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Research paper

High-pitch dual-source CT for coronary artery calcium scoring: A head-to-head comparison of non-triggered chest versus triggered cardiac acquisition

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ABSTRACT

Background: To determine the effect of low-dose, high-pitch non-electrocardiographic (ECG)-triggered chest CT on coronary artery calcium (CAC) detection, quantification and risk stratification, compared to ECG-triggered cardiac CT.

Methods: We selected 1,000 participants from the ImLife study, 50% with coronary calcification on cardiac CT. All participants underwent non-contrast cardiac CT followed by chest CT using third-generation dual-source technology. Reconstruction settings were equal for both acquisitions. CAC scores were determined by Agatston's method, and divided dichotomously (0, > 0), and into risk categories (0, 1–99, 100–399, ≥ 400). We investigated the influence of heart rate and body mass index (BMI) on risk reclassification.

Results: Positive CAC scores on cardiac CT ranged from 1 to 6926 (median 39). Compared to cardiac CT, chest CT had sensitivity of 0.96 (95%CI 0.94–0.98) and specificity of 0.99 (95%CI 0.97–0.99) for CAC detection ($\kappa = 0.95$). In participants with coronary calcification on cardiac CT, CAC score on chest CT was lower than on cardiac CT (median 30 versus 40, $p < 0.001$). Agreement in CAC-based risk strata was excellent (weighted $\kappa = 0.95$). Sixty-five cases (6.5%) were reclassified by one risk category in chest CT, with fifty-five (84.6%) shifting downward. Higher BMI resulted in higher reclassification rate (13% for BMI ≥ 30 versus 5.2% for BMI < 30, $p = 0.001$), but there was no effect of heart rate.

Conclusion: Low-dose, high-pitch chest CT, using third-generation dual-source technology shows almost perfect agreement with cardiac CT in CAC detection and risk stratification. However, low-dose chest CT mainly underestimates the CAC score as compared to cardiac CT, and results in inaccurate risk categorization in BMI ≥ 30.

1. Introduction

Coronary artery calcium (CAC) score, a quantitative imaging biomarker of coronary calcification, is a robust predictor of coronary events.¹ Recently, the ACC/AHA Guideline on the Primary Prevention

of Cardiovascular Disease recommended that CAC scoring can help guide decisions about preventive interventions in selected individuals at intermediate risk.² At present, the standard protocol for CAC quantification is dedicated non-contrast cardiac computed tomography (CT), with prospective electrocardiography (ECG) triggering to minimize

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Abbreviations and acronyms

ACC/AHA	American College of Cardiology/American Heart Association
BMI	Body mass index
CAC	Coronary artery calcium

CI	Confidence interval
DLP	Dose length product
ECG	Electrocardiography
FOV	Field of view
HU	Hounsfield units
SD	Standard deviation

motion artifacts.

CT of the chest is an important radiological modality in the diagnosis of pulmonary disease and low-dose CT has been recommended for lung cancer screening and management.³ As the heart is inherently visualized on chest CT scans, and individuals who are eligible for lung cancer screening also have at least intermediate risk of coronary heart disease,⁴ research interests have been drawn into the possibility of using non-ECG-triggered, low-dose chest CT for CAC scoring to determine the cardiovascular risk of an individual. Knowledge of differences between non-ECG triggered chest CT and ECG-triggered cardiac CT in terms of CAC detection, quantification and strata-based risk classification is a prerequisite for CAC scoring using non-ECG triggered low-dose chest CT. Most previous studies that have compared chest CT to cardiac CT were either performed in small and/or selected populations or used earlier generation CT systems.^{5–8} It was previously concluded that chest CT could not replace cardiac CT due to an average of 8.8% false negatives on chest CT.⁹

In recent years, CT has undergone important improvements in spatial and temporal resolution. For example, third-generation dual-source CT currently can achieve a temporal resolution up to 66 ms. This rapid CT system may improve the performance of CAC scoring without ECG-triggering. Therefore, the aim of this study was to determine the agreement on CAC detection, quantification and CAC stratification between non-ECG triggered low-dose chest CT and ECG-triggered cardiac CT based on high-pitch setting based on third-generation dual-source CT technology.

2. Materials and methods

2.1. Study population

The ImaLife study is an imaging study embedded in the population-based Lifelines cohort, aimed at establishing reference values of image biomarkers for early stages of coronary artery disease, chronic obstructive pulmonary disease and lung cancer in the general population.^{10,11} In brief, Lifelines participants aged ≥ 45 years with completed second round assessment are invited to undergo low-dose, non-contrast CT acquisitions: one of the lungs and of one the heart, in the same visit at one center. For the current substudy, participants were excluded in case of (1) incorrect reconstruction of the chest CT scan, (2) prior cardiac interventions e.g. coronary stenting and coronary artery bypass grafting; or (3) large chest size (> 35 cm in diameter) which required scanning at a lower pitch for the chest CT. To ensure sufficient numbers of subjects across CAC strata for analysis, and to equalize the prevalence of positive CAC in this study population to a previous large-scale population study,¹² we selected 50% of participants with a positive CAC score based on the dedicated cardiac scan. After inclusion of the 500th participant with zero CAC, only participants with positive CAC based on the dedicated cardiac scan were included afterwards. In total, 1000 ImaLife participants scanned from April to December 2018 were included in this study. The ImaLife study was approved by the Medical Ethical Committee of the University Medical Center Groningen, and all participants provided written informed consent.

2.2. CT image protocols

All participants underwent a low-dose, high-pitch ECG-triggered

Fig. 1. Flow chart for inclusion of participants FOV: field of view.

non-contrast cardiac scan at 65% of the R-R interval and a low-dose, high-pitch, non-ECG triggered chest scan with third-generation dual-source CT (Somatom Force, Siemens Healthineers) within one examination, at end-inspiratory breath hold. Participants were not repositioned between the cardiac and chest scan. The cardiac and chest scan were acquired in spiral mode at a pitch of 3.2 and 3.0 respectively, tube current of 64 ref mAs/rot and 20 ref mAs respectively, and tube voltage of 120 kVp. The chest scan covered the entire lungs from the upper apex of the lung to the lung base, while the cardiac scan covered the entire heart from carina to the apex of the heart. Both scans were reconstructed with a matrix size of 512×512 , field-of-view (FOV) of 250 mm centered on the heart, slice thickness and increment of 3.0 mm and 1.5 mm, using filtered back projection and a medium-sharp kernel (Qr36). The heart rate during scan acquisition was registered on the reconstructed CT series.

2.3. Coronary artery calcium score analysis

The presence and amount of CAC were analyzed for the cardiac and chest scan by one experienced researcher (> 2 years of experience in CAC analysis, CX). To limit observer bias, the order of chest scans was randomized before analysis, and analysis took place at least a month after the corresponding cardiac scan was analyzed. Discordant cases (where CAC was present only on one scan) were retrospectively analyzed together with an expert reader (> 4 years of experience in CAC analysis, MV), in order to confirm discrepancy in presence of CAC. The amount of CAC was quantified by using semiautomatic software (CaScoring, Syngo.via VB30A, Siemens Healthineers). The total CAC score was determined according to the Agatston method.¹³ For the purpose of CAC detection, CAC scores were expressed as dichotomous variable, present (> 0) or absent (0). For the purpose of CAC quantification, measures with one decimal were collected. For the purpose of risk classification, CAC scores were rounded to the nearest integer except for scores between 0 and 1 which were rounded up to 1. Four common CAC strata, namely 0, 1–99 (mild), 100–399 (moderate),

Table 1
Characteristics of the study population.

Characteristics	Total (n = 1,000)	CAC absent (n = 500)	CAC present† (n = 500)	p-value
Age (years, median, range)	55 (45–77)	53 (45–62)	56 (45–77)	< 0.001
Male (n, %)	428 (42.8)	136 (27.2)	292 (58.4)	< 0.001
Height (cm)	175.4 ± 9.6	173.4 ± 9.2	177.5 ± 9.6	< 0.001
Weight (kg)	80.6 ± 14.7	77.0 ± 12.9	84.2 ± 15.4	< 0.001
BMI (kg/m ²)	26.1 ± 3.9	25.5 ± 3.5	26.7 ± 4.1	< 0.001
(n, %)				< 0.001
< 25	413 (42.1)	235 (47.6)	178 (36.5)	
25–29.9	431 (43.9)	203 (41.1)	228 (46.7)	
≥ 30	138 (14.1)	56 (11.3)	82 (16.8)	
HR (bpm, mean ± SD)	65 ± 13	65 ± 13	66 ± 14	0.424
(n, %)				0.544
< 60	325 (32.5)	169 (33.8)	156 (31.2)	
60–69	364 (36.4)	186 (37.2)	178 (35.6)	
70–79	186 (18.6)	86 (17.2)	100 (20.0)	
≥ 80	125 (12.5)	59 (11.8)	66 (13.2)	

CAC: coronary artery calcium; BMI: body mass index; HR: heart rate; bpm: beats per minute.

† CAC determined based on cardiac scan.

Table 2
Comparison of CAC detection: chest CT versus cardiac CT.

ECG triggered cardiac scans				
Non-ECG triggered chest scans	CAC	Present	Absent	
	Present	480	7	Positive predictive value 0.99 (0.97–0.99)
	Absent	20	493	Negative predictive value 0.96 (0.94–0.97)
		Sensitivity	Specificity	Accuracy
		0.96 (0.94–0.98)	0.99 (0.97–0.99)	0.97 (0.96–0.98)

CAC: coronary artery calcium.

≥ 400 (severe), were chosen to categorize risk for coronary heart disease.¹⁴

2.4. Radiation dose

The effective radiation dose of the cardiac and chest scans were calculated by multiplying the dose-length-product (DLP in mGy × cm) of each scan with the conversion coefficient $k = 0.017$ (mSv/mGy × cm).¹⁵

2.5. Statistical analysis

Continuous variables were described as mean and standard deviation (SD) or median and range as appropriate. Results of categorical variables were described with frequencies or percentages. Differences in continuous variables between groups were assessed by *t*-test or Mann Whitney *U* test depending on the distribution. In case of categorical variables, chi-square testing was used. Sensitivity, specificity, positive predictive value, and negative predictive value of CAC detection on chest scans were assessed with reference to cardiac scans. The agreement in CAC detection and CAC strata risk classification of chest acquisition compared to cardiac acquisition as reference was assessed using simple kappa and weighted kappa, respectively. A kappa value above 0.90 is interpreted as almost perfect agreement.¹⁶ In individuals with positive CAC on cardiac CT (n = 500), the difference of absolute CAC scores between the two scans was assessed by the Wilcoxon-signed-rank test, accounting for the skewed distribution in the paired groups. The correlation coefficient for CAC scores based on the two scans was determined using Spearman's rho given skewed distribution. Percentage difference in total Agatston score was calculated as follows:

$$\text{Percentage difference} = \left(\frac{2 \cdot |\text{Score}_{\text{Cardiac}} - \text{Score}_{\text{Chest}}|}{\text{Score}_{\text{Cardiac}} + \text{Score}_{\text{Chest}}} \right) \cdot 100\%$$

A Bland-Altman plot was used to visualize any positive and negative difference in actual CAC scores between the two scans. The 95% limits

of agreement were estimated using percentiles in case of skewed data. To explore potential causes for discrepancy between chest and cardiac CT, a comparison of body mass index (BMI) and heart rate between concordant and reclassified groups was conducted. The statistical analyses were performed using SPSS 23 (IBM) and graphs were created using Graphpad prism 7 (GraphPad Software Inc.). Level of significance was defined as $\alpha = 0.05$.

3. Results

3.1. Study population characteristics

In total, 1,000 participants were included in this study, Fig. 1 shows the inclusion flow. The median age was 55 years (range 45–77), 42.8% were male, mean BMI was 26.1 ± 3.9 kg/m², mean heart rate was 65 ± 13 bpm. Participants with CAC were older ($p < 0.001$), had higher BMI ($p < 0.001$) and comprised more men ($p < 0.001$) compared to participants without CAC (Table 1).

3.2. Coronary artery calcium detection

Results of CAC detection are summarized in Table 2. The agreement on CAC detection between chest scans and cardiac scans was almost perfect ($\kappa = 0.95$, 95%CI 0.93–0.97). Sensitivity of chest CT was 0.96 (95%CI 0.94–0.98) and specificity was 0.99 (95%CI 0.97–0.99).

In total, 27 participants were misclassified by the chest CT with regards to CAC presence. Seven of them (0.7%) were identified as false positives while 20 participants (2.0%) were identified as false negatives, see Fig. 2 for examples. For the false positives, the median CAC score was 0.4 (0.2–2.6) based on the chest scan. For the false negatives, the median CAC score based on the cardiac scan was 2.7 (0.5–8.6).

3.3. Coronary artery calcium scores quantification

In participants with positive CAC on cardiac CT (n = 500), there

Fig. 2. Examples of discordant cases with regards to CAC presence. Case 1: No calcification revealed on cardiac CT while probably image noise was perceived as coronary calcification on chest CT. Case 2: A calcified plaque detected on cardiac CT while was missed by chest CT.

Fig. 3. In participants with coronary calcification on cardiac CT ($n = 500$), the scatter plot shows correlation in CAC scores between chest CT and cardiac CT (A); Bland-Altman plot shows the bias and 95% limits of agreement in CAC score between chest CT and cardiac CT (B).

was a very strong correlation between chest CT and cardiac CT ($\rho = 0.973$, $p < 0.001$) (Fig. 3A). However, the median CAC score on the chest acquisition (median 30, range 0–6855) was significantly lower than that based on the cardiac acquisition (median 40, range 1–6926, $p < 0.001$). The median difference of CAC score on cardiac CT to chest CT was 8, and 95% limits of agreement were –9 to 126 (Fig. 3B). Median percentage difference in CAC score was 29% (range 0, 200%). Median percentage difference in CAC score was 41% (range

0–200%), 22% (range 0–85%), and 10% (range 0–73%) for cardiac CT-based CAC score category 1–99, 100–399, and ≥ 400 , respectively.

3.4. Coronary artery calcium risk stratification

Table 3 shows the classification in CAC score categories. The agreement in CAC score classification was almost perfect ($\kappa = 0.95$, 95%CI 0.95–0.95). The reclassification rate for CAC-based risk

Table 3

Cardiovascular risk stratification based on CAC score for chest CT versus cardiac CT.

	ECG triggered cardiac scan					Total
	CAC	0	1-99	100-399	≥ 400	
Non-ECG triggered chest scan	0	493	20	0	0	513
	1-99	7	323	27	0	357
	100-399	0	3	85	8	96
	≥ 400	0	0	0	34	34
	Total	500	346	112	42	1,000

CAC: coronary artery calcium

Fig. 4. Distribution of CAC scores of the 65 reclassified cases.

categorization for chest CT was 6.5% (65/1000). Of these, 84.6% (55/65) shifted to a lower risk category while 15.4% (10/65) shifted to a higher risk category. None of the cases shifted more than one risk category. The distribution of CAC scores among reclassified cases is shown in Fig. 4.

3.5. Effect of BMI and heart rate on reclassification

Cases who ended up in a different risk category based on chest CT, had significantly higher BMI (median 26.3 kg/m², range 20.1–42.4) than concordant cases (median 25.5 kg/m², range 17.6–47.5, $p = 0.01$). Obese individuals (BMI ≥ 30 kg/m²) were more likely to be reclassified by chest CT, compared with healthy weight individuals (BMI < 25 kg/m²) and overweight individuals (BMI 25–29.9 kg/m²) (Fig. 5A). In BMI < 30, the reclassification rate was 5.3%, of whom 82.2% (37/45) shifted one category downward. In BMI ≥ 30, the reclassification rate was 13%, of whom 88.9% (16/18) shifted one category downward. There was no significant difference in mean heart rate between reclassified and concordant cases (66 bpm versus 65 bpm respectively, $p = 0.70$). Reclassification rate showed a slight increase as the heart rate increased (Fig. 5B), but this was not significant ($p = 0.26$).

3.6. Radiation dose

The recorded scan length was 35.5 ± 3.1 cm for the chest acquisition and was 18.0 ± 1.5 cm for the cardiac acquisition. The mean DLP was 58.7 ± 18.4 mGy × cm for the full chest acquisition and 23.7 ± 7.4 mGy × cm for the cardiac acquisition. The participants received an average effective radiation dose of 1.0 ± 0.3 mSv from the chest acquisition and of 0.4 ± 0.1 mSv from the cardiac acquisition.

4. Discussion

In a large population, we performed a head-to-head comparison between non-ECG triggered chest CT and ECG-triggered cardiac CT with third-generation dual-source CT. To our best knowledge, this is the first study evaluating the performance of high-pitch chest CT for CAC scoring in third generation dual-source CT. Although the median CAC score on chest CT was slightly but significantly lower than cardiac CT, there was an almost perfect agreement of chest CT in CAC detection and risk classification based on CAC strata. However, in individuals with BMI ≥ 30, the reclassification rate was considerably higher, 13%.

4.1. Coronary artery calcium detection

Zero CAC score is associated with very low cardiovascular risk.^{17,18} If chest CT is accurate in identifying individuals with zero CAC, a dedicated cardiac CT for CAC scoring may be omitted in individuals with prior chest CT. We found a sensitivity of 0.96 and a specificity of 0.99 for chest CT in detecting positive CAC, which are similar to studies that used recent CT generations,^{15,19} and higher than studies that used older CT generations (Table 4).^{5,6} In our study, the false negative rate on chest CT was 4%, which was comparable to the 3.6% reported by Hutt et al. in a smaller cohort of smokers,¹⁵ slightly lower than the 5.2% reported by Chen et al.,¹⁹ and considerably lower than the 8.8% in a prior meta-analysis based on older scanner generations.⁹ In our study, the false negatives on chest CT were likely due to motion artifacts, resulting in hardly visible CAC with maximum Hounsfield units (HU) of the calcification dropping below the threshold of 130 HU.

4.2. Coronary artery calcium quantification

Consistent with prior studies we found a very strong correlation in CAC scores between chest CT and cardiac CT.^{5,7,8} However, the median CAC score on chest CT was significantly lower than on cardiac CT, as previously reported.^{8,15,19} The difference in absolute CAC score between two scans increased as the CAC score increased, while the percentage difference decreased at higher risk category. Differences in CAC quantification have been found between different CT scanners, different acquisition parameters, and even in case of repeat ECG-triggered scanning with identical settings.^{20–23} We found a median percentage difference of 29% in CAC scores in cases with positive CAC score on cardiac CT. This difference is higher than the intra-scanner comparison of repeated CAC scoring in earlier generation CT systems with ECG-triggering (up to 18%).^{20,24,25} However, our results are consistent with previous studies that compared chest CT with cardiac CT (percentage difference 11%–44%)^{5,7,8,19} and with prior studies that performed ECG-triggered CAC scoring using CT scanners from different vendors

Fig. 5. Reclassification rate for CAC-based risk categorization based on chest CT as compared to stratification based on cardiac CT, by body mass index (A) and heart rate (B). BMI: body mass index; bpm: beats per minute.

(6%–44%).^{26,27} In clinical practice, many different CT systems are used for ECG-triggered CAC scoring; chest CT is not as accurate as dedicated ECG-triggered CT but does not result in higher reclassification rate than the discrepancies in risk classification for ECG-triggered CAC scores based on different older generation CT systems.²⁷ Chest CT does show a tendency towards underestimation of the CAC score. This may have implications in case of initial risk classification (see below), but also in repeated CT scanning with the aim of evaluation of CAC progression, for example as response to treatment. The Society of Cardiovascular Computed Tomography (SCCT 2017) proposed in an expert consensus statement treatment recommendations based on CAC score categorization.²⁸ As the CAC score is currently primarily used as a single time point test to determine a category of cardiovascular risk, differences in absolute CAC score but within the same risk category may not have severe effects in clinical practice since the recommended treatment stays the same. Nevertheless, differences in CAC score near the cutoff values of risk categories may result in reclassification and as a consequence, in a change of recommended treatment. At present, the clinical impact of (change in) treatment based on CAC score on cardiovascular outcomes has yet to be proven in clinical trials.²⁹

4.3. Coronary artery calcium risk stratification

Currently, CAC score categorization is recommended for

cardiovascular risk assessment or risk-based management in asymptomatic individuals at intermediate risk based on classical risk factors.² The agreement between chest CT and cardiac CT for cardiovascular risk stratification was almost perfect (weighted $\kappa = 0.95$). Overall 6.5% of the cases were reclassified into one risk category higher or lower. In reclassified cases, most (84.6%) ended up in a lower risk category based on chest CT. This underestimation of risk may change the decision to initiate statin treatment in patients at intermediate cardiovascular risk. Particularly, in the light of expert opinion treatment recommendations based on CAC scoring,²⁸ statin treatment is recommended in all individual with a positive CAC score. Thus, statin therapy may be incorrectly withheld in case the chest CT results in a false negative CAC score, compared to a dedicated cardiac CT. However, this study showed a low false negative rate for chest CT. The reclassification rate (6.5%) in our study on third-generation dual-source CT is comparable to recent studies comparing chest and cardiac acquisition based on other state-of-the-art CT systems.^{15,19} For example, Hutt et al. reported a reclassification rate of 6% in 185 smokers of whom 60% had positive CAC, and Chen et al. reported a reclassification rate of 4.9% in 1318 participants of whom 14.6% had CAC score.^{15,19} Moreover, the reclassification rate in our study is much lower than that of prior studies that used old CT generations (Table 4).^{5–8} Studies that compared different CT systems or different scan settings have shown that reclassification rates ranged from 3.6% to 9%.^{27,30,31} High heart rate is

Table 4

Prior studies comparing non-ECG triggered chest CT with ECG-triggered cardiac CT in CAC detection and categorization.

Studies, year	Sample size (n)	Study population	CT scanner	Positive CAC on cardiac CT (n, %)	Detection	Categorization
Xia, (current study)	1000	Population-based cohort, adults ≥ 45 years of age; 500 cases with positive CAC and 500 cases with zero CAC were selected	3rd generation DSCT	500 (50%)	Sensitivity 96% Specificity 99%	4 categories ^b concordant 93.5% $\kappa = 0.95$
Chen, 2019 ¹⁹	1318	Patients underwent chest CT for the purpose of lung cancer screening or routine physical examination	256 MDCT	192 (14.6%)	Sensitivity 94.8% Specificity 100%	4 categories ^a concordant 95.1%
Hutt, 2016 ¹⁵	185	Smokers older than 40 years old who had been referred for a chest CT in a variety of clinical situations	2nd generation DSCT	111(60%)	Sensitivity 96.4% Specificity 100%	4 categories ^b concordant 94% $\kappa = 0.95$ (95%CI 0.93, 0.98)
Arcadi, 2014 ⁸	60	Asymptomatic individuals who were referred for the assessment of CAC	64 MDCT	54 (90%)	NR	6 categories ^c concordant 61.7%
Budoff, 2011 ⁷	50	Participants with a minimum of a 10 pack-year of smoking	64 MDCT	33 (66%)	NR	4 categories ^a concordant 92% $\kappa = 0.90$
Kim, 2008 ⁶	128	Smokers	40 MDCT	54 (42.2%)	Sensitivity 91% Specificity 89%	5 categories ^d concordant 82.8%
Wu, 2008 ⁵	483	Asymptomatic individuals self-referred to the health screening center	16 MDCT	221 (45.8%)	Sensitivity 97.7% Specificity 98.1%	4 categories ^a concordant 93.2% $\kappa = 0.89$

CAC: coronary artery calcium; MDCT: multi-detector computed tomography; DSCT: dual-source computed tomography; NR: not reported.

^a Cutoffs for 4 categories were 0, 1–100, 101–400, > 400 .^b Cutoffs for 4 categories were 0, 1–99, 100–399, ≥ 400 .^c Cutoffs for 6 categories were 0, 1–10, 11–100, 101–400, 400–1000, > 1000 .^d Cutoffs for 5 categories were 0, 1–10, 11–100, 101–400, > 400 .

often the cause of motion artifact in cardiac CT. Although there was a trend towards slightly higher reclassification rate at higher heart rate, this did not reach statistical significance. Likely, the motion artifact was due to the fact that the scan was acquired in a phase in which coronary arteries showed larger movement. Inherent to non-ECG triggered chest CT, the ECG-interval in which the images of the heart are acquired is unpredictable. The probability of scanning the coronaries in a sub-optimal ECG phase may increase at higher heart rate. Higher BMI was associated with increased reclassification rate. More specifically, participants with BMI ≥ 30 were considerably more likely to be misclassified by chest CT, with more underestimation of cardiovascular risk. This is in contrast to Hutt et al., who found no difference in BMI for discordant versus concordant cases.¹⁵ This higher reclassification rate in participants with high BMI may be due to higher noise in chest CT in obese patients.³² Our results suggest that in obese patients, chest CT is insufficiently accurate for cardiovascular risk stratification based on CAC scoring, and a dedicated ECG-triggered acquisition and/or higher reference dose is advisable. Or iterative reconstructions could be considered to reduce image noise in obese patients. However, former studies in ECG-triggered cardiac CT have shown that iterative reconstruction may lead to lower Agatston scores and underestimation of the risk category.³³ Thus, at this moment iterative reconstruction for BMI > 30 to obtain chest CT-based CAC scores cannot be recommended, and instead, a dedicated ECG-triggered cardiac CT is advised for CAC scoring. Future studies should investigate whether it is possible to derive correction factors, either for chest CT with FBP or with iterative reconstruction, to improve chest CT-based CAC scores in BMI > 30 . However, for individuals with a low BMI (BMI < 30), our results show that chest CT has high agreement with cardiac CT with regards to CAC presence and risk categorization.

4.4. Limitations

One limitation of our study is that we did not assess inter/intra-reader variability in CAC scoring. However, variability of CAC scoring between and within readers has been reported to be low in cardiac CT

and in non-ECG triggered chest CT.⁹ Double reading of CAC scoring is not performed in clinical practice at this time, and we do not think double reading would have improved our results. We excluded six participants who could not undergo chest scanning at high-pitch (3.0) due to their chest size, for which FOV and pitch needed to be adjusted; our results are limited to non-morbidly obese individuals. For ECG-triggered cardiac CT we used a high-pitch protocol in diastolic phase irrespective of heart rate; CAC scoring is more commonly performed using ECG-triggered sequential CT. In a prior study in second generation dual-source CT, we showed that there is an excellent agreement between high-pitch and sequential mode for CAC scoring, even in higher heart rate.³¹ For third-generation dual-source CT the temporal/spatial resolution and radiation efficiency are even higher.³⁴ Also, several other recent studies have used the high-pitch spiral mode as default mode for CAC scoring.^{35–37} Thus, the high-pitch cardiac CT protocol in this study is considered to yield accurate reference CAC score results. The result of our study was limited to latest generation dual-source CT technology and is not generalizable to other CT systems. In particular, our results are derived from high-pitch scanning, which has high temporal resolution with and without ECG triggering. It is questionable whether the exact same results would be found for second generation dual-source CT, as a prior phantom study in the three generations dual-source CT showed slight differences in accuracy between second and third generation dual-source CT.³⁴ Our results and recommendations are not applicable to CT systems without ability for high-pitch scanning, in which case there is a higher chance of motion artifacts, impacting the accuracy of the CAC score.

5. Conclusion

With the advent of lung cancer screening, there is increasing interest in the potential of chest CT for CAC score determination in order to assess an individual's cardiovascular risk. In this study, a very high agreement for CAC detection and risk stratification was found between non-ECG triggered chest acquisition and ECG-triggered cardiac acquisition for individuals with BMI < 30 scanned with high-pitch third-

generation dual-source CT. This opens up the option to use one chest CT acquisition for both lung and cardiac CT screening under these conditions. Nevertheless, CAC score could be underestimated based on chest CT as compared to cardiac CT, and this resulted in inaccurate risk categorization in individuals with BMI ≥ 30 . Therefore, one should be cautious in cardiovascular risk management based on CAC scores derived from third-generation chest CT in individuals with high BMI.

Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jcct.2020.04.013>.

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