CT Angiography by Reduced Tube Voltage

More Than a Single Step*

James K. Min, MD, Troy M. LaBounty, MD

New York, New York

Many a man has taken the first step. With every additional step you enhance immensely the value of your first.

—Ralph Waldo Emerson (1)

Coronary computed tomographic angiography (CCTA) has emerged as a promising noninvasive test for detection and exclusion of coronary artery disease (CAD). Yet, CCTA is associated with non-negligible radiation doses, and physicians must consider both the benefit of diagnostic information derived from it as well as its potential risks.

Recently, lay and scientific reports have raised concerns regarding the radiation doses associated with CCTA. These published data remain confusing for the nonphysicist, given the complexity of measuring radiation exposure and estimating risk. Radiation imparted by CT is most easily described by the dose-length product (DLP), a summary measure of the integral of radiation dose and scan length. Yet the DLP method, although useful for ascribing absolute radiation exposure, does not account for organ-specific susceptibilities to radiation risk. For this, the effective biological radiation dose—measured in millisieverts (mSv)—is preferred and permits comparison of CCTA with other radiation-based medical tests.

Effective radiation doses can be determined by multiplication of the DLP by organ-specific conversion coefficients. The recommended conversion coefficient for CCTA is $0.014 \text{ mSv} \times \text{mGy}^{-1} \times \text{cm}^{-1}$ (2), although its accuracy for the latest-generation CCTA scanners is uncertain. There are numerous factors that can affect the radiation dose of any given CCTA exam, in contrast to nuclear medicine procedures, which use fixed amounts of radioisotopes with discrete quantifiable radiation doses. These variables—including z-axis length, tube current, tube current modulation, method of electrocardiography (ECG) gating, and tube voltage—can dramatically impact CCTA radiation dose by an order of magnitude or greater.

In this issue of JACC, Bischoff et al. (3) report on the latter of these methods to determine the impact of 100-kV tube voltage imaging on radiation dose and image quality. The study cohort of this analysis represented a pre-defined subgroup of the PROTECTION I (Prospective Multicenter Study on Radiation Dose Estimates Of Cardiac CT Angiography I) study and included 82 patients undergoing 100-kV imaging compared with 239 patients undergoing 120-kV imaging. Imaging by 100-kV tube voltage resulted in a 53% median effective dose lowering as compared with 120-kV tube voltage use (6 mSv vs. 14 mSv, $p < 0.001$). As might be expected, 100-kV CCTAs were associated with increased image noise, although diagnostic image quality was similar in both groups and did not seem to be influenced by body weight differences between groups.

This study is the latest within a contemporary series aiming to reduce radiation dose while preserving CCTA image quality. This study was well performed and, although the number of patients studied was small, demonstrated the feasibility of 100-kV CCTA imaging in a careful multicenter fashion. Yet, although the feasibility of this technique was illustrated, its generalized applicability

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From the Department of Medicine and Radiology, Weill Cornell Medical College, New York, New York.
was not. Indeed, amongst the 50 study sites that participated in the PROTECTION I study, only 16% employed 100-kV imaging. Even at sites that preferentially adopted this method, only 82 patients underwent 100-kV imaging, representing <5% of the entire PROTECTION I study population. With an upper-limit body mass index of 30 for 100-kV imaging—as has been suggested as reasonable for employment of this technique—this translates to 77.6% of patients who qualify for but did not undergo 100-kV imaging. This inconsistency in practice patterns is reflected amongst the greater PROTECTION I cohort, as evidenced by the 6-fold variation in radiation dose between study sites (4). Of note, no enrolling site in the PROTECTION I study employed 80-kV CCTA imaging, which—in smaller “proof of principle studies”—suggests a potential radiation dose reduction of almost 90% (5).

Given the multiplicity of other factors that can increase CCTA dose, it follows that modifications of these factors can similarly reduce dose, and this is in fact the case. The simplest of these adjustments is minimization of z-axis coverage—or the distance scanned in the supero-inferior direction—to the least amount necessary for complete coverage of the heart. Although seemingly obvious, alternate CCTA protocols that include a “triple rule out” of CAD, pulmonary emboli, and aortic dissection will require increased z-axis coverage and might double or even triple radiation dose.

Further, adjustments of tube current can reduce radiation dose. Tube current, as measured in milliamps (mA), can be adjusted in several ways. Automatic tube current modulation (ATCM) adjusts photon numbers imparted as the X-ray gantry rotates about the patient and reduces these numbers when scanning anterior-to-posterior while increasing these numbers from side-to-side, where a greater amount of tissue will require greater numbers of photons for equivalent image noise and constant image quality.

Dose modulation with retrospective ECG-gated CCTA is another method that permits reduced current. Because coronary motion is typically most quiescent (and thus, most often evaluable) during the diastasis phase of diastole, increasing current during the mid-diastolic period and reducing it during the remainder of the cardiac cycle advances high-quality images for coronary evaluation while reducing overall radiation.

As the traditional method for CCTA performance, retrospective ECG-gated acquisition permits concurrent evaluation of coronary arteries and cardiac function. Yet many individuals undergoing CCTA have undergone prior testing for cardiac function, and this information, although important, might be superfluous. In this regard, prospectively ECG-gated image acquisition (PGA) can be a very effective means of dose reduction for CCTA. PGA differs from retrospective ECG-gated CCTA in that image acquisition is acquired by a pure axial method without overlap. Image acquisition occurs by radiation “pulsing” during the mid-diastolic phase alone with only a small window of radiation exposure within the R-R interval. This method of CCTA image acquisition precludes assessment of cardiac function, because it is only imaged during diastole. Although theoretically image inevaluability could increase with PGA (as fewer phases are available), studies suggest that PGA can reduce effective biological radiation dose by >80%, with either equivalent or improved image quality (6,7).

In the PROTECTION I study, only 2.9% and 4.9% of study individuals underwent PGA scanning with 120-kV and 100-kV imaging, respectively, suggesting that radiation dose could be lowered even further by use of prospective axial triggering. The penetration of the aforementioned dose-reduction techniques into current practice outside of specialized centers—including 100-kV imaging—is not well known, but a recent registry suggests that “real world” practice is not as sanguine as the PROTECTION I study results would suggest. In a multicenter single-state registry, reported median doses of radiation during CCTA were 25 mSv before initiation of a quality improvement program and 13 mSv after (8); the post-intervention “improved” dose reflects roughly the 120-kV arm of the PROTECTION I substudy. These data suggest that systems-based methodologies are still needed for better training of technologists and physicians in dose reduction techniques in this still relatively nascent field of CCTA. In this regard, the study by Bischoff represents a significant additional step forward toward this goal, while concurrently enhancing all of the steps before it.

Reprint requests and correspondence: Dr. James K. Min, Assistant Professor of Medicine, Department of Medicine, Weill Cornell Medical College, 520 East 70th Street, K415, New York, New York 10021. E-mail: jkm2001@med.cornell.edu.
REFERENCES


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