Diagnostic Accuracy of the Coronary Calcium Score Acquired with Reduced Radiation Dose and Iterative Reconstruction

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Abstract

Background: The calcium score is an imaging test used to evaluate cardiovascular risk by detecting coronary artery calcification (CAC). However, exposure to ionizing radiation during computed tomography (CT) has been a concern.

Objective: The objective of this study was to evaluate radiation dose and the diagnostic quality of the calcium score using reduced tube voltage and iterative image reconstruction.

Methods: This was a cross-sectional, observational study with patients over 18 years of age. Patients with previous coronary artery disease and patients who declined to participate were excluded. We acquired calcium score twice (120 kV and 100 kV) with different iterative reconstruction techniques. Two professionals interpreted the exams.

Results: We evaluated 153 patients, and the reduction in radiation dose between acquisitions with 120 kV and 100 kV was 43%. The agreement of the degree of CAC between the different acquisitions was high, ranging from 93.9% to 96.2%. In Bland-Altman analysis, we observed a slight overestimation of the results in the acquisition with 100 kV compared to the acquisition with 120 kV.

Conclusion: Calcium score acquired at 100 kV using Iterative Model Reconstruction (IMR) iterative reconstruction resulted in a significant reduction in radiation dose. Furthermore, agreement with acquisition at 120 kV was high, indicating that this approach may be a viable alternative to decrease radiation exposure during calcium score testing. However, it is important to underscore the slight overestimation of the results in the acquisition with 100 kV, which must be considered in the clinical interpretation.

Keywords: Vascular Calcification; Coronary Artery Disease; Radiation Dosage; Tomography.

Introduction

Cardiovascular diseases represent one of the leading causes of mortality worldwide, with approximately 17.3 million deaths per year; of these deaths, 7.3 million are associated with coronary atherosclerotic disease.[1]

The use of diagnostic imaging methods for earlier detection of coronary atherosclerotic disease has intensified in recent years. Some of these methods use ionizing radiation, raising concerns regarding their possible side effects. Ionizing radiation can cause biological damage to those who are exposed to it. The damage is classified into 2 categories: stochastic and deterministic effects. The stochastic effects occur proportionally to the radiation dose received, without the existence of a threshold, and they are related to the development of cancer and genetic mutations, being the main cause of health risks resulting from radiation. Deterministic effects are caused by the total radiation that a patient receives during a procedure, so that tissue damage is caused at the focus of radiation that is not compensated by cellular repair, which generates damage, such as skin lesions.[2,3] Accordingly, means of reducing the effective radiation dose in these exams have become the focus of research by professionals in the fields of cardiology and radiology worldwide.[4]

The calcium score is a cardiovascular diagnostic imaging test that uses ionizing radiation in its acquisition. It is indicated for cardiovascular risk stratification, detecting the degree of coronary artery calcification (CAC), a pathognomonic sign of coronary atherosclerotic disease, by means of cardiac computed tomography (CT).[5,6] The radiation dose used to obtain the calcium score is usually low, around 0.9 to 1.3 millisieverts, but it may pose a risk to the health of patients if it is used more widely as a screening tool for cardiovascular disease.[4]

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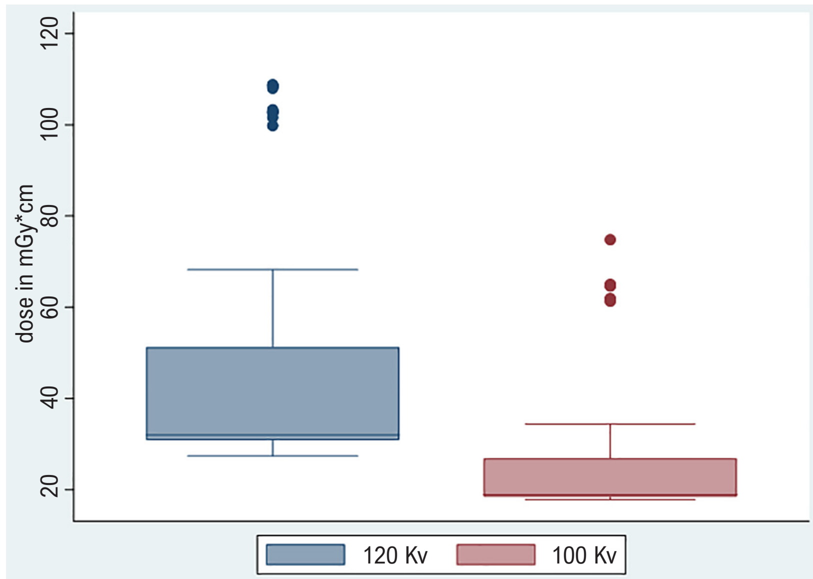
Central Illustration: Diagnostic Accuracy of the Coronary Calcium Score Acquired with Reduced Radiation Dose and Iterative Reconstruction



Radiation dose in mGy*cm; voltage in kV

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Image quality and radiation dose are positively related. Reducing the dose leads to a decrease in image quality, so that excessively zealous efforts to obtain low doses can produce poor quality images.[2] Reduced radiation dose increases image noise, and the current method of reconstruction with filtered back-projection (FBP) is not able to consistently generate diagnostic quality images at reduced x-ray tube currents (mA).[7] Thus, the iterative reconstruction method is an excellent alternative to improve the quality of images obtained, as it manages to reduce the amount of image noise and artifacts that are normally associated with FBP, so that the worsened image quality resulting from the decrease in tube voltage is compensated by the iterative image reconstruction.[8]

In this study, our objective was to compare the effective dose of radiation in the acquisition of the calcium score with tube voltage of 120 kV and 100 kV, using different forms of reconstruction, and their impacts on the diagnostic accuracy of the exam.

Methods

Study population

We included 156 patients who underwent calcium score testing at an imaging clinic in the city of Curitiba, Paraná, Brazil from October 2019 to February 2020. The inclusion criteria were as follows: patients over 18 years old referred to the clinic by medical specialists to undergo coronary calcium score testing. Patients already diagnosed with coronary heart diseases and/or patients who declined to participate in the study were excluded. All patients referred to the imaging clinic filled out a questionnaire before the test, providing the following data: sex, age, weight, height, history of systemic arterial hypertension, diabetes, dyslipidemia, smoking, family history of heart disease, acute myocardial infarction, percutaneous revascularization, and surgical revascularization. This information was recorded in the clinic's database. Three patients were excluded from the analysis because they had a history of previous acute myocardial infarction (2) or percutaneous revascularization (1), leaving 153 participants for analysis. All participants provided consent prior to the test. The study was submitted to the institution's ethics committee, and it received approval under opinion number 3.623.828.

Study type

This was a cross-sectional, observational study.

Image acquisition protocol

The calcium score was acquired by means of transverse sections, up to 3 millimeters thick, of the heart on CT synchronized with an electrocardiogram, without the use of intravenous contrast. In this study, patients were submitted to 2 consecutive cardiac CT scans to obtain the calcium score. The first with a tube voltage of 120 kV (gold standard) and the other with a voltage of 100 kV. Both were performed with a 256-slice CT scanner (Brilliance, Philips, Healthcare, The Netherlands), and patients remained in the same position during both acquisitions, with the current adjusted by the body mass index (BMI), which was the same in both acquisitions (BMI < 30: 30 mAs, BMI between 30 and 35: 50 mAs, and BMI > 35: 100 mAs).

In the images obtained with 120 kV, FBP image reconstruction was performed, constituting the gold standard for obtaining the calcium score. On the other hand, on images acquired at 100 kV, FBP reconstruction and iterative reconstructions were performed with 2 pieces of technology: iDose 6 (Philips, Healthcare, The Netherlands) and IMR 1 (Philips, Healthcare, The Netherlands). Both tests obtained were sent, blindly, to 2 specialist doctors to determine the calcium score, using dedicated software (Heartbeat CS, Philips, Healthcare, The Netherlands). Hyperattenuating images with more than 130 Hounsfield units and an area ≥ 3 adjacent pixels were highlighted by the software, and those confined in the coronary tree were selected by the physician. The software then calculated the sum of these points according to the Agatston method and determined a final score.[6,9] Furthermore, we categorized the calcium score result as follows: equal to 0, between 1 and 99, between 100 and 399, and above 399, in the different combinations of voltage and reconstruction.

Radiation dose

The radiation dose was calculated automatically after each acquisition. The standard used was the dose length product (DLP), which is automatically calculated by the CT acquisition software (iPatient Philips, Healthcare, The Netherlands) and presented in a report at the end of the exam. The DLPs of the 120 kV and 100 kV acquisitions for each patient were recorded in a Microsoft Excel spreadsheet for analysis.

Statistical analysis

Data were collected and stored in a Microsoft Excel spreadsheet. The results were expressed as means, medians, minimum values, maximum values, and standard deviations (quantitative variables) or as frequencies and percentages (qualitative variables). Data analysis was performed using the STATA computer program. The radiation dose used in the acquisitions at 120 kV and 100 kV was compared using the Wilcoxon rank-sum (Mann-Whitney) test, and the correlation of values of the degree of CAC was analyzed using kappa tests. Bland-Altman curves were also used to evaluate the agreement between the scores obtained in the study. P values < 0.05 were considered to indicate statistical difference.

To facilitate the clinical interpretation of the results, we considered clinically significant changes in the calcium score categories between the different acquisitions and reconstructions, those that would lead to a change in clinical management according to the guidelines, namely: change from calcium score of 0 to any positive result (1 to 99, 100 to 399, or above 399) or change from a calcium score below 100 (1 to 99) to greater than 100 (100 to 399 or above 399), given that a score above 100 is considered an aggravating cardiovascular risk factor, and a score above 0 represents the presence of calcified coronary atherosclerosis.

Results

Demographics of the study population

The exams of 153 patients were analyzed, showing a mean calcium score of 221.9 Agatston units.

The mean age of the study population was 58.9 ± 13.1 with a mean BMI of 27.8 ± 4.42. Risk factors for cardiovascular disease were present in research sample participants as follows: systemic arterial hypertension in 65 patients (43.3%), diabetes mellitus in 24 (16%), dyslipidemia in 57 (38%), and tobacco use in 17 (11.3%). The main characteristics of the study population are displayed in Table 1.

Radiation dose

There was a 43% reduction in radiation dose between the 120 kV and 100 kV acquisitions ($p < 0.0001$). For the 120 kV voltage, the average DLP was 41 (± 19.3) mGy*cm ,while it was 23.8 (± 11.4) mGy*cm for the voltage of 100 kV (Central Figure).

Diagnostic accuracy

There was a good correlation between the calcium score calculated by the observers in all forms of acquisition and reconstruction. For 120 kV with FBP, the interobserver correlation coefficient was 0.99. For 100 kV with FBP, the correlation was 0.99. For 100 kV with iDose 6, it was 0.99, and for 100 kV with IMR 1, it was 0.99, considering interclass correlation coefficient between 0.75 and 1 as excellent values.

Agreement of the calcium score in the Agatston classification using the kappa test between 120 kV with FBP and 100 kV with IMR was 94.2% with kappa index

Table 1 – Characteristics of the study population

Variables	N = 156
Age, mean (SD)	58.97 (± 13.13)
BMI, mean (SD)	27.82 (± 4.42)
Female sex, N (%)	65 (41.6 %)
SAH, N (%)	65 (43.8%)
Diabetes, N (%)	24 (16%)
Dyslipidemia, N (%)	57 (38%)
Current tobacco use, N (%)	17 (11.3%)
Family history, N (%)	34 (22.7%)
AMI, N (%)	2 (1.3%)
Percutaneous revascularization, N (%)	1 (0.7%)
Calcium score, mean (SD)	221.95 (± 563.76)

AMI: previous acute myocardial infarction; BMI: body mass index; SAH: systemic arterial hypertension; SD: standard deviation.

of 0.9. For 120 kV with FBP and 100 kV with FBP, it was 93.8% with kappa index of 0.9. For 120 kV with FBP and 100 kV with iDose 6, it was 96.2% with kappa 0.93 ($p < 0.001$). When we stratified agreement using the kappa index in patients with BMI less than or equal to 25 versus greater than 25, we observed a drop in agreement in the most obese patients, as shown in Table 2.

The comparison of the results in the Bland-Altman analysis at the voltage of 120 kV with FBP versus 100 kV with IMR showed the following data: 95% limit of agreement with scores −162.6 to 139.6 and mean difference of −11.5 (confidence interval [CI]: −23.5 to 0.5), as shown in Figure 1. For voltage of 120 kV with FBP versus 100 kV with iDose 6, the 95% limits of agreement were −226.6 to 164.8, with mean difference of −30.8 (CI −46.5 to −15.2; n = 153; p = 0.0001), as shown in Figure 2. For the voltage of 120 kV with FBP compared to the dosage of 100 kV with FBP, the 95% limits of agreement were −366.9 to 252.7 with mean difference of −57 (CI −81.8 to −32.3; p = 0.0001), as shown in Figure 3. For the reconstruction with IMR 1, there was a lower dispersion value with a mean difference of −11.5. We observed an overestimation of the value for IMR 1; thus, for higher calcium score values, the mean difference increased. Using iDose 6 reconstruction, for calcium score of 130 Hounsfield units, the dispersion was −30. Using 100 kV with FBP, for calcium score of 157 Hounsfield units, the dispersion was −57.

When we considered clinically significant changes in the calcium score category between acquisition at 100 kV with IMR compared to the gold standard acquisition (120 kV with FBP), we observed a total of 5 (3.2%) changes, 2 (1.3 %) changes from category 0 to the category 1 to 99 and 3 (1.9%) changes from the category 1 to 99 to the category 100 to 399.

Discussion

In any procedure that involves exposing an individual to radiation for diagnostic purposes, the technique applied must provide maximum visual information using the minimum dose; in other words, the benefit to the patient undergoing radiological diagnostic examination must be associated with optimized practices that guarantee image quality at the lowest dose.[3,10] Iterative reconstruction algorithms can be applied to cardiac CT data, and they can reduce image noise to allow for improved image quality and/or reduced radiation dose.[11,12]

Table 2 – Kappa index of agreement stratified by patients with BMI less than or equal to 25 and above 25.

Kappa index	Agreement for BMI ≤ 25	Agreement for BMI > 25
120 kV FBP vs 100 kV FBP	95.2% (kappa 0.92)	88.2% (kappa 0.83)
120 kV FBP vs 100 kV iDose 6	98.8% (kappa 0.97)	90.8% (kappa 0.86)
120 kV FBP vs 100 kV IMR	94.9% (kappa 0.91)	93.1% (kappa 0.89)

BMI: body mass index; FBP: filtered back projection.

In the reconstruction process of CT images, attenuation data from a large number of projections are mathematically processed to create an image of the volume examined. FBP is the established method, resulting from a quick mathematical procedure. Before reconstruction, the data are filtered to achieve adequate balance between spatial resolution and noise. The limitations of FBP are revealed in low radiation dose acquisitions, where image quality can be compromised by high levels of noise and artifacts.[13] In recent years, these limitations have been circumvented by the introduction of iterative reconstruction methods,[7,3] which can remove noise from low-dose images using a variety of mathematical models.[14-16] Martin J. Willemink et al. performed a systematic literature review of 380 articles, observing that iterative reconstruction reduced noise and artifacts, and improved subjective and objective image quality compared to FBP at the same dose.[7,17]

International studies have shown that it is possible to reduce the effective radiation dose by up to 74% in determined CT scanners, maintaining the diagnostic accuracy of the calcium score. This reduction in radiation dose occurs by decreasing the tube voltage from 120 kV to 100 kV so that the quality of the CT image is maintained with the use of a new reconstruction method.[18,19]

In our study, we compared FBP with 2 methods of iterative reconstruction (iDose and IMR), and we observed that it is possible to perform the calcium score with a lower radiation dose, using modern reconstruction techniques. There was a 43% reduction in radiation dose between acquisitions from the voltage of 120 kV to 100 kV.

In relation to diagnostic quality, there was high agreement (kappa test above 0.9) between the CAC values obtained by the traditional method (120 kV with FBP) and the values obtained by the tested method, both for 100 kV with iDose 6 and for 100 kV with IMR 1, demonstrating the maintenance of clinical applicability of CAC, even when acquired with lower radiation doses.

The Bland-Altman plots demonstrated that, in general, there is an overestimation of the value of CAC when calculated using acquisitions of 100 kV. The difference between the means was smaller when IMR 1 reconstruction was used, ranging from −11.5 (120 kV with IMR 1) to −57.1 (120 kV with FBP). Furthermore, we observed that, in all comparisons, the lower the CAC, the smaller the difference; and the higher the CAC, the greater the dispersion. Therefore, acquisition with 100 kV and IMR reconstruction proved to be the most suitable for clinical application.

A limitation of the study was the occurrence of the COVID-19 pandemic during the inclusion of individuals, which limited the sample size. Studies carried out with a larger sample can help confirm these results.

Conclusion

Acquiring the calcium score with a voltage of 100 kV significantly reduced the radiation dose. When using the IMR 1 iterative reconstruction in the acquisition with 100 kV, it maintained high agreement and slight overestimation of

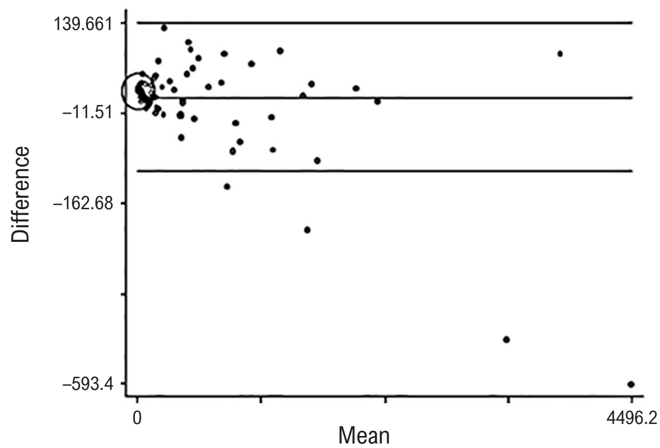

Figure 1 – *Bland-Altman plot comparing calcium scores obtained with 120 kV and FBP reconstruction versus 100 kV and IMR 1 reconstruction*

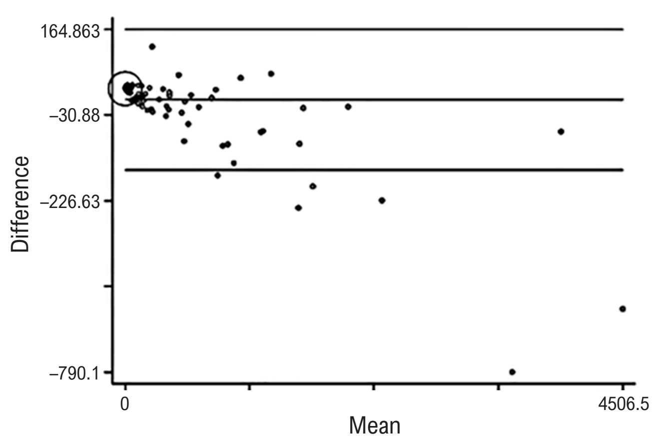

Figure 2 – *Bland-Altman plot comparing calcium scores obtained with 120 kV and FBP reconstruction versus 100 kV and iDose 6 reconstruction*

the results when compared to the acquisition with 120 kV and traditional FBP reconstruction.

Author Contributions

Conception and design of the research, Statistical analysis, Analysis and interpretation of the data, Critical revision of the manuscript for intellectual content: Carnaval DR, Silva MMF, Cerci RJ; obtenção de dados: Liebl A, Sartori BM, Couto CNM, Silva GBG, Vazzoler IGB, Medeiros VM; writing of the manuscript: Liebl A, Sartori BM, Couto CNM, Carnaval DR, Silva GBG, Vazzoler IGB, Cerci RJ, Medeiros VM.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Sources of Funding

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of the Hospital de Clínicas da Universidade Federal do Paraná under the protocol number 20501119.5.0000.0096. All the procedures in this study were in accordance with the 1975 Helsinki Declaration, updated in 2013. Informed consent was obtained from all participants included in the study.

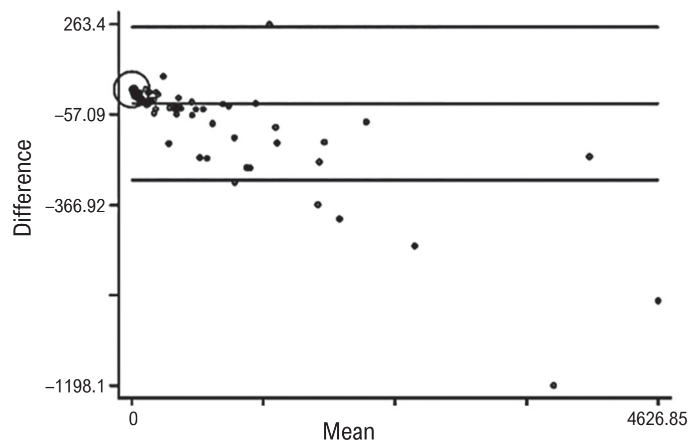

Figure 3 – *Bland-Altman plot comparing calcium scores obtained with 120 kV and FBP reconstruction versus 100 kV and FBP reconstruction*

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