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Title
Radiation Doses in Patients Undergoing Computed Tomographic Coronary Artery Calcium Evaluation With a 64-Slice Scanner Versus a 256-Slice Scanner.

Permalink
https://escholarship.org/uc/item/3d6220vp

Journal
Texas Heart Institute Journal, 49(2)

ISSN
0730-2347

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Publication Date
2022-03-01

DOI
10.14503/thij-18-6793

Peer reviewed

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Decrease in Radiation Dosing for Coronary Artery Calcium scans with Advancement in Computed tomographic technology: The Converge Registry

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Disclosure: Dr Budoff receives grant support from the National Institutes of Health and General Electric. No other author reports any conflict of interest.

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Abstract

Introduction

Coronary artery calcium (CAC) scans provide clinicians with a reliable source of information related to cardiovascular risk stratification. Despite concerns of cost and radiation, new scanners and techniques are being developed to deliver CAC scans at lower doses. In our study, we compared radiation doses from CAC imaging acquired using a 64 slice computed tomography scanner with comparison to the Revolution 256-scanner.

Patients and Methods:

Patients were screened, enrolled, and consented for the Converge Registry. 110 patients underwent CAC scans using the Revolution scanner with matching to 110 patients scanned by a 64-detector scanner. Patients were matched by age, gender and body mass index. Statistical Analysis was performed using t-test and linear regression analysis.

Results:

Comparing the 110 patients in each group, the effective dose was reduced 21% with Revolution 256 detector scanner (1.06 vs 0.84 milliSieverts $p<0.001$). Each weight subgroup had a significant reduction in dose. When adjusted for gender, females required a lower DLP (0.71 vs 0.91 milliSieverts, $p<0.001$). Further regression analysis found that with the increase in weight and waist, the increase in dose was significant for both scanners ($p<0.001$).

Conclusion

The GE Revolution Scanner provides lower radiation doses for CAC scanning. Our study shows significantly lower radiation doses needed than the previously determined 1 milliSievert; even when adjusted for BMI and waist circumference. The radiation doses of CAC scanning are now similar to lung cancer screening, mammography, or background radiation.

Key words:
Coronary Artery Calcium, Radiation dosing, computed tomography

Introduction

Coronary artery disease is a leading cause for morbidity and mortality around the world. Tools have been developed to accurately diagnose and evaluate coronary artery disease. These tools provide detailed imaging in order to deliver a measure of atherosclerosis burden and prognostic information for the clinician and patient .[1] Coronary artery calcification (CAC) imaging allows for personalization of cardiovascular risk independent and incremental of traditional risk factors across many demographics.[2] The

American College of Cardiology Foundation/ American Heart Association (ACCF/AHA) concludes “that measuring 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”.[3] These guidelines indicate that CAC can be used to assess cardiovascular risk in asymptomatic adults at intermediate risk (10-20% 10 year risk), individuals with diabetes (both IIa indications), and individuals at low-intermediate risk (IIb indication).[4,5]

Despite its role as a risk stratification tool, concerns remain regarding the radiation dose risk associated with CAC imaging; especially given CAC evaluation may ultimately be applied to 40% of the adult population (i.e. those at intermediate risk of future atherosclerotic cardiovascular disease). This concern has resulted in uncertainty about potential risks of more widespread screening.[3] These concerns can be alleviated with advancements in technology and protocols allowing for acquisition of CAC scanning at lower radiation doses.

Advancement in technology can be seen with new computed tomography (CT) scanners like the Revolution by GE Healthcare. This is a new wide volume scanner with 256 detector rows, 16-cm cranial-caudal coverage and fast gantry rotation time of 280ms, allows acquisition of the whole heart within a single heartbeat with prospective triggering. Additionally, this scanner uses the next generation of Adaptive Statistical Inerative Reconstruction (ASIR-V) which can allow for lower mA acquisition techniques. These technologies allow for lower dose imaging. In a study by Sulaiman et al emphasized the use of interative reconstruction at lower radiation doses to allow for stable CAC scoring.[6] We used the Converge registry to evaluate our hypothesis. It is a multicenter, prospective registry to evaluate the performance of the 256-detector REVOLUTION (GE Healthcare, Milwaukee, WI) CT Scanner.[7] We aim to compare radiation doses from CAC imaging performed using the CT scanner compared to a prior generation 64-slice CT scanner (VCT by GE Healthcare), across a similar profile of patients; matched across similar age, gender, and patient body mass index (BMI) from each group.

Patients and Methods:

Consecutive patients were screened, enrolled, and consented for the Converge Registry, in accordance with the IRB approved protocol. 110 patients underwent CAC scanning done using the new 256 detector row, 16-cm coverage scanner. We then matched 110 patients by age, gender and BMI who underwent CAC scanner on a 64slice CT scanner as the control group. The scans were conducted at multiple centers including Los Angeles Biomedical Research Institute at Harbor-UCLA Medical Center in Torrance, California, Italy, and Australia.

Scan Protocol:

Coronary artery calcium was assessed by cardiac-gated multidetector CT scanners. We used the 64 slice CT scanner and 256 slice CT scanner.

Certified cardiac CT technicians scanned all study participants. The settings of GE 64 (LightSpeed VCT, General Electric Medical System, Milwaukee, WI) were 120 kVp, 430 mA, 350 ms/per rotation with 227 ms in temporal resolution, with 2.5 mm in slice thicknesses. The scan mode was prospective triggering.

Electrocardiographic triggering was employed, so that each image was obtained at the same point in diastole, corresponding to 75% of the RR interval. Tube current ranged between 122 and 740 mA on the basis of the patient’s BMI. Complete coronary artery visualization was obtained without contrast medium injection, and at least 35 consecutive images were obtained at 2.5 mm intervals beginning one centimeter below the carina and progressing caudally to include the coronary arteries.

Revolution CT imaging: Images were acquired using the volumetric single-beat CT scanner, which provides 0.28-second gantry rotation, intelligent motion correction software, high-definition spatial resolution, and 16-cm detector array. The field of view (z axis) included the mid–ascending aorta to the upper abdomen. No table movement occurred during axial volumetric scanning because of the 16 cm of z-axis coverage the scanner provides. The z-axis collimation was selected based on heart size as displayed on the anteroposterior and lateral surface images. No patient required more than 16-cm z-axis coverage. Tube voltages used at 120 kilovolt potential (kVp). Tube current ranged between 122 and 740 mA on the basis of the patient's BMI. A medium field of view was selected. The gantry rotation time was 0.28 seconds, with a minimum temporal resolution of 140 milliseconds.

A cardiologist read all CT scans at a central reading center (Los Angeles Biomedical Research Institute at Harbor–UCLA in Torrance, California). Both scanners used a 25 cm field of view for acquisition of coronary artery calcium scans. Electrocardiographic gating was used for both scanners, voltage was fixed at 120 peak kilovolts and milliamperes were based upon body habitus as previously described (7, 8). Low dose CACS CT was performed with both scanners by setting the intended iterative reconstruction level to 50%. Dose length product (DLP) is a measure of CT tube radiation output/exposure. It is related to CT dose index ($CTDI_{vol}$)- which is a standardized measure of radiation exposure. Dose length product accounts for the length of radiation output along the z axis (the long axis of the patient), is reported in miliGray by centimeters of which the output takes place (mGy*cm). The effective radiation dose is estimated from the DLP in both CTs was calculated using the following formula: Effective radiation dose = DLP x Conversion coefficient for the chest

(k = 0.014 mSv/mGy cm).

Statistical Analysis:

Participants were matched from the Converge Registry with a control group of similar demographics (age, gender, and BMI). We used the R package MatchIt with "nearest" matching for age, BMI, and exact matching for gender. Statistical Analysis was performed using a t-test and linear regression analysis comparing the Converge study group vs a control group of similar clinical variables (age: for the 64 slice scanner average age was 61.2 and for the 256 slice scanner was 60.7; gender; BMI subgroups: group 1: 18.5<=BMI<=24.9 kg/m2; BMI group 2: 25<=BMI<=29.9 kg/m2; BMI group 3: BMI => 30 kg/m2). The software used for our statistical analysis was Statistical Analysis System- SAS 9.4 (Cary, NC: SAS Institute Inc). A P value of <0.05 was considered to be statistically significant. Further subgroup analysis by linear regression analysis was performed on clinical variables within the Converge group. Effective radiation doses were converted from DLP to mSv using a factor of 0.014.

Results:

The variables used for matching between the 64 slice and 256 slice CT scanner groups did not statistically differ (Table I). Comparing the 110 patients in each group, we found that mean DLP was reduced 21% with use of the 256 detector scanner (75.9 vs 60.2, (mGy * cm)p<0.001). For each BMI subgroup (normal: BMI group 1: 18.5<=BMI<=24.9 kg/m2; overweight: BMI group 2: 25<=BMI<=29.9 kg/m2; obese: BMI group 3: BMI => 30 kg/m2), there was a significant reduction in dose (Table 1). When adjusted for gender (Table II), females were found to have a lower DLP compared to males (50.4

vs 64.7 (mGy * cm), $p<0.001$). Subgroup evaluation using regression analysis found that the incremental increase in DLP with increase in BMI was significant (for BMI 18.5 to 24.9 compared to 25 to 29.9 and compared to BMI >30, all $p<0.001$, Table III). Subgroup evaluation using regression analysis was also done using waist circumference was also statistically significant given the incremental increase in DLP (Table IV).

Discussion

We are able to demonstrate that the 256-detector scanner is able to provide lower radiation doses for coronary artery calcium scanning compared to a 64-row scanner. The 256 slice CT scanner allows improved image quality and clinical capabilities through the convergence of coverage, spatial resolution, and temporal resolution advantages over the 64 slice CT scanner. The rotation speed is faster (280 milliseconds versus 350 milliseconds with 64 slice) which reduces patient exposure by 20%. Furthermore, the whole heart coverage allows the heart to be imaged in one rotation (one heartbeat) due to 16 cm z-axis coverage with no table movement, as compared to the 5 beat acquisition of the 64 slice scanner (due to z axis coverage of only 4 cm). In the MESA (Multi-Ethnic Study of Atherosclerosis) cohort, which included multiple CT scanners, CAC scans mean effective radiation doses were less than 1 mSv.[8,9] Our study shows that one needs significantly less radiation than the previously determined 1 mSV along with our results being statistically significant when adjusted for BMI and waist circumference. Using the 256 slice CT scanner, those with normal body weight had an average dose of only 0.55

milliseiverts (Table I). Of course, the dose reduction is aided with the use of iterative dose reduction algorithms which were used in this study for both the 64 and 256 scanners. Tatsugami et al were able to obtain up to a 67% reduction in radiation dose with its use without significantly sacrificing image quality.[10] Similar results were obtained in our study along with Sulaiman et al with the use of Adaptive Statistical Inerative Reconstruction (ASIR-V) with dose reduction of 21% and 26% respectively.[6] This allows for more advanced modeling as it de-emphasizes the system optics modeling, enabling reconstruction speed similar to filtered back projection.[6] With the use of a new generation CT scanner along with accompanying protocols, we are able to obtain significantly lower radiation doses. Choi et al was able to demonstrate a protocol that allowed for up to a 74% reduction in radiation dose for evaluating CAC without significantly sacrificing image quality.[11] Protocols now exist where one doesn’t need to alter scanning techniques to obtain similar imaging at lower radiating doses.[10,12] We were able to demonstrate a dose reduction without compromise in image quality (see images- Figure 1A and 1B compared to Figure 2A and 2B). This should help alleviate concerns about radiation dosing, especially in regards to the risk of cancer from higher exposures.

In regards to radiation and cancer risk, in a study done by Kim et al, the cancer risk calculated was beginning with a median effective dose of 2.3 mSv and up to over 10mSv.[13] This is much higher than the reported 1mSv generally acquired in 64 detector CAC scans, and the mean 0.84 mSv obtained in our study using the new generation CT scans, with doses of 0.55 mSv for patients of normal body weight. Coronary artery calcium scans are also able to provide a lower dose of radiation when compared to everyday background radiation exposure, ranging from 3-7mSv annually, depending on the altitude of a given location.[1,9,13] The theoretical increase risk of long-term effects has not been shown to exist at low radiation doses associated with either background radiation or CT scanning.[9] Clearly, the clinical benefits must outweigh any potential risks of radiation.

With the advancement in technology, protocols now exist where one doesn't need to alter scanning techniques to obtain similar imaging at lower radiation doses.[11,12] CAC scans also can be used to track the progression of atherosclerosis and the effects of different therapies and progression of CAC predicts all-cause mortality.[14-17] All of the aspects mentioned thus far need updating in future guidelines and should reflect the advances made. The radiation doses of current scanners now approximate that obtained with other screening tests, such as low dose lung scanning and mammography.[18-22]

Limitations

Our study was performed across a similar patient profile using two scanners. Future studies are required using a larger sample size; allowing further validation and randomization of data. With a larger sample size, further statistical analysis can be performed for more valid analysis and interpretation of data. Imaging acquired across a wide variety of CT scanners will provide more detailed information in regards to protocols used and radiation dosing.

Conclusion

We are able to demonstrate that the 256 CT Scanner is able to provide significantly lower radiation doses compared to 64 row CT scanner for CAC scan acquisition. New scanners, with gemstone detector and more detector rows, led to a significant reduction in radiation doses as shown in this study. This allows clinicians to obtain more clinically relevant information at significantly lower doses- aiding in making appropriate clinical diagnosis, decision-making, and alleviating further patient concerns regarding radiation dosing.

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The following table results are discussed above in results section.

Table I. Demographic and clinical characters (VCT 64 vs. Revolution)- Effective Doses

	VCT 64 n=110 mean ± SD	Revolution n=110 mean ± SD	*P*-value
Age, years	61.2 ± 11.2	60.7 ± 13.1	0.79
Weight, kg	83.6 ± 16.3	84.1 ± 18.9	0.85
BMI (kg/m2)	28.2 ± 5.1	27.8 ± 5.6	0.58
CAC_DLP	75.9 ± 22.6	60.2 ± 27.0	<0.001
(Millisieverts)	(1.06 ± 0.32)	(0.84 ± 0.38)	
Normal weight subgroup	67.3 ± 23.0	39.6 ± 13.1	<0.001
BMI group 1	(0.94 ± 0.32)	(0.55 ± 0.18)	
Overweight subgroup	70.7 ± 12.9	58.6 ± 20.4	0.0024
BMI group 2	(0.99 ± 0.18)	(0.82 ± 0.29)	
Obese subgroup	90.6 ± 28.7	64.4 ± 23.1	<0.001
BMI group 3	(1.27 ± 0.40)	(0.90 ± 0.32)	

Doses in DLP (mGy*cm), In parentheses, doses in millisievert (mSv)± SD

BMI group 1: 18.5<=BMI<=24.9 kg/m2¶

BMI group 2: 25<=BMI<=29.9 kg/m2

BMI group 3: BMI => 30 kg/m2

BMI = body mass index; CAC = coronary artery calcium; DLP = dose length product;

kg=kilograms

P value <0.05 was determined as significant

Table II. Gender Characteristics in the Converge population- Effective Doses

	Women n=35 mean ± SD	Men n=75 mean ± SD	*P*-value
Age, yrs	59.3 ± 16.0	61.4 ± 11.6	0.49
Weight, kg	75.6 ± 18.5	88.0 ± 17.9	<.001
BMI, kg/m2	28.4 ± 7.4	27.5 ± 4.5	0.53
Waist Circumference (inches)	33.3 ± 6.1	34.8 ± 3.2	0.24
CAC_DLP	50.4 ± 23.4	64.7 ± 27.6	0.009
	(0.7 ± 0.32)	(0.9 ± 0.38)	

values in DLP, parentheses in mSv; see abbreviations in table 1

Doses in DLP (mGy*cm), In parentheses, doses in millisievert (mSv)± SD

P value <0.05 was determined as significant

BMI = body mass index, kg/m2; CAC = coronary artery calcium; DLP = dose length product, DLP (mGy*cm); kg=kilograms

Table III. Association between DLP levels and BMI in Converge population- Effective Doses

	DLP mean±SD	β (SE)	95% C.I	P-value
BMI group 1	39.6 ± 13.1 (0.55 ± 0.18)	Referent		
BMI group 2	58.6 ± 20.4 (0.82 ± 0.29)	18.1(4.5)	9.4, 26.9	<0.001
BMI group 3	64.4 ± 23.1 (0.90 ± 0.32)	24.8(5.0)	15.0, 34.6	<0.001

¶ Referent group § Adjusted for age, gender, values in parentheses in mSv. See abbreviations in table I

BMI group 1: 18.5<=BMI<=24.9 kg/m2¶

BMI group 2: 25<=BMI<=29.9 kg/m2

BMI group 3: BMI => 30 kg/m2

Doses in DLP (mGy*cm), In parentheses, doses in millisievert (mSv)± SD

BMI=body mass index, k/m2; DLP= dose length product, DLP (mGy*cm)

P value <0.05 was determined as significant

Table IV. Association between DLP and waist circumference in Converge population- Effective Doses

	DLP mean±SD	β (SE)	95% C.I	P-value
Waist circumference ¶	53.3 ± 22.3 (0.75 ± 0.31)	Referent		
Waist circumference>40 (Men) or Waist circumference>35 (Women)	58.5 ± 17.8 (0.82 ± 0.25)	14.9(6.9)	1.4, 28.4	0.030

¶ Referent group, male waist circumference ≤40 | female waist circumference ≤35; both in inches, values in parentheses in mSv, see abbreviations in table I

Doses in DLP (mGyx*cm), In parentheses, doses in millisievert (mSv)± SD

P value <0.05 was determined as significant

DLP= dose length product, DLP (mGy*cm)

Figure legends:

Figure 1A and 2A demonstrate scans performed using the 64 slice scanner.

Figure 1B and 2B demonstrate scans performed using the 256 slice scanner.