Enhanced radiation exposure associated with anterior-posterior x-ray tube position in young women undergoing cardiac computed tomography

Michael Messerli, MD,[a] Anne-Laurène Panadero, MSc,[a] Andreas A. Giannopoulos, MD, PhD,[a] Moritz Schwyzer, MD,[a] Dominik C. Benz, MD,[a] Christoph Gräni, MD, PhD,[a] Ralf W. Bauer, MD, EBCR,[b] Aju P. Pazhenkottil, MD,[a] Oliver Gaemperli, MD,[a] Ronny R. Buechel, MD,[a] Philipp A. Kaufmann, MD,[a] and Cathérine Gebhard, MD, PhD[a,c]
Zurich, Switzerland; and Wiesbaden, Germany

Given the current increase in the incidence of coronary artery disease in younger women as well as the high lifetime risk of developing an x-ray–induced malignancy in this population, we aimed at assessing chest radiation in 206 women ≤55 years old undergoing coronary calcium scoring (CACS) by using a Monte Carlo simulation tool. Our data indicate that the simulated radiation dose of the female breast during CACS depends substantially on the starting position of the x-ray tube, with an almost 2 times excess of breast radiation exposure being measured during anterior-posterior tube positioning. Thus, an additional technical feature taking into account the position of the x-ray tube when acquisition is triggered might be an important tool to reduce radiation exposure of the female breast during CACS. (Am Heart J 2019;215:91-4.)

Although cardiovascular mortality rates in men have continued a steady and remarkable fall since the 1980s, there is evidence that the rate of decline has abated in women.[1] Hence, cardiovascular deaths in women currently exceed those in men.[2] Of particular concern is the rise of coronary artery disease (CAD) incidence and case fatality in young women <55 years old[3,4]; however, evidence to date has failed to adequately explore variables determining the excess cardiovascular risk in this demographic group. Computed tomography (CT) coronary artery calcium scoring (CACS) has emerged as a powerful predictor of future cardiovascular events and significantly improves cardiac risk classification in younger adults also.[5] Accordingly, an estimated 33 million patients are currently eligible for CAC scanning in the United States.[6] Given the increasing cardiovascular risk observed among young women in the United States and Europe,[3,4] the number of younger/premenopausal women undergoing CACS is likely to grow. However, as lifetime risk of developing an x-ray–induced malignancy is highest among younger individuals,[7] concerns regarding radiation safety may limit accurate and early assessment of cardiovascular risk in this population. Thus, we aimed to assess chest radiation in women ≤55 years undergoing CACS by using a Monte Carlo simulation tool. As the breast gland is one of the most radiosensitive organs,[8] 2 different scanning scenarios were tested to develop an algorithm where x-ray dose of the female breast is minimized.

Methods

Between September 2014 and May 2017, a total of 206 consecutive female patients with a mean age of 50 ± 3 years (range 45-55 years) and a mean body mass index (BMI) of 24.7 ± 4.0 kg/m^2 (range 17.1-36.4 kg/m^2) referred for evaluation of CAD at our institution were included in this retrospective analysis. Patients with a history of mastectomy/radiation therapy or breast implants were excluded. The patient's history including risk factors, medication use, and key symptoms including chest pain and shortness of breath were recorded at the time of the imaging study by patient interview as well as by review of medical records. The study conforms to the principles outlined in the Declaration of Helsinki and was evaluated and approved by the local ethics committee (BASEC No. 2017-01112). CACS scanning and assessment

From the [a]Department of Nuclear Medicine, Cardiac Imaging, University Hospital Zurich, University of Zurich, Zurich, Switzerland, [b]RNS Gemeinschaftspraxis GbR, Private Radiology and Radiation Therapy Group, Wiesbaden, Germany, and [c]Center for Molecular Cardiology, University of Zurich, Zurich, Switzerland.
Source of funding: C. G. is supported by grants from the Swiss National Science Foundation; the Olga Mayenfisch Foundation, Switzerland; the OPO Foundation, Switzerland; the Novartis Foundation, Switzerland; the Swissheart Foundation; and the Helmut Horten Foundation, Switzerland. M. M. is supported by a research grant from the Iten-Kohaut Foundation, Switzerland.
Submitted November 26, 2018; accepted May 8, 2019.
Reprint requests: Dr. Michael Messerli, MD, Department of Nuclear Medicine, University Hospital Zurich, Ramistrasse 100, 8091 Zurich, Switzerland.
E-mail: michael.messerli@usz.ch
0002-8703

https://doi.org/10.1016/j.ahj.2019.05.006

were performed on a wide-volume 256-slice scanner (Revolution CT; GE Healthcare, Waukesha, WI) with the following scanning parameters: 256 × 0.625 mm collimation with a *z*-coverage of 12-16 cm and a display field of view of 25 cm, gantry rotation time of 280 milliseconds, tube voltage of 120 kVp, and a tube current of 200 mA. The semiautomatic software SmartScore (GE Healthcare) was used for quantification of CACS (Agatston units). A single-beat acquisition protocol with breath-hold at inspiration and prospective electrocardiographic triggering at 75% of the RR interval was applied. The CT images of the CACS scans were used as an input volume for Monte Carlo simulations. Three-dimensional simulated radiation dose maps were obtained by using a commercially available and validated Monte Carlo tool (ImpactMC; CT Imaging, Erlangen, Germany).[9] All simulations were performed using the specific scanner geometry, collimation, tube voltage, and tube current as used for the CACS examinations. Two different scenarios were tested: (1) an anterior-posterior (AP) simulation with a starting angle of the x-ray tube resulting in an irradiation of the breasts and anterior thorax and (2) a posterior-anterior (PA) simulation with a starting angle of the x-ray tube resulting in an irradiation of the back of the patient. To assess the exact breast organ dose, a region of interest was placed in the retromammary area. The *breast organ dose* was defined as the average measurement of 3 consecutive regions of interest at 3 different z-axis positions. Student *t* test was used for group comparisons of breast organ dose. Prior to analyses, basic assumptions were checked and a 2-tailed *P* value of .05 was considered statistically significant. Assuming that a radiation dose difference between the 2 scenarios (dependent means) of 20% or more would be clinically relevant, a total sample size of 199 was required for a 2-sided significance of .05 and a power of 0.81. SPSS version 24.0 (IBM Corp, Armonk, NY) and G*Power software were used for statistical analyses and sample size calculation.

Results

Patient demographics are given in Table I. In all 206 patients, the mean breast dose measured when the AP scenario was applied was significantly higher than the radiation exposure when applying the PA scenario (1.1 ± 0.12 mGy vs 0.6 ± 0.16 mGy, student *t* $P < .0001$). Accordingly, the mean cumulative dose measured in the retromammilary area was significantly higher in AP than in PA acquisition (Figure 1, *A* and *B*), with an average 1.8 times excess of breast radiation exposure during AP simulation as compared to PA simulation ($P < .0001$). Notably, in 52 (25.2%) patients, radiation dose even exceeded a 2-fold increase when scanned in AP mode as compared to PA mode (Figure 1C). These patients had a higher BMI as compared to patients with a less than 2-fold increase in radiation dose (25.6 ± 3.9 vs 24.2 ± 3.9 kg/m^2, $P = .017$), indicating that women with a higher BMI might particularly profit from PA acquisition.

Table I. Demographics of the study population (n = 206 women)

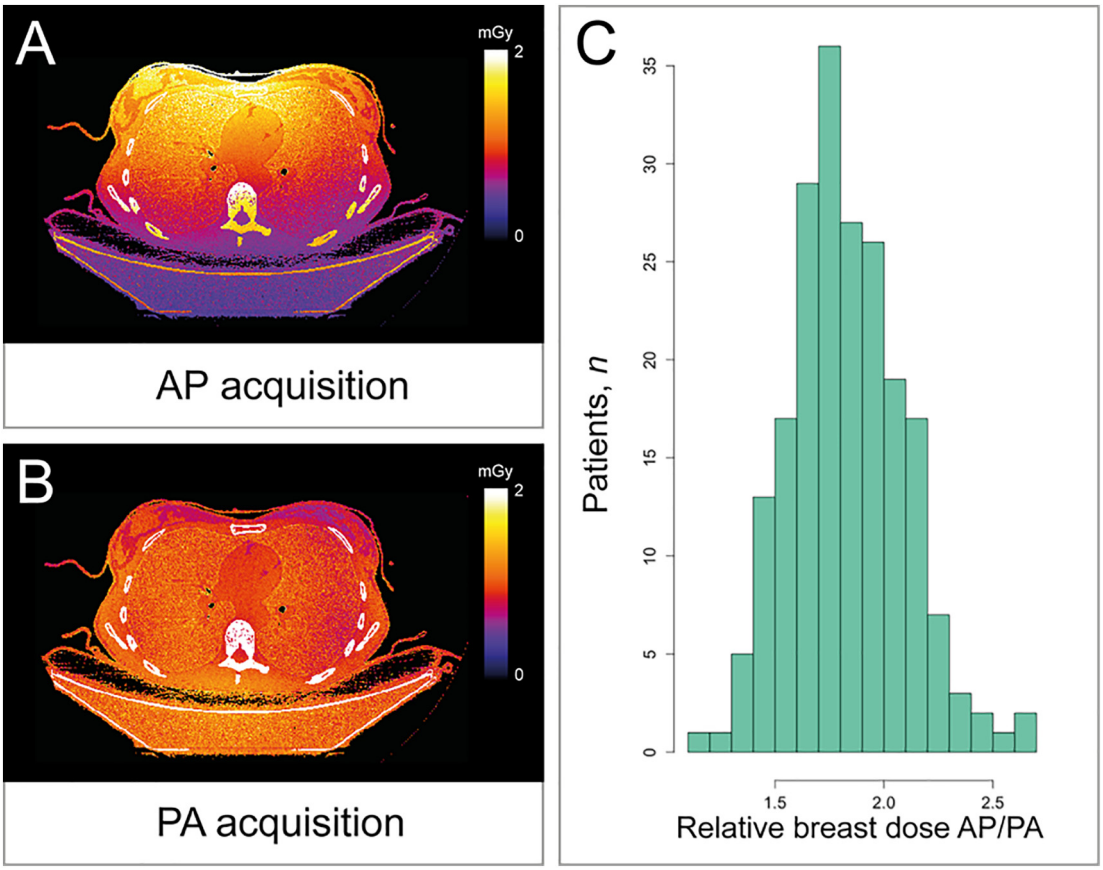
Age, y	50 ± 3 (45-55)
Weight, kg	67 ± 12 (45-105)
Height, m	1.65 ± 0.1 (1.47-1.88)
BMI, kg/m^2	24.7 ± 4.0 (17.1-36.4)
Cardiovascular risk factors, n (%)	
Smoking	47 (22.8%)
Diabetes mellitus	6 (2.9%)
Hypertension	40 (19.4%)
Dyslipidemia	49 (23.8%)
Positive family history	73 (35.4%)
Clinical symptoms, n (%)	
Asymptomatic	43 (20.9%)
Typical angina pectoris	23 (11.2%)
Atypical chest pain	128 (62.1%)
Dyspnea	12 (5.8%)
Medication, n (%)	
Antiplatelet therapy	16 (7.8%)
β-Blocker	18 (8.7%)
ACI/ARB	22 (10.7%)
Statin	16 (7.8%)
CAC score risk class, n (%)	
0	156 (75.7%)
1-99	39 (18.9%)
100-399	6 (2.9%)
≥400	5 (2.4%)

Values given are mean ± SD (range) or absolute numbers and percentages in brackets. *ACI/ARB*, angiotensin-converting enzyme inhibitors/angiotensin-receptor antagonist.

Discussion

Our data demonstrate that the simulated radiation dose of the female breast during CACS depends substantially on the starting position of the x-ray tube. In fact, irradiation of the female breast almost doubles when an AP algorithms is chosen as compared to a PA x-ray tube position. Previous work has demonstrated significant radiation dose reductions for CACS by using iterative reconstruction methods or lowering tube voltage/current, resulting in a maximal dose reduction of 53%-67%.[10,11] Our observation, however, suggests that an additional technical feature taking into account the position of the x-ray tube when acquisition is triggered might be an important tool to reduce radiation exposure of the female breast during CACS regardless of the protocol and scanner used. This so-called organ-based tube current modulation has recently been implemented in noncardiac CT technology to reduce radiation delivery to ventrally located radiosensitive organs including eyes, thyroid gland, and breasts.[12] The fact that image acquisition is uniquely triggered by electrocardiogram signal in coronary CT angiography to reduce motion artifacts has so far precluded its use in cardiac applications. However,

Figure 1



Transverse sections of Monte Carlo–simulated dose distributions for CACS in a 47-year-old woman undergoing cardiac CT for exclusion of CAD. **A,** Dose deposition when an AP starting angle of the x-ray tube is simulated. **B**, Radiation dose when a PA starting angle of the x-ray tube is applied. AP projection resulted in a 1.6-fold increase of cumulated breast dose as compared to PA. **C**, Excess radiation during AP scan illustrated as ratio AP over PA radiation dose (average 1.8) in the whole study group (n = 206). Data are presented as frequencies per dose ratio.

although a timely triggering of image acquisition is of utmost importance when contrast agents are administered, this is not the case in CACS imaging, where theoretically multiple passes could be performed.

As with any study, certain design limitations are inherent. First, this study is a single-center retrospective analysis conducted in a small cohort of young white women, which limits its generalizability. Second, our analysis was designed as a proof-of-concept study assessing the impact of different starting angles on simulated radiation doses of the female breast. The impact of these alterations on image quality and diagnostic sensitivity of CACS was not investigated. Third, the female breast tissue was chosen as the target organ of our analysis because it is the most vulnerable tissue exposed to radiation during a cardiac CT scan. Other body parts were not included in our analysis.

Collectively, our study stresses that there is considerable potential to reduce radiation exposure in young women being evaluated for CAD and emphasizes the need to implement tube current modulation tools in CACS to minimize the risk of cancer induction in this vulnerable population. Further research is warranted to assess potential variations in image quality and CACS values as well as radiation doses of other organs following alterations of tube starting angles.

Disclosures

The University Hospital of Zurich holds a research contract with GE Healthcare. C. G. has received research grants from the Novartis Foundation, Switzerland. All other authors have no relevant disclosures.

References

1. Wilmot KA, O'Flaherty M, Capewell S, et al. Coronary heart disease mortality declines in the United States from 1979 through 2011: evidence for stagnation in young adults, especially women. Circulation 2015;132:997-1002.

2. Townsend N, Wilson L, Bhatnagar P, et al. Cardiovascular disease in Europe: epidemiological update 2016. Eur Heart J 2016;37:3232-45.
3. Gabet A, Danchin N, Juilliere Y, et al. Acute coronary syndrome in women: rising hospitalizations in middle-aged French women, 2004-14. Eur Heart J 2017;38:1060-5.
4. Arora S, Stouffer GA, Kucharska A, et al. Twenty year trends and sex differences in young adults hospitalized with acute myocardial infarction: the ARIC community surveillance study. Circulation 2019;19:1047-56.
5. Paixao AR, Ayers CR, El Sabbagh A, et al. Coronary artery calcium improves risk classification in younger populations. JACC Cardiovasc Imaging 2015;8:1285-93.
6. Ioannidis JP. More than a billion people taking statins?: Potential implications of the new cardiovascular guidelines. JAMA 2014;311:463-4.
7. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med 2007;357:2277-84.
8. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007;37:1–332.
9. Deak P, van Straten M, Shrimpton PC, et al. Validation of a Monte Carlo tool for patient-specific dose simulations in multi-slice computed tomography. Eur Radiol 2008;18:759-72.
10. Tatsugami F, Higaki T, Fukumoto W, et al. Radiation dose reduction for coronary artery calcium scoring at 320-detector CT with adaptive iterative dose reduction 3D. Int J Cardiovasc Imaging 2015;31:1045-52.
11. Baron KB, Choi AD, Chen MY. Low radiation dose calcium scoring: evidence and techniques. Current cardiovascular imaging reports 2016;9:12.
12. Fu W, Sturgeon GM, Agasthya G, et al. Breast dose reduction with organ-based, wide-angle tube current modulated CT. J Med Imaging (Bellingham) 2017;4, 031208.