MINIMIZING RADIATION DOSE IN CARDIAC CT

Part III in our series on Radiation Management in Cardiac CTA

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Minimizing radiation dose during cardiac CT has become a critical topic. The implications extend beyond the medical and ethical concerns related to the risks of radiation-induced malignancy. Opponents of cardiac CT have also seized upon radiation dose to criticize cardiac CT. Virtually every article that appears in the public media highlights the risks of radiation from CTA while almost universally failing to note that alternative tests are often associated with even higher doses. For Cardiac CT to become widely accepted as a standard of care practitioners will need to be increasingly aware of how to minimize radiation dose.

In this newsletter we will highlight four strategies for reducing radiation exposure to the patient while performing Cardiac CTA :

- Reducing Total Exposure Time
- Reducing Spiral Image Overlap
- Reducing Tube Output
- Using External Shielding

Reducing Total Exposure Time
There are two primary methods for limiting total exposure time: modulating the dose according to the ECG, including prospective gating, and limiting the volume of the chest irradiated.

Dose Modulation is available on all 64-slice scanners. This involves reducing the mA during certain phases of the cardiac cycle during retrospective gating. If the beta-blockade is adequate, dose modulation can be employed during systole and returned to full power during diastole. The systolic images are of course, less optimal, but cardiac function can still be assessed and, depending on the reduction in mA, these images are available for high resolution images of the cardiac cycle. ECG dose modulation can decrease the effective dose to the patient from 30%-50%. This protocol applies only to retrospectively gated Cardiac CTA. We recommend using dose modulation on all scans when the patient's heart rate is below 65 beats per minute. At higher heart rates it is more likely that reconstruction of end-systolic images will be needed for full interpretation dues to motion artifacts. Reducing the tube current during those phases will limit interpretation of the study.

Until very recently, the standard approach to MDCT of the coronary arteries has been to use only 'retrospective' ECG gating with spiral (overlapping) imaging. That is, the images are acquired throughout several cardiac cycles and all data are available to the array processor for reconstruction. This allows selection of the phase of the cardiac cycle in which there is the least motion. However, x-ray exposure is continuous during the image acquisition and effective radiation is maximized.

Several of the CT scanner manufacturers have introduced spiral 'prospective' ECG gating. (This is actually a re-introduction of the standard method used for Electron Beam cardiac CT (EBT) first developed and validated in the 1980's.) In essence, this is ECG dose modulation carried to the extreme. Instead of merely reducing the tube output during a portion of the ECG, prospective gating turns on the x-ray tube only during that limited portion of the R-R interval where useful data is expected.

When the heart rate is roughly 65 beats per minute or less, images from the diastolic phase of the cardiac cycle (roughly 65% to 75% of the actual RR-interval) are generally motion-free if the temporal resolution is about 180 msec or less. Limiting the actual time that the x-ray source is 'turned on' to only this portion the ECG cycle reduces the actual time of x-ray exposure to the patient. Studies have shown that prospective gating of the standard spiral Cardiac CT examination can reduce total effective radiation doses by 50%.

However, all prospective gating protocols have two inherent disadvantages. With retrospectively-gated studies multiple phases, at any chosen ECG phase, can be reconstructed. If a motion artifact occurs in an arterial segment at end-diastole it is very possible that an end-systolic phase may allow for better interpretation of that segment. In our experience, it is not uncommon for the 'best' phase to interpret a particular segment to be other than during diastole. Utilizing retrospective gating allows one to have available the dataset for another phase that might allow the study to be diagnostic, even if the heart rate increases during the study to 70-75 beats per minute. The ability to move to a different phase is severely compromised, or even eliminated, with a prospectively gated scan.

The other disadvantage is that by imaging only a limited portion of the cardiac cycle the ability to assess global and regional cardiac function is lost. Of course, if assessment of LV function is required, this could be done effectively using methods without radiation, such as two-dimensional echocardiography or MRA (magnetic resonance angiography).

An additional caveat for using prospective gating is that proper heart rate control during image acquisition is critical. In order to perform prospective gating in a diagnostic mode it is imperative that the heart rate be 60 beats per minute or less and this requires judicious use of beta-blockade in most individuals. (Although dual source scanners may be able to image adequately at higher heart rates, radiation dose is still lower with lower heart rates). Even at a heart rate of 65 beats per minute, it is not uncommon for the most motion free portion of the cardiac cycle to be best during late or end systole (35% to 50% of the cardiac cycle). Thus in the attempt to limit the effective radiation dose to the patient using prospective gating, the radiation dose might be 'wasted' (which in our opinion is a worse scenario) since the examination may not be diagnostic using the only images available. Proper use of beta blockers during Cardiac CT is, in a real sense, a hidden method to reduce effective radiation dose to the patient.

Some patients will have a heart rate below 60 bpm at rest but then jump to higher rates once the contrast infusion begins. In these patients, prospective gating is unlikely to be successful. If prospective gating is used, we highly recommend performing a 30-second hand grip test prior to the scan. If the patient's heart rate increases above 60 bpm while continuously flexing the hand with a simple spring-loaded exercise device, it is unlikely their heart rate will be stable enough for prospective gating during the scan. These patients require either additional beta-blockade or retrospective gating.

Reducing or Eliminating Spiral Scan Overlap

A major source of effective radiation dose is the spiral overlap which is a function of the table pitch. The total area to be imaged for the native coronary arteries is about 12 cm. Using a 64-slice spiral scanner at a pitch of 0.5, requires about 8-10 spirals of the gantry. Reducing the number of overlapping spirals reduces radiation dose.

In standard prospective gating, the scanner gantry continues in the usual spiral pattern, with a pitch generally at 0.5 or lower. While the x-ray source is 'gated' to be turned on only during diastole, the table pitch still results in considerable overlap of the area scanned and thereby limits reduction in radiation dose.

Several of the CT scanner manufacturers have introduced the 'step and shoot' method to eliminate the additional radiation by removing the need for table pitch.   Using this method the patient table is stationary during a cardiac cycle and the x-ray tube is on only for the portion of the cycle chosen by the prospective gating protocol. The table advances after completion of the gantry rotation and then waits for the next protocol-designated cardiac cycle (or portion of the cardiac cycle for prospective gating).

Successful application of this process has been shown to reduce the effective radiation doses by 50% or more. When combined with prospective gating as much as a 70% reduction in effective radiation dose can be achieved compared to standard retrospective spiral gating. Absolute control of the heart rate and limited R-R variability (again, the judicious use of beta-blockers) is crucial.

Several manufactures have introduced MDCT scanners with the capability of taking 256 or 320 slices per gantry rotation. Only 1 or 2 gantry rotations are required to fully image the heart. With a single rotation imaging protocol, pitch is completely eliminated. The spatial resolution and the temporal resolution are the same or only slightly better than that of 64-slice scanners, but the elimination of the need for spiral overlap can greatly reduce the effective radiation. If this method is combined with prospective gating, diagnostic Cardiac CT can be performed with effective radiation doses of 2-3 mSv or less.

Reducing Radiation Dose from the X-ray Tube

Effective radiation doses are very much dependent on x-ray tube current (mA) and x-ray tube voltage (kV). Reducing mA or kV, or both, during Cardiac CT can substantially reduce the effective radiation.

Standard Cardiac CT is done most often using a setting at 120 kV. It has been shown that by reducing this to 100 kV, the effective radiation dose (using retrospective or prospective gating) can be reduced by as much as 30% without sacrificing diagnostic accuracy. The caveat here is that this reduction in kV works well in non-obese patients, about85 kg or less. In obese patients such a method would more likely result in ‘wasting’ radiation as the images may be too noisy.

External Shielding

A final method to reduce incident radiation is to use an external shield. The most common is to limit the radiation dose to the breast in women. Several types of breast shields are available and the manufacturers suggest that breast radiation can be substantially reduced with their device (claims of 25%-70% reduction). Figure 1 shows the application of an external, foldable ‘breast shield’ during a CTA done in a young woman. In this example there is some ‘noise’ in the images of the chest wall, but the coronary scan is not affected and is diagnostic.

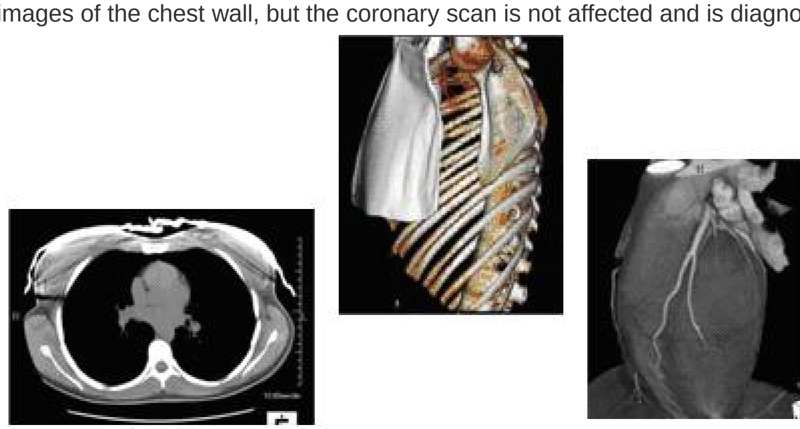

Figure 1.

When properly applied, these techniques can routinely reduce radiation exposure for cardiac CT to as low as a few mSV without compromising diagnostic accuracy. In our next newsletter we will provide specific protocols and recommendations for implementing these strategies in your clinical practice.