Radiation reduction strategies in cardiac computed tomographic angiography

With the introduction of 64-slice coronary cardiac CT angiography (CTA) has emerged as an important tool for assessment of number of indications including the evaluation of symptomatic patients and those with low to intermediate probability of obstructive coronary disease. However the benefits of CTA must be weighed against the possible radiation induced stochastic effects. The risk increases with decreasing age and is higher in young women below 40 years.1-3 These figures highlight the need for dose reduction strategies to minimise small but potential risk of cancer induction in patients undergoing CTA.

Technical considerations
High spatial and temporal resolution is required for optimal imaging during cardiac CTA. Spatial resolution of the scanner depends on various factors like field of view, acquired image width, detector size and number of reconstructed views performed. This resolution is fixed for any individual scanner.

Temporal resolution of a CT scanner can be improved by decreasing gantry rotation time. Currently a gantry rotation of 180 degrees is used. This is obtained with one tube/detector combination rotating through 180 degrees or a two-tube/detector combination through 90 degrees. The fastest gantry rotation time for current scanners is physically limited by the weight of the rotating equipment and current slip-ring technology.

With advances in sophisticated acquisition and image reconstruction software it is now possible to further improve temporal resolution through a number of patient-centric techniques. One such example is cycle gated adaptive multi-segment reconstruction where relevant data is collected over two or more cardiac cycles. These techniques are limited by their reliance on stable RR interval and are subject to image degradation even with slight variability in the acquisition heart rate.

Effects of cardiac cycle
Coronary arteries are most stationary when ventricles are undergoing iso-volumic contraction (75% of R-R interval) or relaxation (45% of R-R interval), which occurs just prior to end-systole and end-diastole respectively. Images acquired during these phases are least likely to suffer from motion blur and are used as the key reconstruction windows for coronary CT.

Good heart control during image acquisition is very important. With slow heart rate (<65bpm) the time for which the heart is stationary, in end-diastole is increased. This reduces the chances of motion blur improving image quality.

Retrospectively gated cardiac CTA
The data is obtained throughout the cardiac cycle using spiral acquisition. A low pitch (0.2-0.5) is used and data is acquired in conjunction with the ECG data. This allows for image reconstruction at any phase of the cardiac cycle. However, the radiation dose with this technique can be five times greater than a standard high pitch helical scan (1.0) and doses as high as 15.2-21.4mSv have been reported during a single coronary CTA examination.4 These figures make one question the risk-benefit balance of the use of coronary CTA in the assessment of low to intermediate risk patients.

This issue of relatively high radiation dose has been addressed by major advances in radiation reduction techniques. In a recent multicentre observational study, a median dose range of 5-30mSv was achieved with variable use of these methods.5 Some of these techniques are discussed below.

Radiation reduction strategies
ECG-linked tube current modulation
Current applied during retrospective cardiac CTA can be varied relative to the ECG. In patients with stable heart rate (<65bpm) it might be possible to get all the required data with maximum tube current centred around 75% of R-R interval and a narrow window. Radiation dose can be reduced by up to 37% if maximum current is applied around this part of the cardiac cycle and reduced by 50-80% for the remainder of the cycle in patients with a stable R-R interval. Also, the narrower the window used, the lower the radiation dose received (figure 1).

If a window of 10% is applied, image quality will be good for phases 70%, 75% and 80% and noisy for the rest of the cycle. However, phase data for rest of the cardiac cycle can still be used to obtain ejection fractions and view wall motion abnormalities.

In patients with tachycardia (heart rate >65bpm) or variable R-R interval, the initial strategy is to reduce the heart rate using beta blockers. If beta blockade is ineffective or contraindicated, modification in tube modulation protocol will be needed. Maximum tube current will be required during both end systole and end diastole for full evaluation. This can be achieved by centring the maximum current at 55% of R-R interval with a window width of 40%.

Prospective axial gating
The scan is performed using sequential axial acquisition technique where on a 64-slice MDCT, a 4cm block of axial images is obtained during a predetermined part of the cardiac cycle. During the next cardiac cycle the table moves on an increment of 3.5cm and during the cardiac cycle after that obtains a further 4cm block and so on until the appropriate volume has been obtained. There is no current outside the predetermined window. This leads to marked reduction in cardiac doses (figure 2).

The images in prospective scanning are reconstructed from several separate blocks of data. This can result in step artefacts (figure 3) which are clinically not usually a problem or are eliminated with large detector systems (eg 640 slice scanner).

Good heart rate control (<65bpm) is mandatory for a diagnostic study with prospective gating. Therefore patients with unstable heart rates usually require aggressive beta-blockade. In a recent audit of our department, 86% of patients were scanned in prospective mode with doses well below 5mSv.
Multiphase data acquisition can be performed with prospective gating by extending the gantry rotation, a technique commonly known as padding. The centre of reconstruction and the extent of padding can be varied up to 200ms (figure 4).

**Patient specific protocols**

Tube voltage and tube current

In the absence of attenuation dependent tube current modulation techniques for cardiac CTA, patient specific protocols are required to optimise the radiation exposure. Body mass index (BMI) is used to prescribe the appropriate tube voltage and current for each individual patient. Tube voltage and current vary with the system used and are evaluated by each centre. The protocol used in our department is outlined in tables 1 and 2.

Dose is proportional to tube current in a linear fashion and to the square of tube voltage. Therefore it is preferable to reduce tube voltage to optimise the image noise and radiation dose. A major limitation of this technique is decreased beam penetration with a resultant increase in tube current. This makes lower tube voltage acquisitions unsuitable for patients with a high BMI. On the other hand, low tube voltage technique leads to an increase in subject contrast. This allows a greater degree of flexibility in the dose of contrast administered.

Patient specific scan length

Radiation dose is directly proportional to the length of the patient's body that is scanned. The length of acquisition must therefore be individually prescribed for each separate patient. Scan length can be planned from either the initial scout images (assessment of coronary stents or bypass grafts) or from the low dose calcium scoring scan (routine coronary assessment). This allows for precise planning and optimisation of radiation exposure.

**Recent developments**

Iterative reconstruction

Filtered back projection is commonly used for image reconstruction in cardiac CTA. It is fast and requires substantially less computing power compared to other reconstruction algorithms. However, the acquired images are often noisy and compensated for by higher photon flux and increased radiation dose. With ever increasing computer processing speeds, iterative reconstruction has been introduced as an alternative with improved CT image quality. The end result is reduced image noise and radiation exposure.

Adaptive statistical iterative reconstruction (ASIR)

ASIR compares the data received to that which was expected and produces further iterations of the image, incorporating modelling of both system optics and system statistics. With ASIR, images with the same quality as filtered back projection can be reconstructed with reduced tube current and a dose reduction of up to 32-65%.

Modulation based iterative reconstruction (MBIR)

MBIR utilises dedicated optical systems to analyse x-ray beam from the focal spot as it passes through the patient three dimensionally and once more as it strikes the detector on the other side of the patient. Statistical modelling is carried out to balance substantial fluctuation of the individual image voxel. Multiple iterative reconstructions are usually required. In a recent study, MBIR improved image quality, reduced image noise and increased CNR when compared to FBP and ASIR in ex vivo human hearts. This was associated with reduced radiation burden.

Garnet detector technology

Certain CT scanners use more efficient garnet-based detectors as opposed to silicon (GOS) detectors. Garnet-based detectors have a primary speed 100 times faster than conventionally used GOS detectors and an afterglow 25% of the GOS. These detectors have reduced inherent noise which allows radiation dose reductions. Its improved contrast resolution appears to allow greater use of low tube voltage techniques in patients with high BMIs. The combined use of iterative reconstruction and garnet-based detectors can result in halving of dose compared to conventional detector technology. When used in combination with high-definition mode, garnet-based detectors can improve image resolution.

**Conclusion**

With the help of the above mentioned strategies, cardiac CTA can be routinely performed at significantly reduced doses (1-7mSv) compared to five years ago. Some of these strategies can be applied to CT in general to further reduce radiation doses.

**References**

TABLE 1
BMI-based patient specific scanning protocol in our department with conventional scanner.

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TABLE 2
BMI based patient specific scanning protocol in our department with Garnet detector scanner.

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FIGURE 1
Retrospective gating with ECG-dependent dose modula- tion. Maximum tube current is applied throughout the diastole but reduced to the minimum possible for rest of the cycle.

FIGURE 2
Prospective gating. Tube current is applied during a predetermined window with marked reduction in radiation doses.

FIGURE 3
Step artefact during prospective axial gating.

FIGURE 4
Prospective gating with padding. This technique is used in patients with tachycardia and or irregular heart rates.