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Coronary calcium scans and radiation exposure in the multi-ethnic study of atherosclerosis

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Abstract

With the increasing use of coronary artery calcium (CAC) scoring to risk stratify asymptomatic patients for future cardiovascular events, there have been concerns raised regarding the theoretical risk of radiation exposure to this potentially large patient population. Newer CT protocols have sought to reduce radiation exposure without compromising image quality, but the reported radiation exposures in the literature remains widely variable (0.7–10.5 mSv). In this study, we report the radiation exposure of calcium scoring from our MESA cohort across several modern CT scanners with the aim of clarifying the radiation exposure of this imaging modality. To evaluate the mean effective doses of radiation, using dose length product, utilized for coronary artery calcium scoring in the MESA cohort, in an effort to understand estimated population quantity effective dose using individual measurements of scanner radiation output using current CT scanners. We reviewed effective dose in milliSieverts (mSv) for 3442 participants from the MESA cohort undergoing coronary artery calcium scoring, divided over six sites with four different modern CT scanners (Siemens64, Siemens Somatom Definition, GE64, and Toshiba 320). For effective dose calculation (milliSieverts, mSv), we multiplied the dose length product by conversion factor k (0.014). The mean effective dose amongst all participants was 1.05 mSv, a median dose of 0.95 mSV. The mean effective dose ranged from 0.74 to 1.26 across the six centers involved with the MESA cohort. The Siemens Somatom Definition scanner had effective dose of 0.53 (n = 123), Siemens 64 with 0.97 (n = 1684), GE 64 with 1.16 (n = 1219), and Toshiba 320 with 1.26 mSv (n = 416). Subgroup analysis by BMI, age, and gender showed no variability between scanners, gender, ages 45–74 years old, or BMI less than 30 kg/m^2. Subjects over age 75 yo had a mean effective dose of 1.29 ± 0.31 mSv, while the <75 yo subgroup was 0.78 ± 0.09 mSv ($p < 0.05$). Effective doses in subjects with BMI > 40 kg/m^2 was significantly greater than other subgroups, with mean dose of 1.47 ± 0.51 mSv ($p < 0.01$). Using contemporary CT scanners and

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Compliance with ethical standards

Conflict of interest Matthew Budoff has received research grants from NIH and General Electric. No other author has conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Human and animal studies This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

protocols, the effective dose for coronary artery calcium is approximately 1 mSv, an estimate which is consistently lower than previously reported for CAC scanning, regardless of age, gender, and body mass index.

Keywords

Radiation; Calcium scanning; Coronary artery disease; Coronary artery calcium

Introduction

Cardiac computed tomography (CT) imaging is a valuable tool for noninvasively evaluating coronary artery disease (CAD). Coronary artery calcium (CAC) scoring is a highly sensitive test for detecting CAD, and the test has an established role in risk stratifying patients who have intermediate risk of CAD events by Framingham scoring [1]. The American College of Cardiology Foundation/American Heart Association (ACCF/AHA) guidelines indicate that CACS can be used to assess cardiovascular risk in asymptomatic adults at intermediate risk (10–20 % 10-year risk; class IIa indication), as well as in individuals with diabetes (class IIa indication), and individuals at low–intermediate risk (6–10 % 10-year risk, class IIb indication) [2]. The Screening for Heart Attack Prevention and Education (SHAPE) guidelines recommend CAC scanning for all asymptomatic patients (men aged 45–75 yo and women aged 55–75 yo) in this intermediate risk group [3]. The new American College of Cardiology/American Heart Association Guidelines for the Treatment of Blood Cholesterol [4] advocate for use of coronary calcium scanning when medical decision making is uncertain, and the Prevention guidelines from the same organizations state “The Work Group notes the contention that assessing CAC is likely to be the most useful of the current approaches to improving risk assessment among individuals found to be at intermediate risk after formal risk assessment [5].” This medical information may help physicians better manage cardiac risk factors and make informed decisions about cholesterol medication doses and necessity. This clinical benefit must be weighed against the risks of ionizing radiation exposure. A dated review of multiple imaging centers reported wide variation in dosing, between 0.8 and 10.5 mSv, with a mean of 2.3 mSv [6]. While low radiation doses have been reported in the literature, confusion about the typical radiation dose with CAC scanning remains unclear, and several advancements in CT imaging have resulted in radiation dose reductions since prior estimates.

The Multi-Ethnic Study of Atherosclerosis (MESA) is a multicenter study of a large, ethnically diverse cohort of individuals without clinically evident CVD at study baseline in whom participants had CT scans for presence of CAC. The scanners used in the most recent examination (2010–2012) included four different 64 + CT scanners. We report recent radiation dosing data from the multi-scanner, multicenter MESA database. The objective is to provide data on the radiation dosing currently required for CAC screening using contemporary scanners. In this study, we report the radiation exposure of calcium scoring from our MESA cohort across several modern CT scanners and centers with the aim of clarifying the risk and benefits of this imaging modality. We sought to evaluate the mean effective doses of radiation, using dose length product, required for coronary artery calcium scoring in the MESA cohort in an effort to help update expected radiation exposure for this imaging modality.

Methods

The MESA cohort at exam 5 consists of 3442 men and women aged 45–84 years who were recruited from 6 US communities (Baltimore, Md; Chicago, Ill; Forsyth County, North Carolina; Los Angeles County, California; northern Manhattan, NY; and St. Paul, Minn). Participants were free of clinical CVD at baseline. Participants were excluded if they had a history of any of the following procedures: coronary bypass surgery, balloon angioplasty, heart valve replacement, pacemaker or defibrillator implantation, or any other cardiac surgery. The study was designed to include whites, blacks, Hispanics, and Chinese. Sampling and recruitment procedures have been described in detail previously [7]. Demographics outlined in Table 1.

Computed tomography techniques

Scanning centers assessed coronary calcium by chest CT with a cardiac-gated multidetector CT scanner. Four scanner types were used: Toshiba One (320 slices, Toshiba Medical Systems, Japan), Siemens 64 (Siemens, Erlangen, Germany), Siemens Somatom Definition (Siemens, Erlangen, Germany), and General Electric VCT (64 slices, General Electric, Milwaukee, WI). Certified technologists scanned all participants over phantoms of known physical calcium concentration. A radiologist or cardiologist read all CT scans at a central reading center (Los Angeles Biomedical Research Institute at Harbor–UCLA in Torrance, California). Each scanner used a 25 cm field of view, two X-ray tubes were used for the Dual Source (Siemens Somatom Definition) and electrocardiograph gating was used in all scanners.

Radiation effective dose estimates

There was no individual dosimeters applied to patients but rather use of dosimetry metrics dose length product [DLP]) individually reported from each scan. CT examination radiation reports are based on a dose metric known as the $CTDI_{vol}$, which is measured in a cylindrical acrylic phantom placed at the scanner isocenter [17]. The $CTDI_{vol}$ was obtained using daily phantom measurements, individual phantoms based upon each scanner's manufacturer. In CT, the total amount of radiation incident on the patient, known as the DLP, is the product of the $CTDI_{vol}$ and scan length (in centimeters) and is measured in milligray-centimeters. We utilized the reported DLP from each individual scan to estimate the effective dose for each study done in MESA. Conversion of doses from DLP to milliSieverts was done using a k constant of 0.014 [16], which has been the standard k for chest CT. Thus, we multiplied DLP by the k constant to obtain the effective dose values in milliSieverts (mSv). Limitations of using the k constant include when patient size differs from the “standard” phantom size used to derive the k factors that convert DLP into effective dose.

Data analyses

The study population for the present analysis includes all MESA participants from April 2010 to February 2012 who had data available on radiation. Radiation exposure was reported as dose length product (DLP). Within this group, we stratified dose by age, gender, body mass index (BMI), CT scanner used, and location of study. Age was stratified by age greater than or less than 65 years. We stratified BMI by values of less than 25, 25–30, and greater than 30.

Results

Participants

A total of 3442 participants were included with data related to age, gender, body mass index (BMI), and race-ethnicity. The mean effective dose amongst all participants was 1.05 ± 0.45 mSv, a median dose of 0.95 mSV. These doses were well-distributed between different geographic locations and scanners. The mean effective dose ranged from 0.74 to 1.26 across the six centers involved with the MESA cohort. The Siemens Somatom Definition scanner had effective dosing of 0.53 (n = 123), Siemens 64 with 0.97 (n = 1684), GE 64 with 1.16 (n = 1219), and Toshiba 320 with 1.26 (n = 416). Subgroup analysis by BMI, age, and gender showed no variability between genders, ages 45–74 years old, or BMI less than 30. Subjects over age 75 yo had a mean effective dose of 1.29 ± 0.31, while the <75 yo subgroup was 0.78 ± 0.09 ($p < 0.05$). Effective doses in subjects with BMI > 40 were also significantly greater than other subgroups, with mean radiation 1.47 ± 0.51 ($p < 0.01$).

There was little difference in effective dose between BMI < 25 (1.03 mSV), BMI greater than 25 but less than 30 (1.00 mSV), and for BMIs greater than 30 (1.07 mSV) (*p* = n.s.). No significant exposure difference was found between males (1.00 ± 0.45 mSV) and females (1.01 ± 0.44 mSV). There were no significant differences in effective doses between race-ethnic groups or by age, except in those > 75 years old.

Discussion

Our results demonstrate that coronary calcium scoring results in a mean exposure of 1 mSv across multiple scanners and centers. We found no significant difference in effective dose between genders, weight classes, or ages up to age 75 years. It should be noted that in large patients, the organ doses cannot necessarily go up just because volume $CTDI_{vol}$ and mSv goes up. A great deal of attenuation occurs in the adipose tissue. These findings do not mean that large patients receive larger organ doses. Prior reports of doses and subsequent cancer risks are most commonly estimated by a study by Kim et al. [6] which calculated cancer risks based on a median effective dose of 2.3 mSv (more than twice the current doses observed), with a range that goes up to 10.5 mSv for this test, greatly over-exaggerate the radiation risk associated with this test. Evidence of the issues this higher radiation exposure estimate raises is seen in the new Prevention Guidelines by the ACC/AHA [5]. While it was recommended in these guidelines and 2010 guidelines for risk stratification of asymptomatic adults, concerns were still raised, due to “issues of cost and radiation exposure related to measuring CAC” [5]. The theorectical increased risk of long-term effects has not been shown to actually exist at the low radiation doses associated with either background radiation or CT scanning. The clinical benefit of scanning must be weighed against the potential risks of ionizing radiation [8, 9].

All CT operators should follow the principle of administering radiation “as low as reasonably achievable” (ALARA) without compromising diagnostic accuracy. Low radiation doses as low as 1 mSv have been reported for CAC scoring using prior generation scanners [10, 11]. Coronary calcium scoring has equivalent radiation exposure to mammography, and similar to the level of background radiation exposure experienced over 3–4 months in most cities [10].

The risk of low dose radiation exposure remains speculative. Radiation dosing models that define malignancy risk are mainly based upon long term outcome data using data from Japanese atomic bomb survivors and medically-exposed cohorts, used to estimate the excess lifetime risk of radiation-induced cancer [6]. Based upon current estimates, a single CAC scan at 1 mSv would increase the lifetime risk of fatal malignancy by 0.005 % for a number needed to harm of 1 out of 20,000 patients [6]. This is a persistent limitation in discussing the long term risks of medical imaging, though this should not diminish the responsibility of physicians in the field of cardiac imaging from operating under the principle of “as low as reasonably achievable.” Given the potential harm of 1/20,000, the understanding of number needed to benefit also is important. Based on the American College of Cardiology/American Heart Association guidelines [4, 5], those persons with scores >300 and those >75th percentile by age and gender would be up-classified in risk, requiring high intensity statin treatment. Thus, the number of patients identified as high risk (about 1/3 of those screened), would far outweigh the cancer risk of screening in this population. Thus, the potential benefit outweighs the potential risk in the case of screening for heart disease.

The lower radiation exposure reported here reflects efforts to reduce radiation exposure in the field of cardiac CT. Retrospectively gated helical acquisition was the first technique of cardiac CT imaging, exclusively used for calcium scoring until 1998 [12]. Retrospective gating, with its redundant image acquisition, remains preferred for patients with high heart rates (>60) and arrhythmias. However, this redundancy significantly increases effective doses with an average dose of 3 mSv [13]. By switching to prospective ECG gating, timing acquisition to mid-diastole, effective doses are reduced 18–47 % in cardiac CT imaging [14]. Prospective gating was primarily used in this study and should be the preferred approach resulting in a median dose of only 1 mSv exposures. Demonstrating the real world doses of <1 mSv, rather than higher outdated citations of dose, is critically important as we continue to incorporate this measure in clinical guidelines and routine practice.

Improvements in radiation dosing techniques have worked in tandem with advancements in imaging quality. Multiple strategies can minimize radiation exposure without compromising image quality. Further techniques not employed in MESA would likely decrease radiation dosing further. Reductions in tube voltage from 120 to 100kVp significantly reduce radiation, especially in thinner patients [13–15], however increased CAC scores may be encountered as calcium attenuation values go up as kVp decreases. Iterative reconstruction can significantly reduce radiation in low dose CT scans [16]. The iterative process results in the estimated X-ray photon distribution getting closer and closer to the true x-ray photon distribution. The current radiation doses may be further reduced with wider application of these techniques, especially in patients with lower body mass index [15, 17, 18]. The acquisition protocols generally followed the current Society of Cardiovascular Computed Tomographic guidelines on acquisition of CAC scans [13].

Limitations

We did not employ individual dosimeters on patients to measure organ dose, but rather relied on the commonly used metrics measured from the CT scanner for each participant.

The calculation of effective dose (mSV) is based upon the weighting factor, which does not vary based upon age, body habitus or gender. It is known that larger patients, who may receive higher DLP, actually absorb less or similar radiation at the target organs.

Radiation exposure from medical imaging is an important consideration as advancements provide further medical information to help physicians care for their patients. Imaging centers should consistently employ strategies to minimize radiation exposure, which will ensure the low radiation exposure demonstrated in our study regardless of scanner model or body type.

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Table 1

Baseline demographics of the cohort

	n	Mean ± SD or (%)
Age	3646	69.5 ± 9.3
Gender		
Female	1909	52.4 %
Male	1737	47.6 %
Race/ethnicity		
White	1439	39.5 %
Asian	440	12.1 %
African-American	991	27.2 %
Hispanic	776	21.3 %
BMI	3642	28.6 ± 5.5
Diabetes mellitus		
Yes	721	19.8 %
No	2925	80.2 %
Hypertension		
Yes	2183	59.9 %
No	1461	40.1 %
Hyperlipidemia		
Yes	1428	39.2 %
No	2218	60.8 %
HDL	3612	55.6 ± 16.7
LDL	3595	105.1 ± 32.4
Triglycerides	3612	109.7 ± 61.6