Chapter 3: Introduction of fluoroscopy and radiation safety

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With the increasing numbers of transcatheter valve therapies performed worldwide, it is important to understand procedural aspects related to radiation and contrast use, especially since traditional surgical valve replacement is not associated with any radiation or contrast use. In this chapter we focus on best practices to avoid excessive radiation and contrast use as well as predicting the ideal implant angles while using the least amount of radiation and contrast.

Radiation dosage and safety

Proceduralists who operate fluoroscopic equipment in the catheterization lab or hybrid operating room have the responsibility to minimize radiation exposure while obtaining sufficient imaging information for transcatheter aortic valve replacement (TAVR). It is important to recognize that radiation exposure for patients undergoing TAVR is not just related to the procedure itself but also related to the frequent antecedent tests which include cardiac computed tomography (CT), CT angiography of the abdomen and pelvis, coronary angiography and possible percutaneous coronary intervention, peripheral angiography and nuclear stress tests (Table 1).

X-rays are a type of ionizing radiation, meaning they carry enough energy to liberate an electron from its orbit around a nucleus, leaving behind a free radical. Ionizing radiation is known to have both deterministic and stochastic effects. Deterministic effects, such as cutaneous erythema and radiation burns, cataracts and sterility, only occur beyond a certain threshold of exposure, and thus can be prevented by setting maximum exposure limits for both patients and staff. Stochastic effects, such as malignancy, are less predictable and can occur with any dose of radiation, though the overall likelihood increases with increased exposure. Radiation is measured in intensity of the beam (air kerma in Gray (Gy)), and radiation dose to the patient/staff (absorbed dose in Gy; effective dose in milli-Sievert (mSv); dose area product in centi-Gray times centimeter squared (cGy cm^2)). The effective dose of several procedures, in additional to background levels, is presented in Table 1.

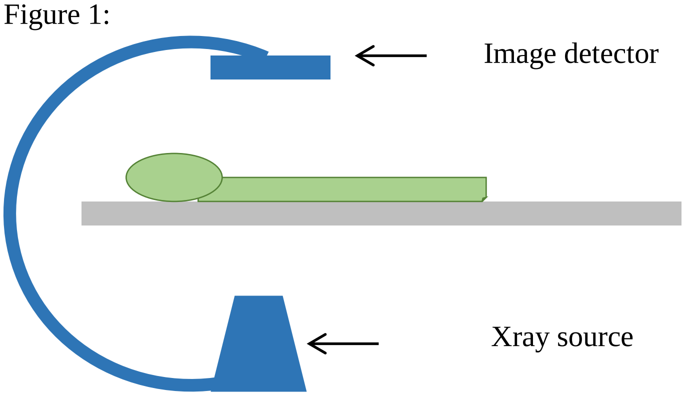
Table 1: Average radiation dose in various cardiac procedures that are related to TAVR

Procedure	Effective Dose (mSv)
Chest X-ray	0.1
Coronary Angiogram	7 (2-16)
Sestamibi stress test (1 day)	9
Percutaneous coronary intervention	15 (7-57)
64 slice coronary CTA	15 (10-30)
Transfemoral TAVR	15-30
Dual isotope myocardial perfusion	25
Aortic valvuloplasty	30-35
Chronic total occlusion intervention	81 (17-149)
Background dose in a year at sea level	2.4

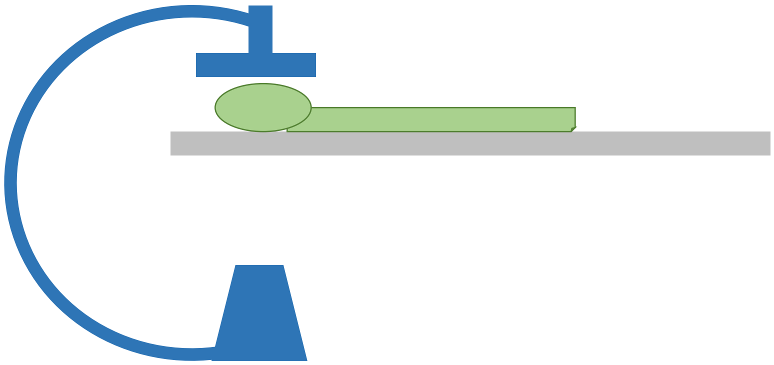
The radiation exposure to the patient, angiographers and operating personnel should be maintained as low as reasonably achievable. Besides increasing the time intervals between procedures that require radiation exposure, procedural techniques to eliminate radiation exposure during TAVR are outlined below. The inclusion of multidisciplinary healthcare workers in the performance of this procedure has resulted in a difference in understanding of the basic principles of radiation and radiation safety. All team members should develop competency and expertise in the use of radiation in the performance of transcatheter procedures. As a general principle every effort to decrease the number and duration of acquisitions and fluoroscopy time should be attempted by preplanning the procedure, determining the implant angle based on cardiac CT, and assessing the iliac vessel based on CT angiography. Below are procedural strategies that can be utilized to minimize radiation exposure to the patient and healthcare workers (Figure 1):

- Decrease frame rate for fluoroscopy (7.5 frames per second) and acquisition
- Decrease distance between patient and image detector, which will minimize scatter radiation to the operator (Figure 1B)
- Increase source to skin distance by raising the table, which will minimize peak skin dose and scattered dose. (Figure 1B)
- Utilize collimation to minimize radiation dose by excluding body parts outside the area of interest.
- Limit the use of magnification; magnification, for example, from 22 cm field-of-view to 16 cm can increase peak skin dose by nearly 50%.
- Minimize the use of subtraction angiography, as it markedly increases radiation dose per frame.
- Use alternative imaging modalities, such as ultrasound, for groin access.

Figure 1:



A. Standard cath lab setup



B. Position of table and fluoroscopy arm to minimize radiation exposure to patient and operator

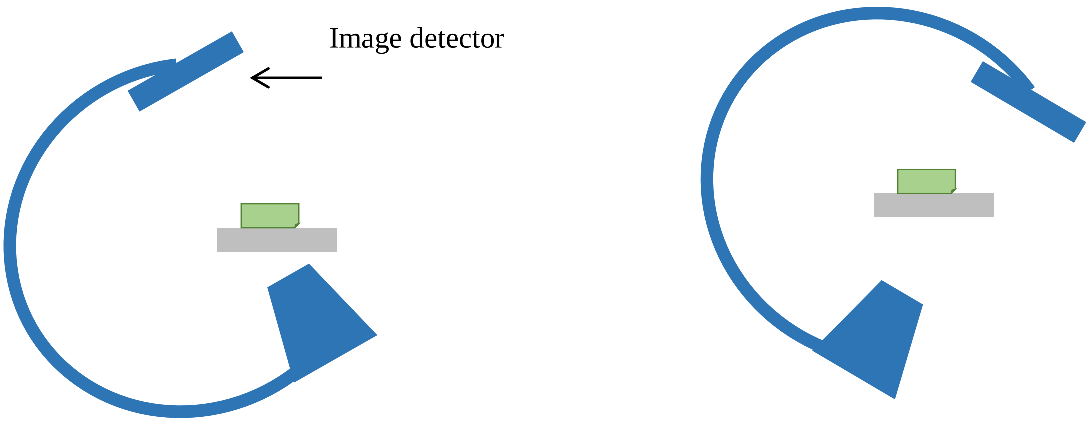
The National Council on Radiation Protection and Measurements (NCRP) recommends an effective dose limit of 50 mSv per year, and a cumulative lifetime dose of 10 mSv multiplied by the age for radiation workers, and 1 mSv per year for general public[1]. Occupational dose is determined through the use of personal radiation dosimeters. These must be used by healthcare workers exposed to radiation and placed at the neck (to quantify total exposure to uncovered areas) and under the lead at the waist (to quantify exposure to the body below the lead). Efforts directed to reduce the radiation dose to the patient also reduce the dose to the operators. In general, radiation exposure to patients during TAVR is within the range comparable to interventional coronary procedures of moderate complexity. Nevertheless, the radiation exposure to the angiographers and the patient during TAVR is considerable.[2] Below are general principles to decrease radiation exposure to the operators:

- Reduce the time near sources of radiation
- Increase distance from radiation sources; the intensity of radiation decreases by the square of the distance from a point source. Therefore, increasing the distance from 1 meter to 2 meters away from the source reduces the intensity of radiation by a factor of 4. Circulating staff maintain their distance for the imaging source.
- Maximize shielding during radiation exposure. Personal shielding includes leaded apron, thyroid collar, leaded glasses (to decrease the incidence of cataracts), and skull caps. Leaded drapes suspended from the side of the catheterization table also provide protection from scatter radiation below the table, and disposable radiation blocking pads placed on the abdomen of the patient decrease scatter radiation from the patient. Every effort should be made to use the overhead movable leaded glass shield as it has the capacity to reduce radiation in the shielded area including the operator's head, thyroid, eyes, and chest by at least 95%. The proper position of the shield to place it between the entry site of the X-ray beam to the patient and the operator. Additional shields can also be placed between the radiation source and other team members, including anesthesiologists and echocardiographers who are often positioned at head of the table.
- Avoid direct radiation exposure to the operator, in particular when their hands are in the field of view, such as during access. Although leaded gloves protect the angiographer’s hands when they placed near the direct beam, they may increase X-ray output if the hands are placed directly in the beam.
- Minimize compound projections with X-ray tube near the operator.

Fluoroscopic projections

Fluoroscopic projections are named based on the position of the image detector relative to the patient: right or left anterior oblique (RAO or LAO), and cranial or caudal.

Figure 2: Fluoroscopic projections, viewed from the foot of the bed



A. RAO B. LAO

Prediction of optimal deployment angles

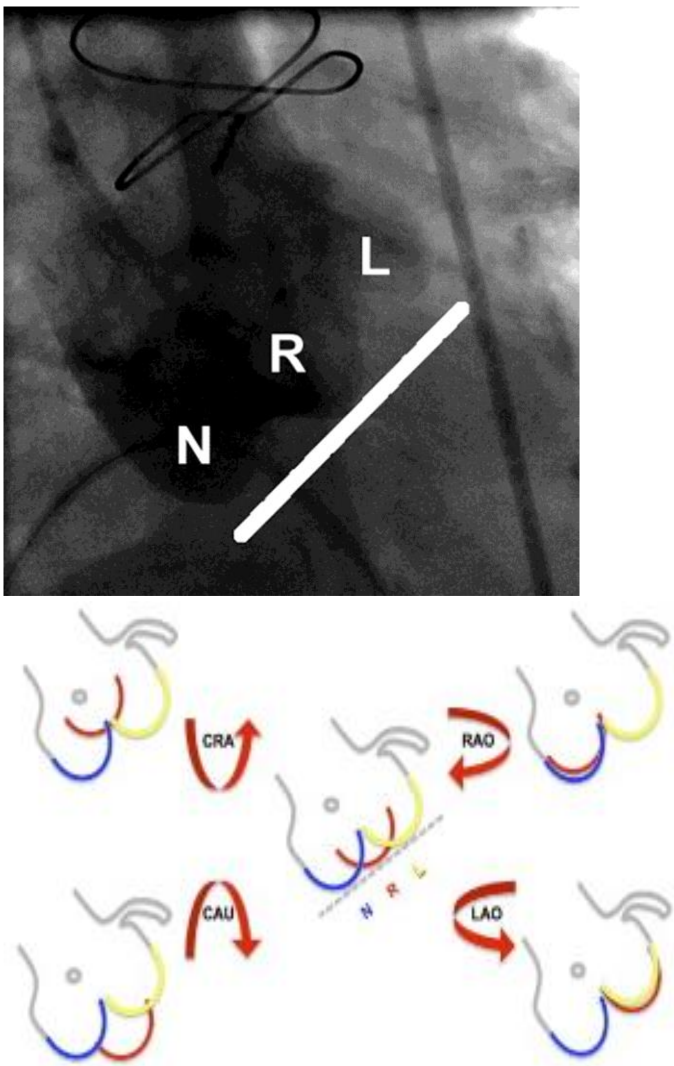
Identifying the optimal fluoroscopic projection is critical for successful valve replacement (Figure 1a). Various imaging modalities including multidetector computed tomography have been proposed for prediction of optimal deployment.[3] Performing repeated aortic root injection increases radiation exposure, and requires larger amounts of contrast. Aortic root reconstruction from multidetector computed tomography is helpful in predicting perpendicular valve implant angles for accurate prosthesis positioning.

Three-dimensional angiographic reconstruction has also been utilized by generating images from C-arm rotational aortic root angiography coupled with the use of special software such as DynaCT (Siemens AG, Erlangen, Germany) to superimpose the CT images on the fluoroscopy screen. This techniques requires rapid pacing to obtain 3-D reconstruction of the aortic root as well as holding respiration for the duration of the camera rotation.

As a general principal, the pigtail can be placed in the noncoronary cusp or the right coronary cusp, a slight LAO projection can be utilized as a starting point to identify the cusps. Cranial angulation can drop the right coronary cusp lower and caudal angulation will move it up. The right coronary cusp will move toward the right with increasing LAO angulation (Figure 1b). One technique to minimize contrast use is to place an additional pigtail via the alternative arterial access in the noncoronary cusp while injecting via the pigtail in the right coronary cusp. This technique allows one to line up the bottom of both pigtails at the same level before performing an angiogram.

Familiarity with different angulations is critical to understand the patient's anatomy for successful implants as well as to understand the relationship of the aortic valve and the origin of the coronary arteries. A steep LAO cranial coronary angiogram for example is critical for valve in valve cases to assure that the ostium of the left main is above the post of the bioprostatic valve to avoid compromising coronary flow during valve in valve implants.

Figure 3: Optimal alignments of the three coronary cusps for optimal implants



As a general principle, moving the camera caudal would raise the right coronary cusp (red cusp), and LAO positioning moves it rightward

Iodinated contrast

It is very important to recognize the frequency of numerous procedures and imaging that require contrast loads in preparation for TAVR including CT, coronary angiography, and coronary interventions. In general, transfemoral TAVR is associated with higher contrast load compared with transapical.[4] Strategies that can be successfully used to reduce contrast loads and the development of contrast induced renal insufficiency include:

- Increase the time interval in between various procedures that require contrast
- Use the preprocedural multidetector CT to predict procedural implant angles and avoid repeated aortograms
- Use of intravascular ultrasound to measure iliac vessels diameter and calcification during transfemoral TAVR procedures.
- Use diluted contrast medium instead of full contrast if that does not degrade image quality
- Use alternative imaging modalities to assess annulus size that does not require contrast medium such as 3D transesophageal echocardiogram
- Use echocardiogram to assess post implant valve function and paravalvular leak instead of repeated aortography especially if hemodynamic assessment does not suggest significant insufficiency.

Not surprisingly, TAVR is also associated with the potential of post-procedural acute kidney injury, ranging from 12-57%, which carries a negative prognostic effect [5]. Strategies to reduce contrast induced nephropathy are critical in the TAVR population and include limiting contrast volume and effective use of periprocedural hydration with special attention to volume status in patient with heart failure. Controversy still exists regarding the optimal amount of fluids as well as the duration of the hydration protocol and the type of fluid used for volume expansion.

Conclusion

Greater attention is being placed on cumulative radiation and contrast exposure for patients undergoing TAVR given multi-imaging modalities requiring contrast and radiation that this patient population undergo. The key factor remains the operator knowledge of the basic principles of minimizing radiation and contrast use by balancing image acquisition, optimizing radiation safety and utilizing prior imaging such as echocardiography and computed tomography to minimize procedural radiation and contrast use.

References:

1. *National Council on Radiation Protection and Measurements 2007. Ionizing Radiation exposure of the population of the United States, Report 160, Bethesda, MD 2009*
2. Daneault, B., et al., *Patient radiation exposure during transcatheter aortic valve replacement procedures.* EuroIntervention, 2012. 8(6): p. 679-84.

3. Samim, M., et al., *Automated 3D analysis of pre-procedural MDCT to predict annulus plane angulation and C-arm positioning: benefit on procedural outcome in patients referred for TAVR.* JACC Cardiovasc Imaging, 2013. 6(2): p. 238-48.
4. Hartrumpf, M., et al., *Radiation Exposure and Contrast Volume Differ between Transapical and Transfemoral Aortic Valve Implantation with the Edwards SAPIEN Aortic Valve.* Thorac Cardiovasc Surg, 2015. 63(6): p. 479-86.
5. Bagur, R., et al., *Acute kidney injury following transcatheter aortic valve implantation: predictive factors, prognostic value, and comparison with surgical aortic valve replacement.* Eur Heart J, 2010. 31(7): p. 865-74.