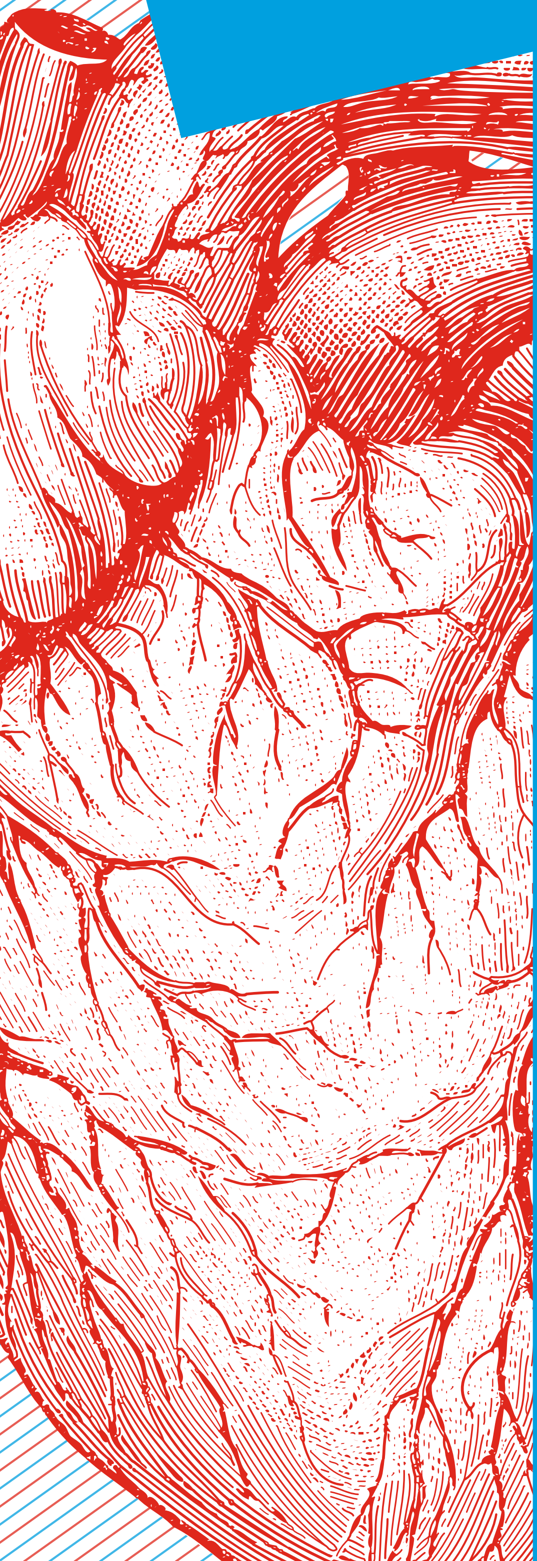

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# RADIATION EXPOSURE

# INFLUENCE OF PROTOCOL OPTIMISATION ON RADIATION EXPOSURE IN CARDIAC IMAGING

BY **VALENTIN SINITSYN** AND **MARIA GLAZKOVA,**
ON BEHALF OF EUROSAFE IMAGING

## We are living in the era of low-dose cardiac and coronary CT

Coronary and cardiac computed tomography angiography (CCTA) is a non-invasive modality that is used more and more frequently in modern healthcare as a valid alternative to invasive coronary angiography for assessment of coronary atherosclerosis and many other cardiac diseases, as well as targeted indications like left atrium and pulmonary vein assessment or cardiac and aorta imaging before transcatheter aortic valve replacement (TAVI). There is a general trend towards increased use of CCTA for diagnostic imaging of the heart and coronary arteries (CA). CCTA has been included in different national and international cardiac referral guidelines. However, wider use of this modality has been criticised by some experts because of the relatively high levels of radiation to which patients are exposed. Yet the situation with regards to radiation exposure associated with CCTA has changed dramatically: we have entered the era of low-dose CCTA, and it is important that radiologists be aware of how to perform low-dose cardiac and coronary CT.

The dose delivered by CCTA can vary substantially depending on patient characteristics and the settings of multiple scanner operating parameters. The major configurable CCTA settings that can affect the dose are: tube voltage (kV), tube current (mA), and various other parameters of the scan protocol, such as type of ECG-gating, pitch, slice thickness, scan length, and the type of image reconstruction (standard or iterative).

## STRATEGIES TO REDUCE RADIATION DOSES IN CCTA

Today CCTA should be carried out with low-dose protocols whenever possible. There are a number of different strategies to reduce or minimise the radiation exposure to a patient during CCTA.

The most important ones are as follows:

- Prospective ECG-gating
- Reduction of tube voltage (kV) and tube current (mA) in combination with iterative image reconstruction
- Tube current modulation (in case of retrospective gating)
- Adjustment of pitch settings
- Tailoring of the scan length to the necessary parameters (avoidance of overscanning)
- Faster data acquisition (high-pitch scanning)

In the case of CCTA, radiologists have to find an optimal balance between image quality, good contrast to noise ratio, and acceptable low radiation dose.

### Prospective ECG-gating

In the case of CCTA, ECG-gating is obligatory in order to get movement-free diagnostic datasets of the heart and vessels. Coronary CTA can be performed with retrospective and prospective ECG-gating (Figure 1). CCTA with retrospective ECG-gating allows for data reconstruction of the whole scan volume at any time point within the cardiac cycle. But employing this technique makes high radiation doses (range 8–16 mSv) unavoidable, unless special measures to decrease radiation are taken. In the case of CCTA with prospective ECG-gating, the images are obtained only in predetermined, fixed R-R intervals (usually 60–70%). With this approach, it becomes impossible to obtain reconstructions in all the phases of the cardiac cycle, but radiation doses can be reduced significantly. CTA performed with a prospective ECG-gating (as opposed to a retrospective one) provides a substantial (3–6 fold) decrease in the effective radiation dose without compromising on image quality. Prospective-gated CCTA works very well in patients with low heart rate (HR) (60–65 beats per minute); though, in cases of high HR, the use of prospective ECG-gating can lead to non-diagnostic images due to motion artefacts. Low dose CCTA with prospective gating has become a new standard for diagnostic evaluation of CA and the heart chambers' morphology when there is no need for functional information. It is suitable even for static (single-shot) studies of myocardial perfusion at stress and rest. CCTA with

Figure 1

Coronary CTA with prospective (A) and retrospective (B) gating. In the case of (A), the centre of the triggering window was set at 70–80% of the RR interval. For (B), images could be reconstructed in every phase of the cardiac cycle without any corresponding increase of radiation exposure.

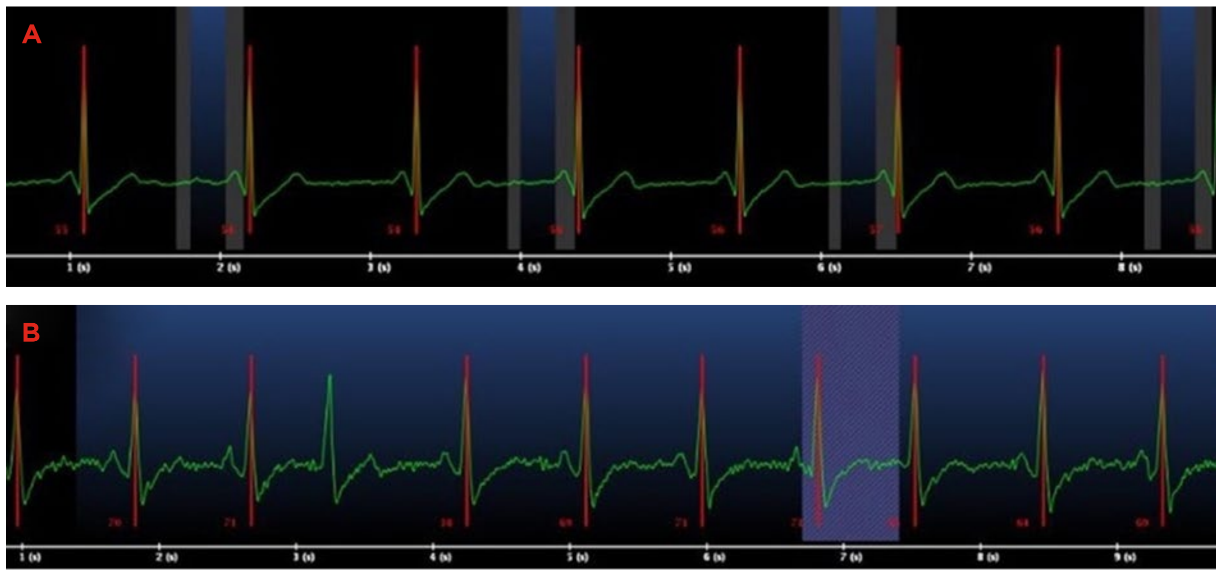
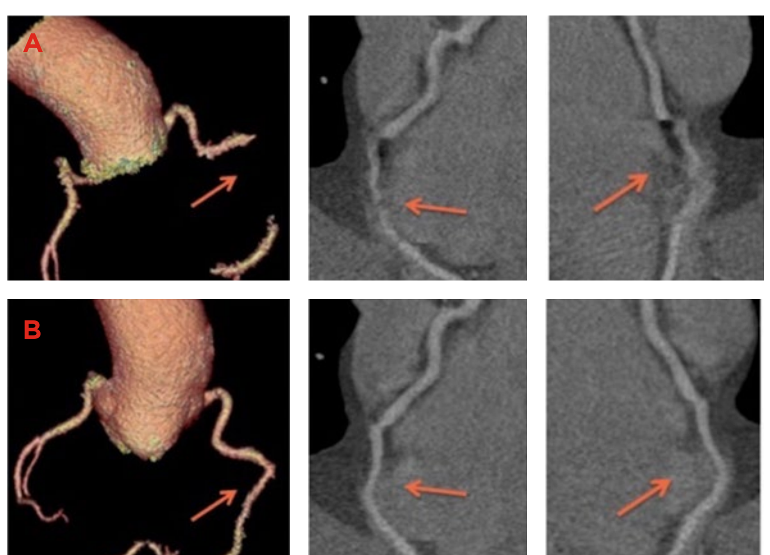



Figure 2

65-year-old male patient with an average HR >65 bpm. The VR and MPR made with standard prospective-gated CCTA show motion artefact in the middle segment of RCA (A). In the case in which the MC algorithm was applied (B), no artefacts are seen. Radiation dose 3.8 mSv.








retrospective gating is used when one needs information about the function of heart chambers and valves or in patients with arrhythmias. Recently, novel motion-correction (MC) algorithms have been developed by several manufacturers. These MC algorithms use information from adjacent cardiac phases obtained with prospectively gated CCTA within a single cardiac cycle. Such an approach minimises the artefacts related to CA motion. These MC algorithms can improve the image quality of prospective gated low-dose CCTA even in patients with higher HR (Figure 2).

## Reduction of tube voltage and current combined with the iterative reconstruction

Reduction of tube voltage (kV) decreases radiation dose roughly proportionally to the square of the voltage settings. Thus, decreasing the tube voltage from 120 to 100 kV reduces the radiation dose by almost 40% whilst decreasing it from 120 to 80 kV reduces the dose by 60–70% (if the tube current remains constant). The kV settings are predefined or selected by the operator according to the subject's body mass index (BMI) and indications of the study. There are some simple rough recommendations for selecting the optimal tube voltage for CCTA: 120 kV for patients with a BMI of more than 30 kg/m$^2$, 100 kV for a BMI from 21 to 29 kg/m$^2$, and 80 kV for a BMI of less than 21 kg/m$^2$. Consequently, the selection of tube voltage settings is in some way a trade-off between image noise and radiation dose. Modern CT scanners with iterative image reconstruction CCTA can, in most cases, be performed with a low tube voltage without any loss in image quality. It is well known that low tube current/voltage leads to reduced exposure to radiation for patients, but also to increased image noise. Due to the introduction of iterative image reconstruction, the radiation dose can be substantially reduced (by 30–70% in comparison to traditional filter back projection) without any losses of fine details on images (Figure 3). Combined application of prospective ECG-gating, low tube current voltage and iterative reconstruction allows for significant reductions in radiation dose – to below 1–2 mSv (Figure 4).

## Tube current modulation

Tube current modulation is an important tool for decreasing the radiation dose in cases where retrospective cardiac gating is necessary – for example, when the evaluation of cardiac chambers, valve function, or dynamic myocardial perfusion studies are needed. The tube current is selected and modified based upon patient weight and/or BMI, thoracic diameter or noise measurement. Most modern scanners offer tube current modulation based upon the thickness of the body estimated from the topogram. For CCTA with retrospective ECG-gating, the tube current can be modulated at different phases of the cardiac cycle, for example, full tube current can be applied at the end- or mid-diastolic phases used for imaging of CA and decreased tube current can be used in other phases for heart chamber visualisation where lower image quality is acceptable. ECG-tube current modulation can reduce the radiation dose of coronary CTA by up to 60% in comparison to scans with fixed tube current settings.

Figure 3

Low-dose CCTA with prospective ECG-gating and low tube voltage (100 kV) in a patient with a BMI of 30.5 kg/m2. Iterative reconstruction allows the study to be performed with low radiation exposure without any loss of image quality due to the use of iterative image reconstruction. Radiation dose 1.59 mSv.

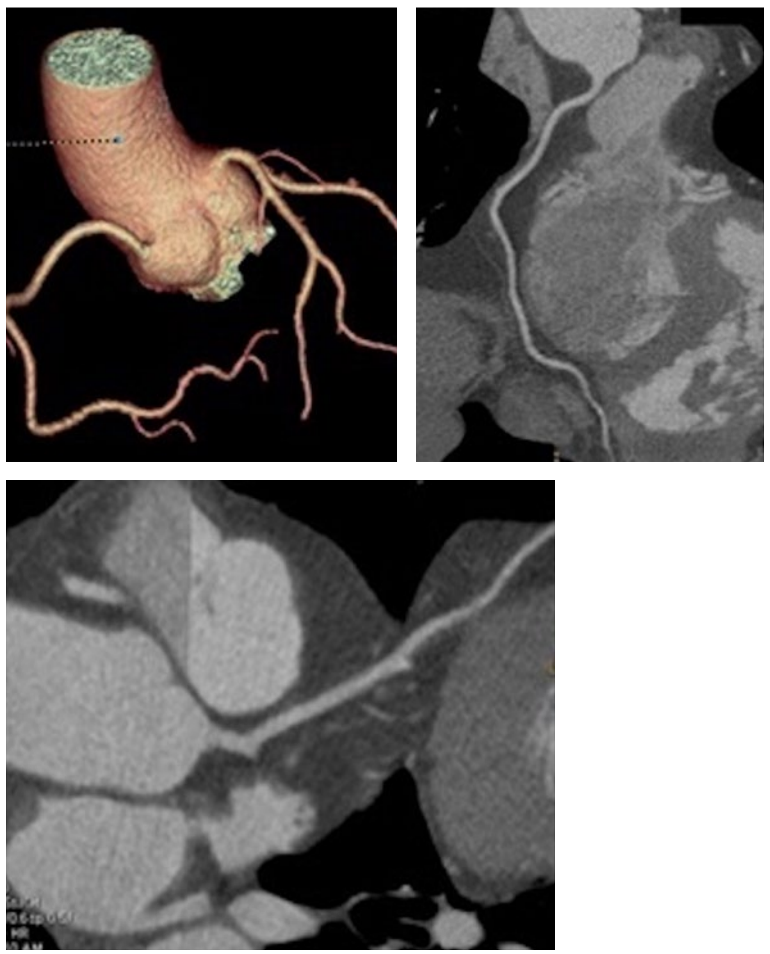
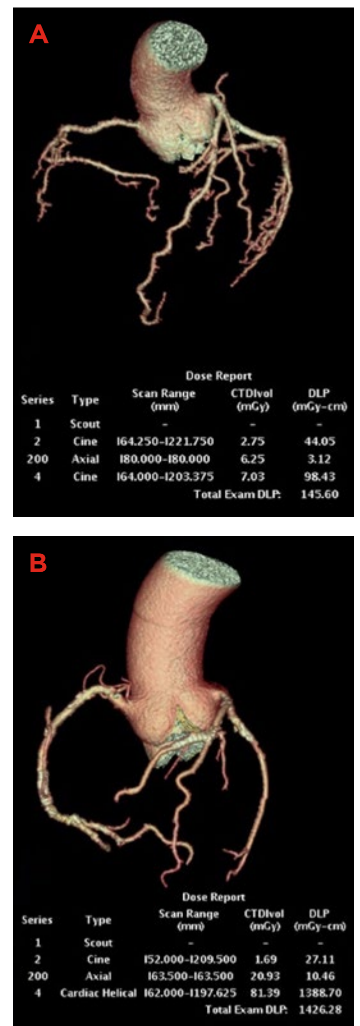


Figure 4

Coronary CTA with prospective (A) and retrospective (B) ECG-gating. The radiation dose was decreased from 19.4 to 1.37 mSv thanks to prospective ECG-gating and low tube voltage without any loss in image quality.








## Adjustment of pitch value

Distance travelled by the CT table divided by x-ray beam width denotes pitch. Radiation exposure for helical scanning at a pitch of 1 is comparable to that obtained during axial scanning. Scanning with pitch settings >1 is associated with a decrease of radiation exposure. A specialised form of helical scanning ('high pitch' or 'super-helical') has been developed for use in new 'fast' CT systems like the latest generation of dual-source CT (DSCT), or wide-detector, systems. According to different studies, the mean dose during high pitch scanning is very low (it could be in sub-millisievert range) without any associated decrease in image quality. High pitch scanning is particularly beneficial in diagnosis of CA anomalies and cardiac anatomy assessment of congenital heart diseases in children and young patients. So far, the main limitation of this technique is its dependence on low HR (typically less than 65 bpm), but this disadvantage may disappear with further improvements in CT techniques.

# CONCLUSION

Just ten years ago, CCTA was associated with relatively high radiation exposure. According to the data from the ACC/HRS/NASCI/SCAI/SCCT Expert Consensus Document on Optimal Use of Ionising Radiation in Cardiovascular Imaging (2018)[1], the radiation dose during cardiac CTA can range from 0.5 to 30 mSv (Table). However, in most cases of CCTA, this is no longer a big problem.

In summary, we would like to stress the most effective ways to decrease radiation exposure in coronary and cardiac imaging[2, 3]:

1. Selection of the right indications for the examination (e.g. use iGuide4 from ESR)
2. Details such as the patient's age, sex, weight, and height must be taken into consideration
3. Scan length should be tailored according to the aim of the study
4. Prospective ECG-gated CTA should be used in most cases when sufficient image quality can be expected
5. Retrospective ECG-gated CCTA should be done with tube current modulation

Table

Typical effective doses for different CCTA scanning protocols

| SCANNING PROTOCOL | RANGE OF EFFECTIVE DOSES (MSV) |
|---|---|
| CCTA, retrospective gating, no tube current modulation | 8–30 |
| CCTA, retrospective gating, with current modulation | 6–18 |
| CCTA, prospective triggering | 0.5–7 |
| CCT, high-pitch helical | <0.5–3 |
| CTA, pre-TAVR: coronary (multiphase) and chest/abdomen/pelvis | 5–50 |
| Calcium score | <0.5–3 |

6. Iterative image reconstruction (combined with appropriate decreases of tube voltage and current) is recommended for CCTA in all examinations (if the scanner has this option)

7. New technical features (e.g. high-pitch scanning, motion correction algorithms) should be used when possible and appropriate

## ABOUT EUROSAFE IMAGING

EuroSafe Imaging is the European Society of Radiology's flagship campaign to promote quality and safety in medical imaging. The mission of EuroSafe Imaging is to support and strengthen medical radiation protection across Europe following a holistic, inclusive approach. Radiation protection focuses on three cornerstones, namely justification of any medical exposure, optimisation of the imaging task to keep the exposure as low as reasonably achievable, as well as dose limits. EuroSafe Imaging has launched its Call for Action 2018 to guide all activities, which build upon these principles. The ESR's EuroSafe Imaging campaign is pleased to present this article focusing on protocol optimisation in cardiac imaging.

References

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**PROF. VALENTIN SINITSYN, MD, PHD, FACR (HON), EBCR**

*is Chair of Radiology at the Medical Faculty of Moscow Lomonosov State University, Moscow. He is one of the pioneers of cardiac MRI and CT in Russia. His research interests are concentrated on cardiac imaging, abdominal radiology, contrast media and computer applications in radiology. Professor Sinitsyn is the President of the Russian Society of Radiology, past-President of the European Society of Cardiovascular Radiology (ESCR) and was Congress President of ECR 2014.*

**DR. MARIA GLAZKOVA, PHD**

*is a radiologist in the Federal Centre of Medicine and Rehabilitation, Moscow. She graduated from the Lomonosov Moscow State University in 2011 and began her residency in radiology at the Federal Center of Medicine and Rehabilitation, where she became a certified radiologist in 2013. Dr. Glazkova's special field of interest is cardiac radiology.*