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Cardiac-Specific Conversion Factors to Estimate Radiation Effective Dose From Dose-Length Product in Computed Tomography

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ABSTRACT

OBJECTIVES This study sought to determine updated conversion factors (*k*-factors) that would enable accurate estimation of radiation effective dose (ED) for coronary computed tomography angiography (CTA) and calcium scoring performed on 12 contemporary scanner models and current clinical cardiac protocols and to compare these methods to the standard chest *k*-factor of 0.014 $mSv \cdot mGy^{-1}cm^{-1}$.

BACKGROUND Accurate estimation of ED from cardiac CT scans is essential to meaningfully compare the benefits and risks of different cardiac imaging strategies and optimize test and protocol selection. Presently, ED from cardiac CT is generally estimated by multiplying a scanner-reported parameter, the dose-length product, by a *k*-factor which was determined for noncardiac chest CT, using single-slice scanners and a superseded definition of ED.

METHODS Metal-oxide-semiconductor field-effect transistor radiation detectors were positioned in organs of anthropomorphic phantoms, which were scanned using all cardiac protocols, 120 clinical protocols in total, on 12 CT scanners representing the spectrum of scanners from 5 manufacturers (GE, Hitachi, Philips, Siemens, Toshiba). Organ doses were determined for each protocol, and ED was calculated as defined in International Commission on Radiological Protection Publication 103. Effective doses and scanner-reported dose-length products were used to determine *k*-factors for each scanner model and protocol.

RESULTS *k*-Factors averaged 0.026 $mSv \cdot mGy^{-1}cm^{-1}$ (95% confidence interval: 0.0258 to 0.0266) and ranged between 0.020 and 0.035 $mSv \cdot mGy^{-1}cm^{-1}$. The standard chest *k*-factor underestimates ED by an average of 46%, ranging from 30% to 60%, depending on scanner, mode, and tube potential. Factors were higher for prospective axial versus retrospective helical scan modes, calcium scoring versus coronary CTA, and higher (100 to 120 kV) versus lower (80 kV) tube potential and varied among scanner models (range of average *k*-factors: 0.0229 to 0.0277 $mSv \cdot mGy^{-1}cm^{-1}$).

CONCLUSIONS Cardiac *k*-factors for all scanners and protocols are considerably higher than the *k*-factor currently used to estimate ED of cardiac CT studies, suggesting that radiation doses from cardiac CT have been significantly and systematically underestimated. Using cardiac-specific factors can more accurately inform the benefit-risk calculus of cardiac-imaging strategies. (J Am Coll Cardiol Img 2017;■:■–■) © 2017 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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ABBREVIATIONS AND ACRONYMS

CT = computed tomography

CTA = computed tomography angiography

DLP = dose-length product

ED = effective dose

kVp = kilovolt peak

MOSFET = metal-oxide semiconductor field-effect transistor

Cardiac computed tomography (CT) has experienced tremendous advances in the past decade. Growing evidence supports the role of coronary artery calcium scoring for risk stratification, and some guidelines now recommend it as a reasonable test for asymptomatic adults at intermediate risk (1). Coronary computed tomography angiography (CTA) has demonstrated high accuracy for diagnosing obstructive coronary artery disease (2), the ability to improve prognostication (3), and in some settings, capability to more rapidly and cost-effectively diagnose chest pain in patients (4). In many clinical contexts, coronary CTA now stands as an option that can be selected to guide optimal patient management and incorporated into clinical pathways (5,6).

Each cardiac imaging modality has strengths and weaknesses, and optimizing management requires a weighting of these features for each option in the context of the patient and clinical question. One particular concern for coronary CTA is its associated radiation burden. Although initial studies found high radiation dose and risk (7), numerous technical advances such as prospectively triggered axial scan modes, lower tube potentials, and iterative image reconstruction now enable, in the best-case scenario, performing coronary CTA with extremely low radiation burden, comparable to that of several chest radiographs (8). However, such low coronary CTA doses require a confluence of several factors: availability of these technical advances which are not all implemented on entry level scanners, operator expertise, favorable patient heart rate and rhythm and habitus, and willingness to tolerate some image noise and limitation in the number of phases of the cardiac cycle available for interpretation. Thus, although some patients will receive extremely low doses, many will still receive considerably higher doses. Indeed, contemporary coronary CTA practice is characterized by a wide range of radiation doses among laboratories and among patients (9), and thus the benefit-risk calculus of coronary CTA and its comparison with other modalities may vary depending on the particular radiation dose. In particular, when taking care of patients with chest pain, the physician's choice between coronary CTA and nuclear myocardial perfusion imaging may depend in part on radiation burden. Such comparison is predicated on accurate radiation dosimetry for both examinations.

The single parameter most commonly used to compare ionizing radiation burdens among different imaging modalities, scanners, and protocols is the effective dose (ED), in units of millisieverts (mSv). Effective dose characterizes whole-body exposure from a nonuniform radiation exposure as a weighted average of organ absorbed doses. It is presently defined in accordance with a formulation specified by the International Commission on Radiological Protection (ICRP) in its Publication 103 (10) as the sum over all specified organs of doubly weighted organ-absorbed doses, where weights reflect both the relative sensitivity of each organ to radiation and the radiation source. Effective dose is not without limitations (11,12); for example, the organ weights are averages for all ages and both sexes, thus precluding a sex-specific ED; and ED is not patient-size dependent. Accordingly, ED is not designed for patient-specific radiation risk assessment. Nevertheless it remains the only metric that can be easily used to compare whole-body radiation exposure across modalities and protocols. This has led to its great popularity in clinical publications and practice. ICRP Publication 103 (10) updated the radiation weighting factors for each organ based

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