshold of 2 to 3 Gy is commonly considered to be at risk.¹ The dose area product (DAP, in Gy cm²) is the product of the AK by the exposed area. The DAP accumulated during the procedure is linked to the stochastic effect (ie, the increased risk of cancer) and can be converted in a first approximation to the effective dose (in Sv) using a conversion factor.² However, there is no consensus on the method used to compute this conversion factor. Since DAP was introduced on fluoroscopy equipment a long time ago, it has been widely used for comparing doses among procedures performed in the same anatomic region and between different institutions.

TECHNIQUES TO REDUCE RADIATION DOSE

The risk-benefit ratio of x-ray use in medical practice has to be considered for each patient and procedure in order to obtain sufficient image quality at a minimum dose while allowing for safety and efficacy.³ This concept is referred to as the “as low as reasonably achievable” (or ALARA) principle. To achieve this goal, different strategies should be combined, from x-ray system technical settings optimization to good and advanced clinical practice. When available, non-x-ray procedures need to be considered.

Room Setup and Dose Awareness

Because x-rays are undetectable by the human eye, passive protection and alerts are needed to help the operator protect himself or herself, the staff, and the patients at all times.

Distance and shielding. The main source of radiation to the operator is scattered radiation. Levels of scattered radiation decrease by the inversed squared distance from its main source, the patient. Therefore, a longer distance from the main beam (eg, by working with longer sheaths) can help decrease occupational exposure.

Scattered radiation is more important at the entrance point of the beam into the patient—under the table. Most x-ray energy deflected upward will be absorbed by the

patient's tissues, but x-rays deflected downward will not encounter any obstacle. Thus, radiation levels are higher at the operator's legs, reinforcing the need for table-mounted lead skirts. Consequently, the tube should always be positioned under the table to avoid the highest scattered radiation being directed at the operator's head. Likewise, in lateral angulations, operators should preferentially stand on the side of the detector, and ceiling-mounted shields need to be used.^{4,5}

Monitoring patient exposure. Modern interventional fluoroscopy systems are capable of displaying a number of metrics related to patient dose, including the fluoroscopy time, the DAP, and the cumulative AK (CAK). These metrics do not directly measure patient dose, but are intended to provide enough information in real time to allow the physician to decide to stop the procedure or change strategy.

Fluoroscopy time can be useful as a quality assurance tool for assessing the efficiency of a physician in completing a procedure, but it has shown poor correlation with the other dose indicators, as it does not take into account any of the x-ray system settings. Moreover, its definition varies and can either represent total pedal time or x-ray pulse duration. Therefore, this indicator should be used carefully and only if no other metric is available.

DAP correlates poorly with the skin dose for individual patient procedures but is more reliable as an estimator of energy imparted to the patient and, therefore, of stochastic risk.

Last, monitoring AK provides a practical way for estimating the dose at the patient's skin in order to avoid deterministic effect due to high-dose radiation during the procedure. However, CAK has limitations related to the size and position of the patient. In addition, CAK and DAP measures ignore the effect of the backscatter from the patient.

Monitoring staff occupational exposition. The effective dose to the operator can be reported in Sv. Passive dosimeters do not provide direct readouts and operate without any active means. As opposed to a passive dosimeter, active dosimeters provide a direct display of the accumulated dose and dose rate, as well as some additional functions, such as alarm threshold settings for dose or dose rate values. The active dosimeter allows the medical staff to adjust their behavior and avoid unnecessary occupational radiation exposure.

Longitudinal dose analysis. Collecting and storing dose data allows for continuous self-evaluation and thus helps to manage and control the risk to patients and staff in the long term. Dose information tracking systems, called *dose archiving and communication systems* (eg, DoseWatch, GE

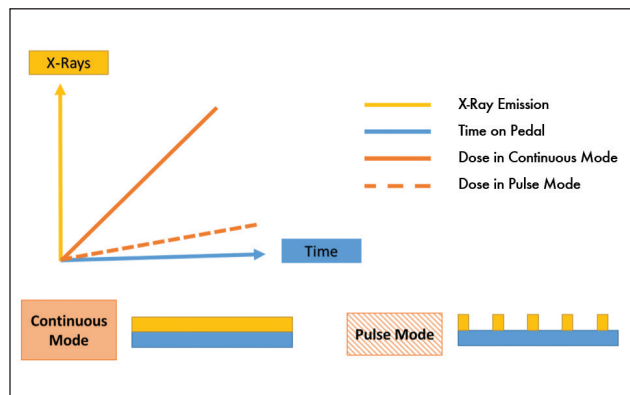


Figure 1. In continuous mode, x-rays (in yellow) are continuously emitted while the foot stays on the pedal (in blue); however, x-rays are only emitted during short pulses in pulse mode. Therefore, the delivered dose rises faster in continuous mode (continuous orange line) than in pulse mode (dashed orange line).

Healthcare), are currently available. They can automatically collect dosimetric information from different x-ray modalities, perform statistical analysis, manage patient dose history, and send alerts.

Optimizing X-Ray System Technical Settings

Modern fixed angiography systems come with smart designs and technology, delivering the best image quality at low radiation levels. It is important to understand these designs and technology to better optimize their use in daily practice.

Flat panel detector technology. Flat panel detector technology, which is widely used in liquid crystal display monitors, achieves a high level of radiographic performance thanks to a high signal-to-noise ratio, wide dynamic signal range, limited geometric distortion, and high uniformity of performance across the field of view (FOV). Evidence in the literature suggests that this technology can be associated with a reduction in radiation exposure of up to 30% when compared with the previous generation of devices using image intensifiers.⁶

Pulse mode. Any modern angiography system is now equipped with a pulsed mode, where images are obtained via multiple short x-ray pulse emissions, as opposed to continuous fluoroscopy (Figure 1). Digital image display at a constant frame rate is then used to compensate the loss of temporal resolution and to obtain a smooth shift between each image. At a typical frame rate of 7.5 images per second in a pulsed mode, a 90% reduction of produced images is achieved compared with the continuous mode (typically 30 images per second). Therefore, the frame rate must be lowered and adjusted to each procedure type.

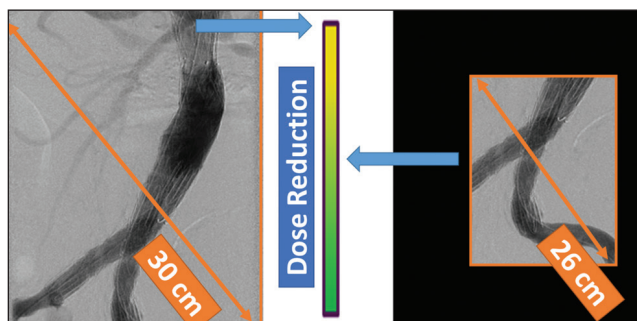


Figure 2. Optimal collimation on the area of interest allows significant dose reduction (proportional to the image reduction).

Auto exposure settings. In modern angiography systems, x-ray exposure is automatically adjusted in real time to deliver constant image quality at the lowest dose via continuous patient thickness estimation. Image quality can then be adjusted with the help of the manufacturer to each physician's specific daily practice and preference, so that procedures systematically start with the lowest settings that provide sufficient image quality. Easy upgrade of these settings must be available at any time from tableside if higher image quality is required at specific times during the procedure.

Low-dose setting. Most of the commercially available imaging systems now offer half and/or low-dose modes. Experimental studies on phantoms have demonstrated that routine use of the half-dose setting is associated with an entrance skin dose reduction of almost half without impairment of the image quality compared with full dose.⁷

Antiscatter grids. Antiscatter grids are commonly used to increase image quality by reducing scatter-induced background noise. However, the introduction of an additional matter thickness leads to significant dose increment. Removal of the grid is possible but would allow dose savings only in very specific cases such as very small anatomies or pediatric patients.

Good Radiological Practice

Time on the pedal. It is obvious that the foot pedal should be engaged only when information is required. It is important to disengage the pedal as soon as data acquisition is no longer relevant.

Digital subtraction angiography (DSA) versus fluoroscopic mode. DSA allows high-quality loop acquisition with subtraction of nonvascular structures. It is commonly used for diagnosis or documentation purposes. However, DSA requires substantial additional radiation exposure compared with standard fluoroscopy. Therefore, the use of fluoroscopy must be preferred and DSA runs limited where possible.⁸ Digital storage of fluoroscopic loops can replace most DSA runs.

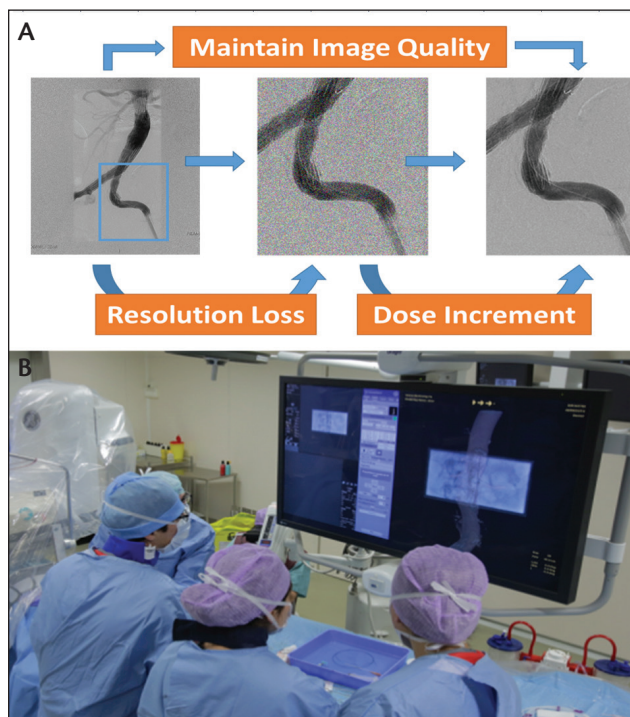


Figure 3. Magnification increases the dose (A), but this can be avoided by using large display monitors (B).

Collimation. Reduction of the FOV through appropriate vertical, horizontal, or iris collimation allows one to focus on the area of interest. It reduces scattered radiation and therefore increases image accuracy. Moreover, it limits the exposure of surrounding tissues. Radiation exposure is decreased in proportion to the reduction of image size (Figure 2).⁹ The use of virtual collimation, when available, can help with positioning the collimation leaves without fluoroscopy.

Magnification. Magnification is sometimes used to achieve better visibility by using a smaller FOV (Figure 3). Zooming is applied to the image, making it easier to see the objects because they are bigger and also because monitors are used at relatively long distances compared with their display capability. Collimation is automatically adapted to protect surrounding tissues, which also has an effect on removing scattered radiation, thus improving the image contrast. In general, to compensate for the loss in resolution by magnification, the equipment is designed to increase the dose rate with the reduction in FOV, either approximately linearly or in a quadratic way with the magnification factor. Typically, flat panels and corrected image intensifiers would experience an approximate linear increase of the dose rate with the magnification factor. The need for magnification can be limited by digital zooming and the use of large display monitors.

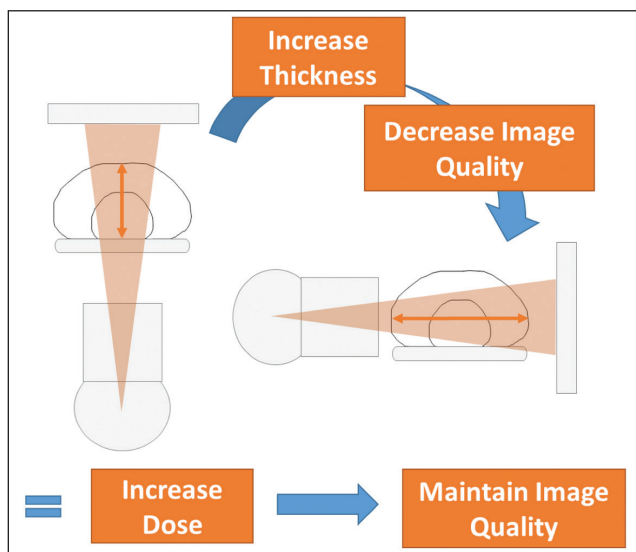


Figure 4. Whenever possible, angulations should be avoided. In lateral (or craniocaudal) angulations, x-rays cross more tissues, which increases attenuation and decreases image quality. To compensate, the system increases the beam energy to maintain image quality.

Limit angulations. An exponential increase of scattered radiation is observed when the gantry position is $> 30^\circ$ in left or right anterior oblique angulation or 15° in cranial angulation (Figure 4). Angulation increases staff exposure, and image quality deteriorates. Extreme gantry angulations should be avoided or used in short increments with adequate collimation when required.

Imaging chain geometry. The detector must be placed as close to the patient as possible to avoid beam energy dispersion and acquisition of a lowered signal, which would result in an increase of dose production settings by generators (Figure 5). Table height must be adjusted so that the operator's head and chest are not too close to the patient, who is the main source of scatter radiation.

Advanced Techniques to Reduce Radiation During EVAR

Operator-controlled imaging. Additional exposure can be induced by a misunderstanding or incorrect coordination between radiographers and operators. A dose reduction of approximately 30% has been reported during EVAR procedures with complete operator-controlled imaging from the tableside compared with radiographer-controlled imaging.¹⁰

Preoperative image analysis. Meticulous planning of the EVAR procedure with preoperative imaging analysis on a three-dimensional (3D) workstation allows for the assessment of access routes and for selecting specific angulations and working positions. Consequently, direct

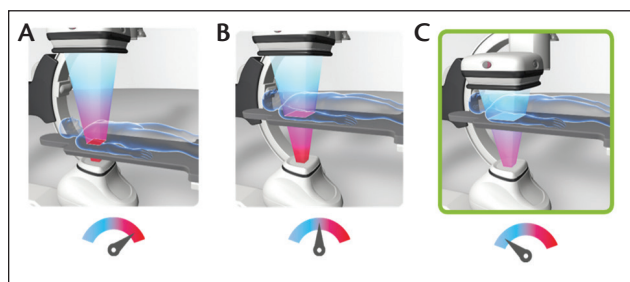


Figure 5. When the table is too low, the FOV will decrease, and the dose delivered to the patient's skin will increase (A). If the table is too high, the operator's head and chest are too close to the patient and are exposed to scattered radiation (B). The detector must be placed as close as possible to the patient to limit background noise (more scattered radiations will reach the captor) (C).

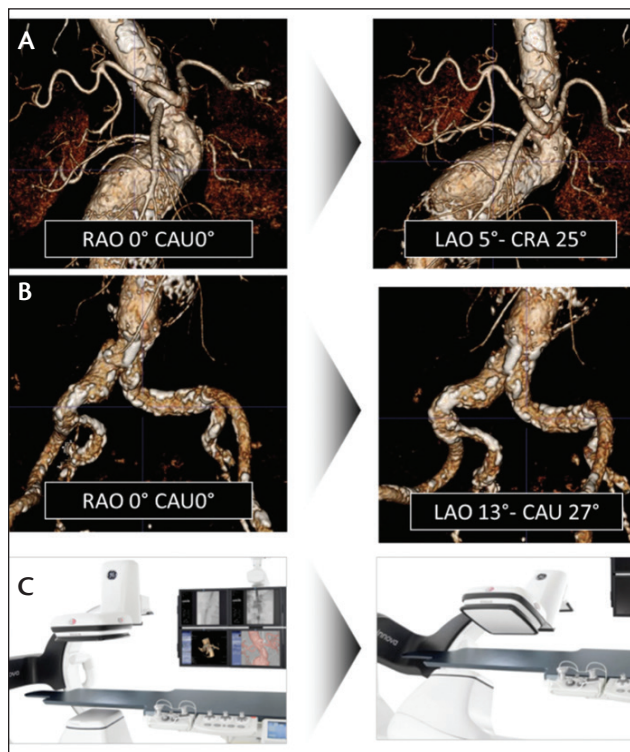


Figure 6. Proximal (A) and distal (B) sealing zones are analyzed on a dedicated workstation before the intervention in order to appropriately position the gantry during the intervention (C) and avoid unnecessary radiation.

positioning of the gantry at the proper angulation can be performed during the procedure, thus minimizing fluoroscopy or DSA runs (Figure 6). The old-fashioned "diagnostic" run at the beginning of interventional procedures is no longer required.

Advanced imaging applications. Advanced imaging applications, such as fusion imaging, are available in most hybrid rooms. Several methods are described to register a

3D volume, either from the preoperative CT angiography or a contrast-enhanced cone-beam CT acquired during the procedure, such as Innova Vision (GE Healthcare). Because the fused aortic 3D model automatically follows table and detector movements, fluoroscopy is only performed once the gantry and the table are precisely positioned to visualize the working FOV. This allows consequent dose savings. A reduction of up to 70% of the procedure's total radiation has been reported in complex EVAR cases supported by this technique.^{11,12}

CONCLUSION

Before, during, and after EVAR procedures, patients undergo extended exposure to x-ray and iodinated contrast, and the clinical staff is also exposed to scattered radiation on a daily basis. Specific attention must be paid to the application of regulations of radiation dose reduction and to the monitoring of patients and personnel. Specific education and training of the clinical staff, optimization of angiographic systems settings, and adherence to good clinical practice are therefore keys to reducing radiation and contrast media volume while ensuring safe and efficient EVAR procedures. ■

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