News and Views From the Literature

Cardiac CT Angiography

Radiation Dose—How Effective Are We in Reducing Radiation Dose From Cardiac CT Angiography?

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Estimated Radiation Dose Associated With Cardiac CT Angiography

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Since the 64-slice computed tomography (CT) scanner became commercially available in 2004, its enhanced spatial and temporal resolution has allowed for accurate motion-free image acquisition of the coronary arterial system in a single breath-hold of approximately 10 to 15 seconds. The rise in cardiac CT angiography (CCTA) has subsequently escalated exponentially to become a commonly used noninvasive imaging modality for the evaluation of coronary artery disease (CAD). The American Heart Association has recommended using a 64-slice multidetector CT (MDCT) to refine risk profiling and select patients for more aggressive medical therapy in intermediate-risk patients for CAD.[1] However, CCTA requires use of ionizing radiation and the potential risk of developing cancer from radiation exposure is a recent public health concern.[2] In the Prospective Multicenter Study On Radiation Dose Estimates of Cardiac CT Angiography in Daily Practice I (PROTECTION I) study, the researchers sought to estimate the radiation

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dose associated with a typical clinical CCTA scan in daily practice, the prevalence of use, and the effectiveness of radiation dose-saving algorithms (DSAs), as well as the independent predictors attributing to radiation dose.[3]

In a cross-sectional, multicenter, observational study of 50 international sites, the estimated radiation dose was calculated for 1965 consecutive patients receiving clinical CCTA during a 10-month period between February and December 2007. The CT scanners examined in the study varied from 16-slice to 64-slice systems (including the dual-source CT) from 4 vendors. Coronary artery assessment was the main indication for scanning (82%). The other 18% included indications for the evaluation of bypass grafts (12%); planning for electrophysiology studies (2%); "triple rule-out" for acute chest pain to exclude CAD, pulmonary embolism, and aortic dissection (2%); and cardiac anatomy and coronary anomalies (2%). The primary endpoint was radiation dose estimates, which were approximated by dose length product (DLP), calculated from the volume CT dose index (CTDI) and scan length. Secondary endpoints were the frequency and clinical utility of 4 DSAs, which included automated exposure control, electrocardiographically controlled tube current modulation (ECTCM), reduced tube voltage of 100 kilovolt (kV) from 120 kV, and sequential (or prospectively triggered) scanning.

The authors found that the median DLP for all scans was 885 milliGray (mGy) × centimeter (cm) (interquartile range [IQR], 568-1259 mGy × cm), which, when multiplied by the chest-weighting factor of 0.014, corresponded to a median estimated radiation dose of 12 millisievert (mSv) (IQR, 8-18 mSv). Most interestingly, the median DLP varied drastically from site to site with highly variable effective radiation doses of 5 mSv to 30 mSv, with the majority of sites located in Europe (15 in Germany, 15 in Western Europe) and only 5 sites located in the United States and Canada. In the evaluation of system-specific radiation dose, due to the paucity of patients (72; 4%) and only 3 sites with the 16-slice CT system, the remainder of their analyses included only the 64-slice CT systems (1893 patients; 96% of the CT scans). Of the 1546 patients undergoing CCTA for coronary artery assessment, 77% (1197) had a body mass index (BMI) between 20 and 30 kg/m^2, and the median radiation dose was slightly less at 11.6 mSv. Interestingly, the Siemens 64-slice single-source scanner (Siemans SOMATOM® Sensation Cardiac 64-slice scanner; Siemens Medical Solutions USA Inc., Malvern, PA) had the lowest median dose (9 mSv), followed by the Philips 64 (10 mSv) (Philips Brillance 64-slice CT scanner; Philips Healthcare, Andover, MA), the Siemens 64 Dual-Source (11 mSv), the Toshiba 64 (15 mSv) (Toshiba Aquilion™ 64; Toshiba America Medical Systems, Tustin, GA), and the highest dose with the GE 64 scanner (19 mSv) (GE Lightspeed CT 64-slice scanner; GE Healthcare Global Diagnostic Imaging, Waukesha, WI) ($P < .001$).

Of the 4 DSAs, ECTCM was the most frequently used (79%) and resulted in a DLP reduction of 25%. Sequential scan algorithm (dose reduction of 78%) and lower tube voltage to 100 kV (dose reduction of 46%) resulted in significantly less radiation dose without impairing diagnostic image quality, they were both used in only 6% of CCTAs. Of note, automated exposure control was used in 38% of patients (n = 580) but did not result in any significant reduction in radiation dose ($P = .09$).

In multivariable linear regression analysis, independent factors associated with higher radiation doses included greater patient weight, increased scan length, and nonsinus rhythm, whereas factors associated with lower radiation dose included ECTCM, lower tube voltage, sequential scanning, site experience in CCTA, and higher volume of CCTAs performed per month. Within this multivariable model, as compared with the single-source Siemens 64 CT scanner, the other four 64-slice CT systems were independently associated with a higher radiation dose.

The authors concluded that median doses of CCTA differ significantly among sites and CT systems. ECTCM was the most frequently used DSA, but resulted in modest dose reduction as compared with the infrequently used tube voltage kV reduction and sequential scanning. Thus, these DSAs are underutilized and efforts to increase their use should be encouraged.

The findings presented in the PROTECTION I study are important and warrant discussion. Especially surprising is the variability in doses among study sites and CT systems. Despite the availability of multiple DSAs and the utilization of ECTCM in the majority of scans, the median estimated radiation dose of 12 mSv could be improved upon. Although this estimated dose may appear high, it is comparable and may even be lower than some nuclear stress examinations, which average around 10 mSv but can range to above 20 mSv.[4] Whereas nuclear cardiac scans provide perfusion data and the functional significance of CAD, new research has shown that adenosine-stress CT is feasible.[5] Combining anatomic, perfusion, and functional data in a single test could be potentially cost effective. However, the incremental value of functional assessment by CCTA needs to be balanced with its higher radiation dose, given the availability of other nonradiation modalities such as echocardiography. Although diagnostic cardiac angiography is reported to have an estimated radiation dose of 7 mSv,[6] this test is invasive and carries its own procedural risks.

In the PROTECTION I study, the analyses performed for the efficacy of radiation reduction used a single DSA in the scanning protocol, but in reality multiple DSAs can be used simultaneously. It is unclear from this study how frequently these DSAs are used together and what the effects of combining multiple DSAs have on image quality and diagnostic accuracy. Interestingly, although the PROTECTION I study evaluates tube voltage reduction, it lacks mention of lowering the tube current, a commonly used DSA. The authors do mention automated exposure control, which changes the tube current dependent on patient body habitus. However, in patients with increased BMI, automated exposure control does not change tube current, thus negating the benefit of this DSA for an overall population.

It is important to generally note that the risk of death from a motor vehicle accident and second-hand smoke is 10- to 20-fold higher than the risk of a fatal malignancy from a single CCTA.[6] From a societal perspective, encouraging the utilization of seatbelts and smoking cessation may save more lives when targeting an entire population. However, radiation dose is cumulative with respect to the estimated risk of malignancy.[7] Thus, to comply with the “As Low As Reasonably Achievable” ALARA principle, multiple, repeated CCTAs should be avoided and DSAs used whenever possible, without the compromise of diagnostic image quality. When used, these algorithms have been currently shown to be effective in reducing radiation dose.[8]

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Although the sequential scanning or prospectively triggered CT scans have the greatest reduction in radiation dose (78%), this algorithm requires the patient to have a regular and slow heart rate for diagnostic image quality.[9] Sequential scanning modulates the scanner such that the source is only turned “on” for a particular predefined phase of the cardiac cycle and prospectively acquires the image. If there is heart rate variability, the quality of the scan decreases significantly and misregistration of sequential images can occur.[3] Furthermore, this DSA does not allow for any functional analysis, which may be warranted if regional and global wall motion assessments are desired, and does not allow for any valvular evaluation.

If functional analysis is needed, a retrospectively gated CT scan should be performed. Methods of DSA for retrospectively gated scans include ECTCM, tube voltage and current reduction, and scan range reduction. ECTCM can decrease tube current during desired phases of the cardiac cycle. This allows for both lower radiation doses as well as some functional analysis. With the use of ECTCM, the tube current lowers to 20%, or 4% of its maximum, during phases of the cardiac cycle that are not of interest. With the decreased current, images are noisier and therefore the functional assessment may be less accurate.[10] Reducing the tube voltage from 120 kV to 100 kV will also allow for functional assessment and has proven to be effective in lowering total radiation dose to the patient. However, reducing the tube voltage increases the background-to-noise ratio and can affect image quality and thus should be used in thinner patients, with a suggested BMI cut-off of 25 kg/m^2.[11] In addition, minimizing the scan range will also decrease the radiation dose and still allow for functional assessment without affecting image quality.

As CT technology continues to develop, newer CT scanners are becoming available. With wider detector arrays and increased slice numbers, full cardiac volume coverage may be possible in 1 heart beat, resulting in significant radiation dose reduction. The 256- and 320-slice CT scanners are currently commercially available, and the radiation doses are reported at lower values than for the 64-slice scanners.[12,13] Most recently, dual-source SOMATOM Definition Flash (Siemens), which uses two 128-slice detectors, has been developed and promises submillisievert cardiac CT scans.

The PROTECTION I study demonstrated both the variation in CCTA doses and how effective the use of DSAs can be. These algorithms should be implemented whenever possible, although a high image quality should be maintained as much as possible. ■

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