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Review article

The impact of dose reduction on the quantification of coronary artery calcifications and risk categorization: A systematic review

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ABSTRACT

Multiple dose reduction techniques have been introduced for coronary artery calcium (CAC) computed tomography (CT), but few have emerged into clinical practice while an increasing number of patients undergo CAC scanning. We sought to determine to what extend the radiation dose in CAC CT can be safely reduced without a significant impact on cardiovascular disease (CVD) risk stratification. A systematic database-review of articles published from 2002 until February 2018 was performed in Pubmed, WebOfScience, and Embase. Eligible studies reported radiation dose reduction for CAC CT, calcium scores and/or risk stratification for phantom or patient studies. Twenty-eight studies were included, under which 17 patient studies, 10 phantom/ex-vivo studies, and 1 study evaluated both phantom and patients. Dose was reduced with tube voltage reduction and tube current reduction with and without iterative reconstruction (IR), and tin-filter spectral shaping. The different dose reduction techniques resulted in varying final radiation doses and had varying impact on CAC scores and CVD risk stratification. In 78% of the studies the radiation dose was reduced by ≥ 50% ranging from ($CTDI_{vol}$) 0.6–5.5 mGy, leading to reclassification rates ranging between 3% and 21%, depending on the acquisition technique. Specific dose reduced protocols, including either tube current reduction and IR or spectral shaping with tin filtration, that showed low reclassification rates may potentially be used in CAC scanning and in future population-based screening for CVD risk stratification.

1. Introduction

The amount of coronary artery calcification (CAC) expressed in Agatston scores has shown to be strongly associated with risk of cardiovascular disease (CVD).[1] CAC assessment with computed tomography (CT) has substantially gained interest, resulting in increased numbers of CAC CT examinations. Ongoing and future research will evaluate the feasibility of population based screening for CVD by determining the amount of CAC on CT images.[2,3] If positive, millions of people worldwide will be eligible for screening, leading to an even further increase of individuals exposed to ionizing radiation. Moreover, repetitive screening or follow-up scans might be required, adding to the cumulative radiation dose.[4]

Therefore, continual efforts have been made to reduce the radiation dose in cardiac CT, resulting in the introduction of multiple dose reduction techniques. While radiation exposure has been dramatically reduced for coronary CT angiography in the last decade,[5–11] this has not been the case for CAC CT. In fact, clinically used acquisition protocols are nowadays still similar to the methods used in the 1990s on electron beam tomography.[12] The impact of the available dose reduction techniques were examined in multiple small-sized phantom and/or patient studies on a variety of CT scanners from different vendors. Although many studies evaluated these techniques, there is no clear overview and guidelines regarding their impact and there is only limited implementation of these techniques into clinical practice for CAC imaging.[13]

Abbreviations: ADMIRE, Advanced model based iterative reconstruction; AIDR-3D, Adaptive iterative dose reduction 3D; ASIR-V, Adaptive statistical iterative reconstruction-V; BMI, Body mass index; CAC, Coronary artery calcifications; CTA, Computed tomography angiography; CVD, Cardiovascular disease; CT, Computed tomography; DSCT, Dual-source computed tomography; hIR, Hybrid iterative reconstruction; IMR, Iterative model based reconstruction; IR, Iterative reconstruction; n.s., Not specified

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The aim of the current study was therefore to systematically review the available dose reduction techniques for CAC CT and to determine to what extend the radiation dose can be safely reduced without significantly impacting the CAC score and/or CVD risk stratification.

2. Methods and materials

2.1. Search strategy

A systematic literature search was performed in February 2018 for studies assessing dose reduction in CAC CT using the Pubmed, Embase and Web of Science databases. The following search strategy was used in Pubmed: ((((((coronar*)) AND (calcium OR calcification*)) AND (radiation OR dose) AND (reduc* OR low*)). Additionally, Embase and Web of Science were searched using adjusted search strategy to fit the search matrix of the database source.

2.2. Inclusion and exclusion criteria

Inclusion criteria were published studies less than 15 years old; single or multicenter; either included phantom, ex vivo and/or patient data; included non-contrast electrocardiography (ECG) triggered cardiac CT; reported quantification of radiation dose reduction, CAC scores (e.g. Agatston score, volume score, mass score), and/or CVD risk stratification. Exclusion criteria were non-English written full text articles; abstracts without full text; editorials, reviews, case reports, letters and guidelines. Studies were excluded that did not report the outcome of interest or if the outcome of interest could not be calculated from the results. We also excluded studies with protocols for which the primary indication was not CAC quantification (e.g. lung CT scans and CT angiography).

2.3. Study selection and data extraction

Studies for the systematic review were selected using the PRISMA flow diagram, see Fig. 1.[14] The screening of title and abstract of each paper was independently performed by two reviewers (MV, NvW). Subsequently, both reviewers independently evaluated the full-text of each article for eligibility based on the in- and exclusion criteria. In case of disagreement, eligibility of the article was discussed between the two reviewers to obtain consensus.

Study characteristics and data extraction of selected articles was performed independently by two authors (MV, NvW) according to a predefined protocol. The following study characteristics were collected: author, year of publication, study type, radiation dose reduction technique, scanner type and vendor, acquisition and reconstruction and radiation dose parameters, CAC scores, and percentage of dose reduction, number of included patients, and impact on CVD risk stratification. The final retrieved data were reviewed by one author (MV).

2.4. Analysis of data

Data were grouped per radiation dose technique, and per IR algorithm that was applied. The key parameter setting leading to the radiation dose reduction was extracted for the full dose and low dose protocols. Remaining acquisition and reconstruction parameters were logged. If a study investigated multiple low dose protocols, only the results of the protocols leading to no significant different Agatston scores or showing high agreement for risk categorization with the full dose protocol were included in the tables. The impact on Agatston scores was extracted. If available, volume and mass score were also extracted. Percentage differences between the radiation dose for the full and reduced dose scans and impact on CVD risk stratification were extracted or calculated.

3. Results

3.1. Characteristics of included studies

In total 28 studies were included, of which 17 were patient studies, 10 were phantom/ex vivo studies, and 1 study included both phantom and patients. The used dose reduction techniques were tube voltage reduction, tube voltage reduction with iterative reconstruction (IR), tube current reduction, tube current reduction with IR, and spectral shaping with tin-filter. All studies used multi-detector or dual-source CT and used either retrospectively or prospectively ECG-gated acquisition in patients. All studies used a tube voltage of 120 kVp (except for the study by Mahnken et al.[15]), either a fixed or adaptive tube current and FBP as the reference full dose protocol. An overview of the $CTDI_{vol}$ of the full and reduced dose protocols per dose reduction technique is shown in Fig. 2.

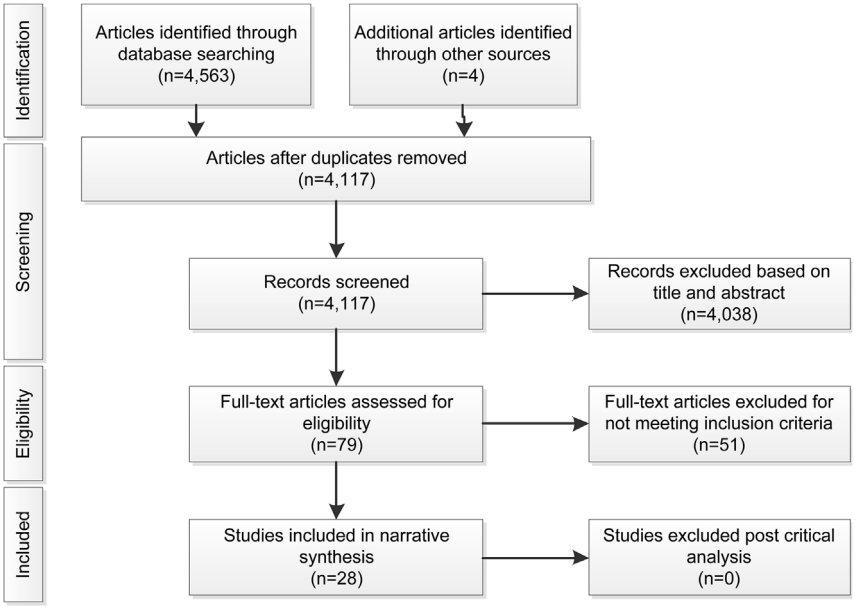

Fig. 1. Flowchart of the systematic review of dose reduction in CAC scanning.

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