



Radiation exposure and coronary artery calcium scans in the society for heart attack prevention and eradication cohort

Amish A. Patel^{1,3} · Jeffrey Fine² · Morteza Naghavi² · Matthew J. Budoff^{1,2}

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Abstract

Coronary artery calcium (CAC) scoring is used in asymptomatic patients to improve their clinically predicted risk for future cardiovascular events. Current CT protocols seek to reduce radiation exposure without diminishing image quality. Reported radiation exposure remains widely variable (0.8–5 mSv) depending on the type of protocol. In this study, we report the radiation exposure of CAC scoring from the Society for Heart Attack Prevention and Eradication (SHAPE) early detection program cohort sites, which spanned multiple centers using 64-MDCT (multi-detector computed tomography) scanners. We reviewed radiation exposure in milliSieverts (mSv) for 82,214 participants from the SHAPE early detection program cohort who underwent CAC scoring. This occurred over a 2.5-year period (2012–2014) divided among 33 sites in 7 countries with four different types 64-MDCT scanners. The effective radiation dose was reported as mSv. Mean radiation dosing amongst all 82,214 participants was 1.03 mSv, a median dose of 0.94 mSv. The mean radiation dose ranged from 0.76 to 1.31 mSv across the 33 sites involved with the SHAPE program cohort. Subgroup analysis by age, gender or body mass index (BMI) less than 30 kg/m² showed no variability. Radiation dose in patients with BMI > 30 kg/m² were significantly greater than other subgroups ($\mu = 1.96$ mSv, $p < 0.001$). The use of 64-MDCT scanners and protocols provide the effective radiation dose for CAC scoring, which is approximately 1 mSv. This is consistently lower than previously reported for CAC scanning, regardless of scanner type, age or gender. In contrast, a greater BMI influenced mean radiation doses.

Keywords Coronary artery calcium · Radiation · Cardiac computed tomography

Introduction

Cardiac computed tomography (CT) Imaging remains a valuable tool in assessing coronary artery disease (CAD). It allows for the visualization of the heart by attaining thin slices of cardiac anatomy and coronary arteries. This can be used to identify and quantify coronary artery calcium (CAC), which is an established surrogate for atherosclerosis or CAD by assigning a CAC score [1]. The updated American College of Cardiology Foundation/American

Heart Association (ACC/AHA) guidelines for the Treatment of Blood Cholesterol supports the use of CAC scoring in intermediate risk patients when clinical decision making is indeterminate [2]. The ACC/AHA Guideline for Assessment of Cardiovascular Risk in Asymptomatic Adults indicated CAC scoring to be a class IIA recommendation, which suggested it was reasonable to assess asymptomatic adults at intermediate risk (10–20%, 10-year Framingham Risk), as well as adults with diabetes (class IIA recommendation), and adults with low-intermediate risk (6–10%, 10-year Framingham Risk, class IIB recommendation) [3].

These guidelines assist clinicians in the decision making process to better manage cardiac risk factors. The clinical benefit of CAC scoring should always be weighed against the risks of radiation exposure. A review of imaging at multiple centers reported a wide variation in radiation dosing, between 0.8 and 10.5 mSv, median 2.3 mSv [4]. Current CT protocols seek to reduce radiation exposure without diminishing image quality. A recent study of the Multi-Ethnic Study of Atherosclerosis (MESA) of 3442 participants

✉ Matthew J. Budoff
mbudoff@labiomed.org

¹ Division of Cardiology, Los Angeles Biomedical Research Institute at Harbor-UCLA Medical Center, Torrance, CA 90502, USA
² Society for Heart Attack Prevention and Eradication Program, Palo Alto, CA, USA
³ Riverside School of Medicine Department of Cardiovascular Medicine, University of California, Riverside, CA, USA

reported a range of 0.74–1.26 milliSieverts (mSv), mean 1.05 mSv [5].

The society for heart attack prevention and eradication (SHAPE) early detection program is a multicenter study of a large cohort of asymptomatic individuals without known cardiovascular disease (CVD) at baseline whom were community referred for CAC scans. Over a 2.5-year period (2012–2014) we reported radiation dosing of four different quality 64-MDCT scanners across the multicenter SHAPE cohort. We evaluated the mean radiation doses per year, using dose length product, required for CAC scoring in an effort to help update predicted radiation exposure in a large cohort using this type of CT imaging modality.

Methods

The SHAPE cohort consists of 82,214 men and women individuals aged 22–84 years who from 18 U.S communities (Los Angeles, CA, Phoenix, AZ, Harrisburg, PA, Tampa FL, Springfield, MO, Richmond, VA, Rogers, AR, Dallas, TX, New York, NY, Detroit, MI, Houston, TX, Huntington, WV, Bend, OR, Philadelphia, PA, Framingham, MA, Bakersfield, CA, Tyler, TX, Plano, TX) in 33 medical facilities (25 hospitals, 4 practices/clinics, 4 imaging centers) in 7 different countries (USA, Malta, Australia, Portugal, Turkey, France, United Arab Emirates) between January 2012 and June 2014. Referral basis were majority from community physicians (59%), with self-referral being (39%) and employer referral (2%). Participants were asymptomatic without known CVD at baseline. Exclusion included a history of any of the following procedures: balloon angioplasty or percutaneous intervention, coronary bypass surgery, heart valve replacement, pacemaker or defibrillator implantation, or any other cardiac surgery. Demographics outlined in Table 1.

Computed tomography techniques

CAC score was assessed by Cardiac CT with cardiac-guided multi-detector CT scanner. Four scanner types were used: Toshiba Aquilion (64 Slices, Toshiba Medical Systems, Japan), Philips Brilliance (64 Slices, Amsterdam, Netherlands), Siemens Sensation 64 (64 Slices, Siemens, Erlangen, Germany), and General Electric VCT (64 Slices, General Electric, Milwaukee, WI). All participants were scanned by certified technologists over phantoms of known physical calcium concentration. Either a cardiologist or radiologist read all CT scans. For all studies, prospective ECG-triggering CT acquisition was used for non-contrast CT. Scan parameters were obtained as follows: 2.5 or 3 mm slice thickness, 30–35 mm field of view, 512 × 512 matrix size, and peak tube voltage of 120 kVp. Tube current was 300–550

Table 1 Baseline demographics for SHAPE cohort

	n	Mean ± SD or (%)
Age (years)	82,214	54.3 ± 13
Gender		
Male	44,396	54%
Female	37,818	46%
Ethnicity		
White/Caucasian	56,728	69%
Black/African-American	10,688	13%
Asian	6577	8%
Hispanic/Latino	4933	6%
Other	3288	4%
Body mass index (kg/m ²)	82,214	28.3 ± 12
Family history of heart disease	31,241	38%
Hyperlipidemia	21,376	26%
Diabetes mellitus	15,621	19%
Hypertension	13,976	17%
Tobacco user	13,154	16%
Low HDL	5755	7%
Obesity	4933	6%

milliamperes (mA), based upon body weight utilizing automatic exposure control systems. Iterative reconstruction was not used by any center for CAC acquisition. Iterative reconstruction does not affect acquisition.

Radiation dose estimates

No individual dosimeters were applied to patients but rather a use of dosimetry metrics (volume CT dose index [CTDI vol] and dose length product [DLP]) were individually reported from each scan. The radiation reports of each CT examination were based on a dose metric known as the CTDI, which is measured in a cylindrical acrylic phantom placed at the scanner isocenter [6]. CTDI were obtained using daily phantom measurements, individual phantoms were based upon each scanner's manufacturer (Siemens, GE, Toshiba, Phillips). The total amount of radiation incident on each patient during a CT, known as the DLP, is the product of the CTDI volume and scan length (in centimeters) and is measured in milligray-centimeters. We utilized the reported DLP from each individual scan to estimate the effective radiation dose for each study done in SHAPE. Conversion of radiation doses from DLP to mSv was done using a k constant of 0.014 [7] which has been the standard k for chest CT. Therefore, we multiplied DLP by the k constant to obtain the effective radiation dose values in mSv. The limitations of using k constant are when patient size differs from the standard phantom size used to calculate the k factors that convert DLP into effective dose.

Data analysis

The study population for the present analysis includes all SHAPE cohort participants from January 2012 to June 2014 who had data available on radiation dosing. Radiation dosing was reported as dose length product (DLP). Within this group, we stratified radiation dosing 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 30, and greater than 30.

Results

A total of 82,214 participants were included within the study. The data related to age, gender, body mass index (BMI) and ethnicity. The mean radiation amongst all 82,214 participants was 1.03 mSv, a median dose of 0.94 mSv. The mean radiation dose ranged from 0.76 to 1.31 mSv across the 33 sites involved with the SHAPE program cohort. Subgroup analysis by age, gender or body mass index showed no intra-scanner variability between age (range 22–84 years old), gender (male 54%) or BMI less than 30 kg/m². Radiation dose in patients with BMI > 30 kg/m² were significantly greater than other subgroups ($\mu = 1.96$ mSv, $p < 0.001$).

Discussion

This study demonstrates that CAC scoring results in a mean exposure of 1.03 mSv within a large cohort, a majority of which were community referred and across multiple scanners and centers. No significant difference in radiation exposure between age, gender or weight classes. This is consistent with a recent study reporting a mean radiation dose of 1.05 mSv among the MESA cohort [5]. In larger patient it should be taken into account that organ doses do not go up in concert with rises of volume CTDI vol and mSv. This is due to a good deal of attenuation which occurs in the adipose tissue. Therefore, larger patient will not receive larger organ doses, even though they receive a higher DLP. Unfortunately, the effective dose, expressed in mSv, doesn't take into effect the larger attenuation from adipose and muscle, and it seems like larger patients receive higher doses. Prior to this report and that of Messenger, reports of dosing and subsequent cancer risks were based on a study with median dose of 2.3 mSv with a range of 0.8 to 10.5 mSv [4]. A consensus statement by the AHA discussed the appropriate imaging parameters to radiation exposure to patients [8]. Guidelines were outlined by the society for atherosclerosis imaging and prevention tomographic imaging and prevention councils in collaboration with the society of

cardiovascular computed tomography for limiting radiation exposure to patients. If applied correctly, the mean effective radiation dose associated with CAC scans should average 1.0–1.5 mSv and not exceed 3.0 mSv [9]. A recent review article also addressed this issue and concluded that due to recent technical advancements in CAC scoring, significant radiation dose reduction is achievable [10]. CT centers and operators should follow the principle of administering radiation “as low as reasonably achievable” (ALARA) while maintaining diagnostic accuracy. A CAC scan has the equivalent radiation exposure to a mammogram and similar to the background level of radiation exposure over 3–4 months in most major cities [11].

The theoretical increased risk associated with radiation exposure and long term effects has not yet been shown to actually exist at the low radiation doses associated with CT scanning or background radiation [12, 13]. As useful comparisons, a standard chest radiograph has an effective radiation dose of 0.02 mSv [14], and the average annual background radiation in the United States is 3.0–3.6 mSv [7]. Our current knowledge of risks associated with radiation exposure is derived from Japanese atomic bomb survivors and medically exposed cohorts, which was used to create radiation dosing models that define malignancy risk over a lifetime [4]. Currently, it is estimated that 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 [4]. In weighing risks versus benefits of this screening modality, the ACC/AHA guidelines recommended those persons with scores > 300 and those > 75th percentile by age and gender would be up-classified in risk, requiring high intensity statin treatment. Recent studies have shown CAC progression is proven to add incremental value in predicting coronary heart disease events and all-cause mortality [15–17]. Therefore, in the high risk population, the potential benefit outweighs the cancer risk in the case for screening for heart disease.

Our report of a lower radiation coincides with efforts in recent years to reduce radiation exposure in cardiac CT angiography imaging. Prospective ECG gating, timed acquisitions to mid-diastole, can significantly reduce effective doses [18, 19]. While retrospectively gated acquisition which was first used in cardiac CT imaging is now limited to patient with heart rates > 60 beats per minute or arrhythmias. Retrospective gated imaging has redundant imaging acquisition and can significantly increase effective doses of radiation [20]. This reinforces that prospective gating should remain the preferred method of cardiac CT imaging. The improvements in radiation dosing techniques have coincided with the advancement in imaging acquisition quality. This has led to minimizing radiation exposure without significantly compromising imaging quality. Strategies not uniformly utilized in the SHAPE cohort study

would likely reduce radiation dosing further. Reductions in tube voltage from 120 to 100 kVp significantly reduce radiation, particularly in lower BMI patients [21]. Though increased CAC scores may result as calcium attenuation values rise as kVp decreases [22]. Another option for decreasing X-ray exposure is to use noise-reducing statistical iterative reconstruction algorithms [23]. When compared with standard analytical reconstruction methods that are based on filtered back projections, statistical iterative reconstruction produces equivalent signal-to-noise ratios at lower radiation doses without a loss in spatial resolution [24]. It should be noted that iterative reconstruction was not used by any center for CAC acquisition in our study.

Recent efforts have challenged the appropriate use of k constant (0.014) to calculate effective dose of radiation [25, 26] based on the new tissue weighting factors published by the international commission of radiation protection [27]. A recent study performed radiation dose measurements for 120 cardiac CT protocols on 12 different scanners (including the 4 scanner types used in this study) currently in clinical use and recommended that a scanner and protocol specific conversion factor should be used for estimating effective dose from cardiac CT [26]. They concluded that if scanning information was unavailable, then the suggested mean and median conversion k constant (0.026) be used. This is considerably higher (46%) than the currently used k constant (0.014) which was used in this study [26]. Though the current standard k constant underestimates the effective dose used per study, the overall radiation dose per procedure for cardiac CT has been decreasing over time due to advancements in technology and increased user awareness about radiation exposure. Therefore, we conclude that radiation doses can be reduced with application of these mentioned techniques and utilization of the current society of cardiovascular computed tomographic guidelines on acquisition of CAC scans [9].

Limitations

Individual dosimeters on patients were not utilized to measure organ dose. This then does not account for breast equivalent doses which have been reported to be significant. Standard metrics measured from the CT scanner for each patient was alternatively used for each patient. Effective dose calculation in mSv is based upon the weighting factor, which did 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. Minimizing radiation exposure should remain a priority in medical imaging and employ ALARA while maintaining diagnostic accuracy regardless of scanner type or body habitus.

Compliance with ethical standards

Conflict of interest Matthew Budoff has received research grants from 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.

Research involving human and animal rights 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.

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