



## Accuracy of non-gated low-dose non-contrast chest CT with tin filtration for coronary artery calcium scoring

Ying Liu<sup>1,\*</sup>, Xuezhi Chen<sup>1,\*</sup>, Xianchen Liu, Hao Yu, Lianjun Zhou, Xiaoling Gao, Qinglin Li, Shujun Su, Lin Wang, Jia Zhai

Department of CTMR, Ningcheng County Central Hospital, Ningcheng, Inner Mongolia 024200, China

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### ABSTRACT

**Objective:** The study investigated the accuracy of coronary artery calcium scores (CACS) and the potential for reducing radiation dose using non-gated low-dose non-contrast chest computed tomography (CT) scanning with tin filtration for one-stop screening of the lungs and heart.

**Methods:** A prospective study was conducted, 193 Patients received two scans for determining CACS, including an ECG-gated CT at 120 kV (ECG-gated CT), followed by a non-gated low-dose chest CT using 100 kV with tin filtration (non-gated Sn100 kV-LDCT). The Agatston score (AS), risk stratification, and radiation dose were compared between the scan types.

**Results:** There was good consistency in the AS from both an ECG-gated CT and a non-gated low-dose chest CT scan, which had a high correlation ( $r = 0.970$ ). The Kappa value of risk stratification of the two scan types was 0.549. The area under the ROC curve (AUC) of the CACS was used to develop a new risk stratification standard for non-gated Sn100 kV-LDCT evaluation of CACS. In comparison to the CACS measured by ECG-gated CT, non-gated Sn100 kV-LDCT had an AUC of 0.951 and an optimal critical value of 4.6 in the low-risk category. The AUC of low-medium risk was 0.966, and the optimal critical value was 41.2. The AUC of the medium-high risk category was 0.968, and the optimal critical value was 230. The consistency in CACS measured by ECG-gated CT and non-gated Sn100 kV-LDCT had a Kappa value of 0.831. The Effective dose (ED) of non-gated Sn100 kV-LDCT and ECG-gated CT was  $0.056 \pm 0.017$  mSv and  $0.685 \pm 0.455$  mSv, respectively ( $p < 0.05$ ).

**Conclusion:** The Agatston score of CACS using non-gated low-dose chest CT was accurate, but there was an underestimation in risk stratification. This study developed a new risk stratification standard for non-gated Sn100 kV-LDCT evaluation of CACS, which is in closer agreement with CACS derived from ECG-gated CT scans.

### 1. Introduction

Coronary atherosclerotic heart disease has become a major cardiovascular disease in China. A common pathological feature of atherosclerosis is vascular calcification. A coronary artery calcification score (CACS) is an important non-invasive indicator for diagnosing coronary heart disease. It is used to perform cardiovascular risk stratification, determine the presence and prognosis of coronary heart disease, and assist in selecting clinical treatment strategies [1–3]. Combining the CACS with a dedicated electrocardiograph (ECG)-gated CT scanning protocol has served as a reference standard for the non-invasive detection and quantification of calcification [4,5].

In recent years, several studies [6,7] have shown that non-gated low-dose chest CT scans can also be used to evaluate CACS accurately. As a result, non-gated low-dose chest CT scans have the potential to achieve one-stop screening of the lungs and coronary artery calcification for populations with lung cancer, thereby avoiding the need for an additional scan. However, according to the national lung screening trial (NLST), the mean radiation dose of low-dose chest CT was 1.5 mSv, with patients receiving a total radiation dose of 8.5 mSv over three years. Several studies have shown spectral shaping with a tin filter is a promising technique for chest scanning, which can greatly reduce the radiation dose to 0.2 mSv while also ensuring image quality [8]. In addition, scans using spectral shaping with a tin filter and ECG gating can be used

\* Corresponding authors.

E-mail addresses: [liueagle2012@163.com](mailto:liueagle2012@163.com) (Y. Liu), [chenxuezhi666@163.com](mailto:chenxuezhi666@163.com) (X. Chen).

<sup>1</sup> These authors contributed equally to this work

to accurately evaluate calcification scores compared to conventional 120 kV scanning [8,9]. However, there is still no relevant research on whether accurate calcification scores can be determined by non-gated chest CT scans with a tin filter.

Therefore, the purpose of this study was to investigate the accuracy of calcification scores measured by non-gated low-dose chest CT scans with tin filtration compared to conventional 120 kV ECG-gated scans. Acceptable agreement will enable one-stop chest screening and risk assessment of cardiovascular diseases.

## 2. Materials and methods

### 2.1. General information

In this prospective study, all participants signed informed consent before the examination. From all CT angiography scans in our hospital from October 2020 to February 2021, patients with coronary artery calcification were identified and included in this study. Patients were excluded if they were allergic to the iodine contrast agent, had received a stent implantation, or had bypass surgery. Finally, 193 cases were included in the study, of which 114 were male, and 79 were female, with an average age of  $61.94 \pm 9.80$  years (range: 36–88 years). Further patient demographics and baseline characteristics are presented in the Table 1.

### 2.2. CT scanning and coronary artery calcium scoring

All imaging was performed on a third-generation dual-source CT system (SOMATOM Force, Siemens Healthineers, Forchheim, Germany) equipped with two X-ray tubes. Participants received two types of scans, including an ECG-gated CT at 120 kV (ECG-gated CT), followed by a non-gated low-dose chest CT using 100 kV with tin filtration (non-gated Sn100 kV-LDCT). The ECG-CT group received ECG-gated calcification integral scanning with the following parameters: tube voltage was selected 120 kV, automated anatomical tube current modulation (CARE Dose 4D, Siemens Healthineers), collimation was  $38 \times 12$ , gantry rotation time was 0.25 s. In the Sn100kV-LDCT group, low-dose chest CT scans were performed with the following parameters: tube voltage Sn100kV, automated anatomical tube current modulation (CARE Dose 4D), collimation  $192 \times 0.6$ , gantry rotation time was 0.25 s. In both groups. Images were reconstructed with a 3.0 mm section thickness and an increment of 1.5 mm, using a medium sharp convolution algorithm (Qr36f), reconstruction by filtered back projection method.

### 2.3. Image analysis

A dedicated post-processing and evaluation software (syngo.via, version VB10B, Siemens Healthineers) was used for quantitative image analysis. One subspecialty-trained cardiovascular radiologist with ten years of experience evaluated all images, with each image series assessed in a random order to reduce recall bias. Calcifications were defined according to the Agatston convention as a plaque with an area of at least 1.03 mm<sup>2</sup> and with an attenuation threshold of 130 HU.

Calcified areas of each branch of the coronary artery were automatically marked, and the total area was taken as the CACS. According to the evaluation standard of the American Heart Association, Agatston scores were categorized as minimal (1–10), mild (11–100), moderate (101–400), or severe ( $> 400$ ) [10].

A subjective evaluation was provided by two doctors, each with more than ten years of diagnosis experience, who were blinded to the patients' characteristics and exam reports. A third doctor was invited to discuss the case when there was disagreement between the first two doctors. The subjective scoring standard included: 1 point (unqualified): the image artifacts were serious and did not meet any of the requirements for diagnosis; 2 points (poor): image artifacts existed, and most of the diagnostic requirements could not be met; 3 points (general): slight image artifacts existed, which met the basic diagnostic requirements; 4 points (good): no obvious image artifacts, and meets diagnostic requirements; 5 points (excellent): no obvious image artifacts, excellent image quality.

An objective image quality analysis was performed by placing a region of interest (ROI; 2 cm<sup>2</sup>) in the ascending aorta just above the level of the coronary arteries. The corresponding Hounsfield units (HU) and standard deviations (SD) were recorded, while image noise was defined by the SD. The signal-to-noise ratio (SNR) was calculated by dividing the mean signal intensity by the SD. The contrast noise ratio (CNR) was calculated as (CT aorta -CT pericardial fat) /SD aorta.

### 2.4. Radiation dose

The volumetric CT dose index (CTDI<sub>vol</sub>) and the dose-length-product (DLP) were recorded. For comparative purposes, the conventional conversion factor of 0.014 mSv/mGy  $\times$  cm was used to calculate the effective radiation dose (ED) equivalent.

### 2.5. Statistical analysis

Statistical analysis was performed with SPSS22.0 software. Bland-Altman analysis and Spearman correlation coefficients were used for evaluating agreement and correlation, respectively. A Wilcoxon test was used for comparing effective dose, as well as subjective and objective evaluations between the two scan types. A Kappa test was used for assessing the consistency of integrated heart disease risk between the two scan types. A Kappa value  $\leq 0.4$  indicated poor consistency,  $0.4 < \text{Kappa value} \leq 0.6$  indicated medium consistency,  $0.6 < \text{Kappa value} \leq 0.8$  showed good consistency, and  $0.8 < \text{Kappa value} \leq 1$  was considered excellent consistency. A p-value  $< 0.05$  was considered statistically significant. A receiver operating characteristic (ROC) curve was used to test diagnostic efficiency, and the node with the largest Jordan index was taken as the optimal critical value (Figs. 1–3). Kappa tests were carried out on the newly obtained critical value as the new risk stratification and the stratification obtained by conventional gated CT, with the difference being statistically significant at  $p < 0.05$ .

## 3. Results

### 3.1. Image quality evaluation

The subjective scores of the ECG-CT scan were significantly higher than the Sn100kV-LDCT ( $p < 0.05$ ). The ascending aorta noise ( $19.81 \pm 2.40$ ) in the Sn100kV-LDCT scan was higher than that in the ECG-CT scan ( $14.52 \pm 2.47$ ) so that the signal-to-noise ratio (SNR) and contrast noise ratio in the Sn100kV-LDCT scan were significantly lower than in the ECG-CT scan ( $p < 0.05$ ; Table 2).

### 3.2. Coronary Artery Calcification Score

The Agatston score from the ECG-CT scan ( $250.435 \pm 442.178$ ) was significantly higher than that from the Sn100kV-LDCT scan

**Table 1**  
Further patient demographics and baseline characteristics.

Age ( year )	61.94 $\pm$ 9.80
Men	114 ( 59.1% )
Women	79 ( 40.9% )
Height(m)	1.67 $\pm$ 0.07
Weight(kg)	69.59 $\pm$ 11.76
Body-mass-index (kg/m <sup>2</sup> )	25.00 $\pm$ 3.49
Diabetes mellitus	27 ( 14% )
Hypertension	81 ( 42% )
Smoking history	55 ( 28.5% )
Family history of CAD	21 ( 10.9% )

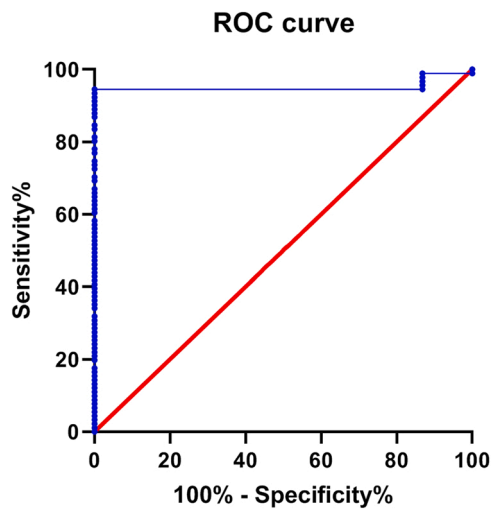


Fig. 1. ROC curve, AUC of very minimal-mild risk group: 0.951.

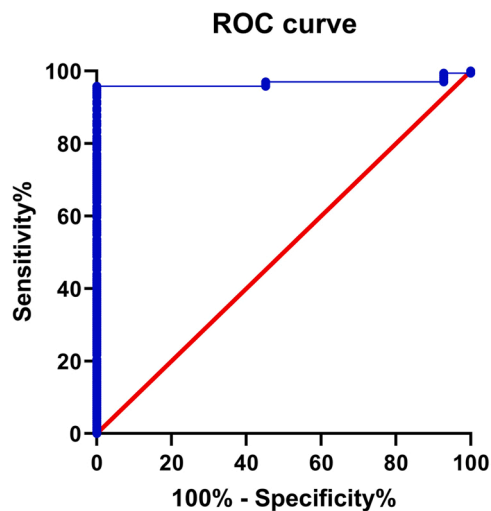


Fig. 2. ROC curve, AUC: 0.966 In mild-moderate risk group.

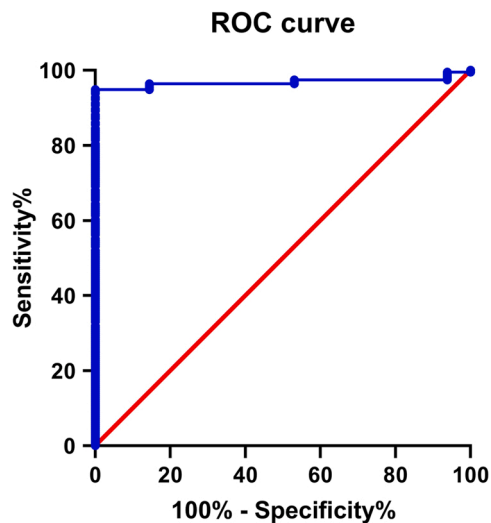


Fig. 3. ROC curve, AUC of moderate-severe risk group: 0.968.

Table 2

Comparison of objective image quality between ECG-CT group and Sn100 kV-LDCT group.

Group	Noise of aortic root	SNR	CNR
Sn100KV-LDCT group	27.563 ± 3.274	3.436 ± 0.671	2.469 ± 0.659
ECG-gated CT group	14.370 ± 2.442	1.697 ± 0.274	5.158 ± 0.737
T value	-49.453	36.111	-39.941
P value	0.000	0.000	0.000

(169.401 ± 346.371;  $p < 0.05$ ).

### 3.3. Correlation and risk stratification comparison of calcification score

The Agatston's score (AS) of the ECG-CT and Sn100kV-LDCT scans showed good agreement (Fig. 4) and a high correlation ( $r = 0.970$ ). The risk stratification between the scans had a Kappa value of 0.549 (Table 3;  $p < 0.05$ ), showing moderate consistency. There were 28 patients identified at severe risk from the ECG-CT scan, of which 11 patients were classified as moderate risk from the Sn100-LDCT scan. Seventy-four patients were identified as moderate risk from the ECG-CT scan, of which 29 patients were classified as mild risk by the Sn100-LDCT scan. Of the 79 patients at mild risk following the ECG-CT scan, 19 patients were classified as minimal risk from the Sn100-LDCT scan (Fig. 5).

### 3.4. The CACS measured by the Sn100kV-LDCT and ECG-CT methods were accurate

The area under the ROC curve (AUC) of the minimal to mild risk category was 0.951 ( $p < 0.05$ ), with an optimal critical value of 4.6 (Jordan index). The AUC of mild to moderate risk was 0.966 ( $p < 0.05$ ), and an optimal critical value of the Jordan index of 41.2. The AUC of moderate to severe risk was 0.968 ( $p < 0.05$ ), and according to the Jordan index, the optimal critical value was 230. Diagnostic efficiency was high for all risk levels. Based on the best critical value (integer) obtained from the ROC curve above, a new risk stratification was developed, i.e.,  $< 4.6$  is minimal,  $4.6-41.2$  is mild,  $41.3-230$  is moderate, and  $> 230$  is severe risk. The consistency between this new risk stratification and the CACS risk stratification measured by ECG-CT was tested (Table 4), revealing a Kappa value of 0.831, with good consistency ( $p < 0.05$ ). (Figs. 6-7).

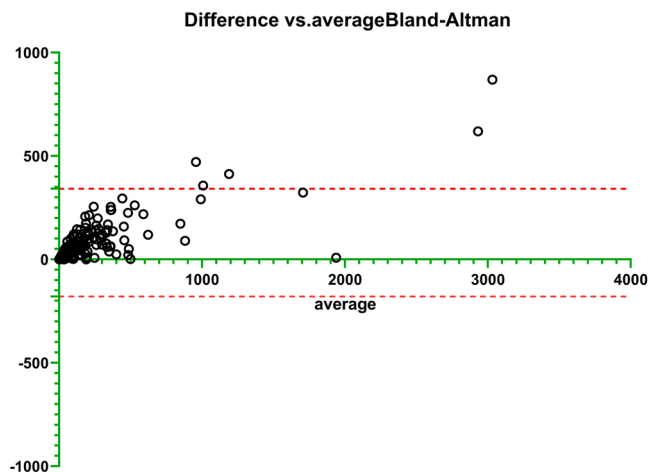
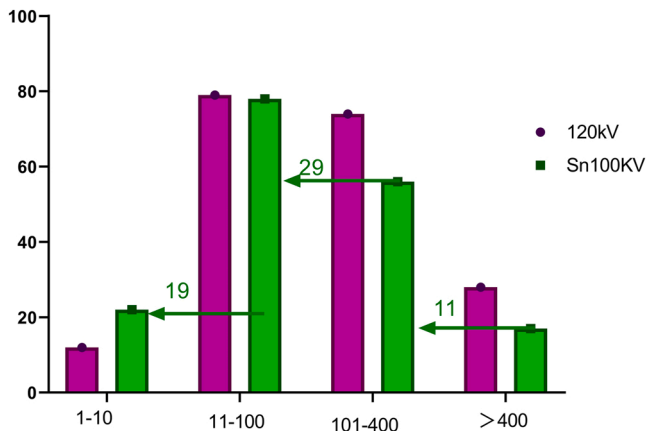


Fig. 4. Bland-Altman plot comparison of Agatston scores using Sn100 kV-LDCT and ECG-CT. Results are presented as average differences between Sn100 kV-LDCT and ECG-CT. The average difference value is illustrated as a green line with corresponding double SD intervals (red dotted lines).

**Table 3**  
Risk stratification comparison between original standard ECG-CT and Sn100kV-LDCT (Kappa Value 0.783).

ECG-CT group	Sn100kV-LDCT group				Total
	Score < 10	Score 10–100	Score 101–400	Score > 400	
Score < 10	12	0	0	0	12
Score 10–100	19	60	0	0	79
Score 101–400	0	29	45	0	74
Score > 400	0	0	11	17	28
Total	31	89	56	17	193



**Fig. 5.** Agatston score categories and Agatston score percentile-based risk categorization. Arrows and numbers represent the number of patients reclassified to a different category.

**Table 4**  
ECG-CT and Sn100kV-LDCT optimal threshold risk stratification comparison.

ECG-CT group	Sn100kV-LDCT group				Total
	Score < 10	Score 10–100	Score 101–400	Score > 400	
Score < 10	12	0	0	0	12
Score 10–100	0	69	10	0	79
Score 101–400	0	1	62	11	74
Score > 400	0	0	0	28	28
Total	12	70	72	39	193

### 3.5. Radiation dose

The CT DIvol was  $3.172 \pm 1.63$  mGy compared to  $0.236 \pm 0.068$  mGy utilizing the 120 kV (ECG-gated CT) and Sn100 kV protocols, respectively ( $p < 0.01$ ). The DLP was  $48.931 \pm 32.515$  mGy.cm with the 120 kV and  $3.978 \pm 1.254$  mGy.cm with the Sn100 kV ( $p < 0.01$ ). The calculated ED was  $0.685 \pm 0.455$  mSv for the 120 kV protocol and  $0.056 \pm 0.017$  mSv for the Sn100 kV protocol using the  $0.014$  mSv/mGy.cm conversion factor, showing a significant reduction in the Sn100 kV protocol (91.82%;  $p < 0.00$ ; Table 5).

### 4. Discussion

Our results show that determining CACS with non-gated low-dose chest CT with tin filtration using filtered back projection image reconstruction showed moderate agreement with Agatston score categories

( $r = 0.944$ ,  $P < 0.05$ ) and percentile-based cardiac risk stratification ( $K = 0.549$ ) compared with the standard 120 kV protocol. This study re-evaluated the diagnostic efficiency of CACS based on the category, and obtained a better percentile-based cardiac risk stratification ( $K = 0.831$ ) compared with the standard 120 kV protocol. In addition, tin filtration reduced the effective radiation dose by 91.82%, with a mean dose of 0.056 mSv.

Morbidity and mortality due to cardiovascular diseases are on the rise in China, and about half of the people suffering cardiogenic death have not been previously diagnosed with cardiovascular diseases or were asymptomatic [9]. In asymptomatic populations, the detection of coronary artery calcification is helpful for the early diagnosis and treatment of cardiovascular disease. Coronary artery calcification is an important pathological change that contributes to coronary atherosclerosis. Coronary artery calcification is closely related to an increased risk of developing cardiovascular diseases. The AS is one of the most commonly used quantitative detection methods for coronary artery calcification [11]. Non-gated low-dose chest CT scans have become the primary method for screening patients with lung cancer and other lung diseases. A single non-gated low-dose chest CT scan can simultaneously display lung and mediastinal diseases, and the mediastinal images enable the measurement of CACS and the stratification of cardiovascular disease risk. The CACS evaluated by non-gated low-dose chest CT scans is in good agreement with the CACS evaluated by ECG-gated conventional-dose CT [12]. Budoff et al. [13] showed that a low-dose chest CT plain scan was reliable for observing coronary artery calcification and evaluating CACS, and it was highly correlated with ECG-CT scans ( $r = 0.96$ ). Therefore, CACS evaluated by non-gated low-dose chest CT scans provide a one-stop evaluation of lung (lung cancer and chronic obstructive pulmonary disease) and cardiovascular diseases without increasing radiation dose while simultaneously reducing the personal economic burden and enabling early detection, diagnosis, and treatment of cardiovascular diseases.

In the present study, the radiation dose of low-dose chest CT was reduced, a finding that is similar to previous reports. For example, Liu Haifeng et al. [14] used CARE Dose4D technology to measure CACS and radiation dose and applied a low tube voltage of 100 kV at the same time. The method did not affect CACS, but the radiation dose was reduced. McQuiston et al. [15] used a large pitch (3.2), low tube voltage (100 kV), and CARE Dose 4D technology (reference tube current 40 mA) in combination to reduce radiation dose by 91.9%. In this study, the third generation Force CT photon detector Sn100kV plus CARE Dose4D technology was used to reduce the effective radiation dose to  $0.056 \pm 0.018$  mSv compared with the conventional tube voltage 120 kV of  $0.685 \pm 0.455$  mSv, which is a reduction of 91.82%. Energy spectrum purification technology (Sn100 kV) [16] was realized by adding a tin filter plate at the output end of the X-ray bulb. The low-energy X-ray in the output of the bulb tube was filtered out, thus reducing ineffective radiation. The purified energy spectrum improves material resolution, and a larger pitch (2.0) can be selected, which is more effective in reducing radiation dose. Euler et al. [17] used a Stellar photon detector with reduced electronic noise and an iterative reconstruction algorithm and found that this method not only reduced the radiation dose for chest examination by 45.6% but it also improved the signal-to-noise ratio and contrast noise ratio of the image. In this study, image noise and the contrast noise ratio from the Sn100-LDCT scan were significantly higher than from the ECG-CT scan, but the calcified branches of the coronary arteries in the ECG-CT scan were all shown in the Sn100-LDCT scan, and the coronary artery calcification score was calculated without omission.

The CACS measured by non-gated low-dose chest CT is consistent with the risk stratification derived from ECG-CT measurement results, but there is an underestimation. In this study, were classified as severe-risk from the ECG-CT group, Eleven patients(5.7%) were classified as moderate-risk from the Sn100-LDCT group; were moderate-risk patients identified in the ECG-CT group, twenty-nine patients(15%) were



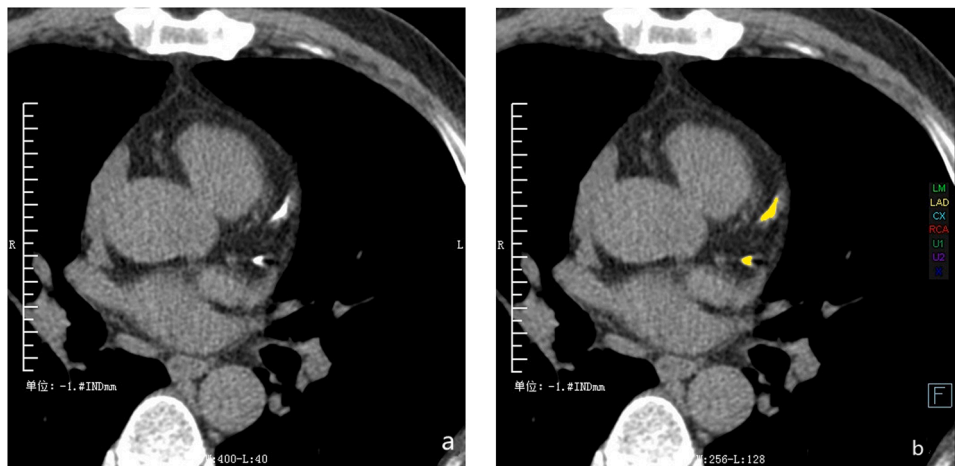


Fig. 6. a-b The CACS Agatston score measured by ECG gating method is 198.6 (located in the 101–400 interval, which is a moderate risk group).



Fig. 7. a-b The CACS Agatston integral measured in non-ECG-gated chest low dose image is 90.1 (located in the new standard 41.3–230 interval, which is a moderate risk group).

**Table 5**  
Radiation dose comparison between ECG-CT and Sn100kV-LDCT.

	Cases	CTDIvol (mGy)	DLP (mGy.cm)	ED (mSv)
ECG-CT	193	3.172 ± 1.630	48.931 ± 32.515	0.685 ± 0.455
Sn100kV-LDCT	193	0.236 ± 0.681	3.978 ± 1.254	0.056 ± 0.0176
T value		25.377	19.456	19.456
P value		0.000	0.000	0.000

classified as mild-risk by the Sn100-LDCT group; were identified as mild-risk from the ECG-CT group, nineteen patients (9.8%) were classified as minimal-risk by the Sn100-LDCT group. This underestimation may be due to using low-dose CT with tin filtration reducing the absorbed radiation dose. A similar observation was reported by Fan Rongrong et al. [6], who used a Philips iCT256-slice CT scanner (chest low-dose scanning parameters: tube voltage 120 kV, tube current 50 mA, pitch 0.758). Among the ECG-CT high-risk outcomes, 17.9% were classified as medium risk, and 1.2% as low risk. Christian et al. [7] showed that two (3%) and four (7%) of 60 patients receiving Sn100kV combined with Advanced modeled iterative reconstruction (ADMIRE) 3 and ADMIRE 5 were assigned to the next lower risk classification level, while Vincenzo et al. [18] showed that 99% of patients were classified into the same risk category using an Sn100kV scheme.

In view of the obvious underestimation from the Sn100-LDCT examination, a new stratification of Sn100-LDCT CACS risk was developed. A ROC curve was used to evaluate the diagnostic efficiency of non-gated low-dose chest CT plain scans based on the CACS measured by ECG-CT. The AUC was > 0.9, and the diagnostic efficiency was high, especially for the moderate - severe risk category, where the AUC was 0.968. The maximum value of the Jordan index was taken as the critical diagnostic value, and a new risk stratification was developed as following: < 4.6 is the minimal risk, 4.6–41.2 is the mild risk, 41.3–230 is the moderate risk, and > 230 is the severe risk. This stratification differs from that proposed by Fan Rongrong et al. [6], who described low risk as 1–87, medium risk as 88–255, and high risk as > 255. This disparity is likely due to the different machines and low-dose parameters between the studies.

The calcification scores measured by Sn100kV according to the new standard were compared with the CACS risk stratification measured by ECG-CT. There were ten patients (12.66%) classified with mild risk who actually had a minimal risk classification. In the mild-risk category, the new standard identified one case (0.014%) as minimal risk, and 11 (14.86%) cases were classified as moderate risk. Therefore, over-diagnosis may occur, as a proportion of those in minimal and mild risk categories were classified as higher risk. In retrospective image analysis, it was identified that all these calcifications were dense, with high maximum CT values and well-defined nodules. Combined with CTA images, these calcifications were wall-like and did not cause lumen

stenosis. The effect of these calcifications on long-term cardiovascular events needs confirmation in further studies.

Some limitations of this study should be considered. First, this study established a new risk stratification for non-gated 100 kV CT, however, consistency was only evaluated with the CACS risk stratification measured by ECG-gated 120 kV CT. Further verification of the new stratification system with another patient group should be determined in future work. Second, our findings cannot be generalized or adjusted to other CT systems as the image data is post-processed using tin filtration. Third, inter-observer differences in CACS, which is usually performed by a single radiologist in daily clinical routine, have not been evaluated.

## 5. Conclusions

A low-dose chest CT scan enables the screening of lung cancer, chronic obstructive pulmonary disease, and cardiovascular diseases while not increasing the radiation dose, thereby maximizing examination benefits. Although there is underestimation in the assessment of CACS, the underestimation is reduced, and diagnostic consistency is improved by the newly developed criterion of CACS risk stratification conforming to non-gated non-contrast chest CT.

## CRediT authorship contribution statement

**Conceptualization:** Ying Liu \*, Xuezhi Chen \*, Xianchen Liu, Hao Yu, Lianjun Zhou, Xiaoling Gao, Qinglin Li, Shujun Su, Lin Wang, Jia Zhai, **Data curation:** Ying Liu, Xiaoling Gao, Qinglin Li, Shujun Su, **Formal analysis:** Ying Liu, Lin Wang, Jia Zhai, **Funding acquisition:** Ying Liu, Xuezhi Chen, **Methodology:** Ying Liu, Xuezhi Chen, Xianchen Liu, Hao Yu, Lianjun Zhou, Xiaoling Gao, Qinglin Li, Shujun Su, Lin Wang, Jia Zhai, **Project administration:** Ying Liu, **Resources:** Ying Liu, Xuezhi Chen, **Software:** Ying Liu, Hao Yu, Lianjun Zhou, Xiaoling Gao, Jia Zhai, **Supervision:** Ying Liu, **Validation:** Ying Liu, Xuezhi Chen, Lianjun Zhou, **Writing-original draft:** Ying Liu, Xuezhi Chen, **Writing-review&editing:** Ying Liu, Xuezhi Chen.

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## Conflicts of interest statement and funding

The authors have declared that no competing interests exist.

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