Focus on radiation exposure from cardiovascular imaging with computed tomography

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Received: 11 February 2009 / Accepted: 11 February 2009 / Published online: 4 March 2009
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After the recently published results from the PROTECTION trial [1], which demonstrate large differences in radiation exposure for cardiovascular indicted CT scans between experienced centers, in this issue Gopal et al. [2] describe potential significant reduction of radiation exposure using prospective triggering and lower tube voltage in selected patients. The editors would also like to announce an upcoming Focus Issue of the journal dedicated to various dose saving strategies. Guest-edited by Frank Rybicki, MD, PhD of Brigham and Women's in Boston, a series of articles from a group of international experts, will discuss the impact of state-of-the-art scanner technology of all major CT manufactures.

Since its introduction to diagnostic medical imaging in the 1970s [3], the use of computed tomography has risen sharply and has allowed more precise diagnosis of a wide range of conditions, including cardiovascular disease. However, the increased use is

associated with rising radiation exposure [4], and recent articles have highlighted its potential long-term side effects [5]. The general principle in medicine that the diagnostic or therapeutic intervention should not be worse than the disease, is reflected by the 'ALARA principle (as low as reasonably achievable)' in diagnostic imaging using ionizing radiation [6].

In order to minimize the radiation exposure from CT in general and for the individual patient in particular, it is important to consider appropriate clinical indications and scan protocols. Appropriateness criteria for cardiovascular CT have been published [7]. In the realm of vascular imaging, CT is typically used initially instead of another tests associated with exposure to ionizing radiation. If, as would be the case for a patient with suspected pulmonary embolism or aortic dissection, CT provides a reliable diagnosis and makes nuclear imaging or angiography unnecessary, CT is considered appropriate. On the other hand, if a positive coronary CTA would most likely need confirmation by conventional angiography, as would be likely in a patient with known CAD or high pre-test probability, the test is not considered appropriate. It is also important to consider, that the relatively non-invasive nature of a test alone does not establish its usefulness for screening (or supports performance out of curiosity), in particular because false-positive test in patients with low pre-test probability can be associated with untoward outcome [8].

Editorial comment on 9396 (DOI: [10.1007/s10554-008-9396-z](https://doi.org/10.1007/s10554-008-9396-z)).

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Once the appropriate indication of CT is established for a specific patient, it is critical to choose the most appropriate protocol using state-of-the-art equipment. However, there is a wide variety of different protocols and a lack of standardization. This is confounded by rapid technical developments in the field of cardiovascular CT in the past few years [9, 10]. A central challenge in cardiovascular CT is the rapid motion of the heart and subsequent need to synchronize data acquired during several heartbeats to the identical cardiac phase in the RR-interval. Modern scanners with fast gantry rotation times and large number of detectors allow two general approaches. In helical acquisitions, data is acquired throughout the cardiac cycle but subsequent reconstructions use only data from limited, typically diastolic, windows ('spiral imaging with retrospective gating'). These protocols allow review of multiple reconstructions along the cardiac cycle in case of motion artifact and also for limited functional assessment. However, because X-ray exposure occurs throughout the cardiac cycle (despite reduced tube current outside a pre-specified, typically diastolic window = 'tube current modulation') these protocols are associated with higher radiation exposure. More recently, sequential acquisition has become possible for cardiovascular CT, where data is acquired only in the pre-specified window of the cardiac cycle ('axial imaging with prospective triggering') [11]. Because the X-ray tube is turned off outside the pre-specified window, radiation exposure is significantly reduced. However, the reduced dose comes at the price of less flexibility for additional reconstructions. Other recent developments include improved use of radiation filters, fast helical scanning, and use of lower tube current voltage (100 kV) [9, 10].

The choice between these different protocols is not well standardized, and the PROTECTION trial demonstrate that there are large differences in radiation exposure for cardiovascular indicated CT scans even in experienced centers [1]. In this cross-sectional, international, multicenter, observational study the estimated median radiation dose (dose-length product, DLP) in 1965 patients was $885 \text{ mGy} \times \text{cm}$ (IR 568–1259 $\text{mGy} \times \text{cm}$), which corresponds to an estimated radiation dose of 12 mSv. There was a high variability in median DLP values between study sites, ranging from 331 to 2146 $\text{mGy} \times \text{cm}$. In linear regression analysis several dose saving strategies

were independently associated with reduced radiation dose, including reduced scan length (5%; 95% CI, 4–6%), electrocardiographically controlled tube current modulation (–25%; 95% CI, –23 to –28%; applied in 73% of patients), 100-kV tube voltage (–46%; 95% CI, –42 to –51%; applied in 5% of patients), sequential scanning (–78%; 95% CI, –77 to –79%; applied in 6% of patients), and type of 64-slice CT system (for highest vs. lowest dose system, 97%; 95% CI, 88–106%). Importantly, the algorithms for dose reduction were not associated with deteriorated diagnostic image quality in this observational study.

The article by Gopal et al. [2] in this issue describe a retrospective analysis of CT scans performed in 149 consecutive patients. The authors compare prospective and retrospective protocols and the additional use of 100 kV scanning using 64-MDCT scanners. Two different voltages were utilized based on body habitus (100 kVp for a weight <85 kg, or standard 120 kVp for a weight >85 kg). Radiation doses and image quality (signal to noise ratio) was measured for each patient, and compared between different acquisition protocols. Use of 100 kVp reduced radiation dose by 41.5% using prospective triggering and 39.6% using retrospective imaging as compared to 120 kVp ($P < 0.001$). Use of prospective imaging reduced radiation exposure by 82.6% as compared to retrospective imaging ($P < 0.001$). Using both prospective imaging and 100 kV radiation dose was reduced by 90% ($P < 0.001$). The prospective ECG-triggered acquisition and 100 kVp images were of diagnostic quality, allowing adequate assessment in all patients.

The reduction of exposure associated with prospective imaging is larger than reported in other recent publications and the results may be limited by selection bias and small subgroups, but the trend is consistent with the literature. In particular, the absolute dose of 1.9 mSv for coronary CTA with prospective scanning at 100 kV appears achievable [11]. As pointed out by Achenbach in an accompanying editorial the goals of high diagnostic image quality and low radiation dose need to be balanced in individual patients, "even if it requires a little extra effort".

We hope that both the article by Gopal et al., and the upcoming Focus Issue will contribute to the discussion about appropriate use of computed tomography in cardiovascular imaging.

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