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# Dual-Energy Subtraction Technique Using Dual-Source CT: Improved Assessment of Coronary Stenosis Severity and Pericoronary Adipose Tissue Measurement in the Presence of Severe Calcification

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## ABSTRACT

**Objective: To investigate the value of dual-energy CT subtraction technique in evaluating plaque stenosis severity and pericoronary adipose tissue fat attenuation index (FAI) in patients with severe coronary artery calcification. Methods: Fifty-three patients with suspected or confirmed coronary artery disease who visited Jining No. 1 People's Hospital from April 2022 to September 2023 were enrolled. All patients underwent dual-energy coronary computed tomography angiography (DE-CCTA) and invasive coronary angiography (CAG) within 60 days, with a calcium score > 400. According to different reconstruction methods, the patients were divided into a standard reconstruction group and a dual-energy subtraction group. Follow-up for major adverse cardiovascular events (MACE) was performed 2 years after CCTA. Results: Using CAG-diagnosed severe stenosis or occlusion as the reference, the diagnostic accuracy and specificity of the standard post-processing group were 86.9% (53/61) and 54.8% (40/73), respectively; those of the dual-energy subtraction group were 82% (50/61) and 93.2% (68/73), respectively. The dual-energy subtraction group showed good consistency and correlation with CAG for coronary artery stenosis detection. The pericoronary adipose tissue attenuation parameter measured by the dual-energy subtraction method could predict MACE events (OR = 1.110, P = 0.022; AUC = 0.670, P = 0.048), suggesting potential superiority in predicting MACE (AUC = 0.593, P = 0.277), although the overall predictive accuracy was modest. Conclusion: Dual-energy subtraction CTA technique has good clinical value for evaluating coronary stenosis severity in patients with severe calcification. Preliminary exploratory evidence also suggests**

**that it may improve the prognostic utility of pericoronary FAI measurement for MACE, though confirmation in larger cohorts is needed.**

## 1. INTRODUCTION

Coronary computed tomography angiography (CCTA) has the advantages of being less invasive and requiring shorter examination time compared with invasive coronary angiography (CAG) [1]. In recent years, with technological advances, CCTA has a high negative predictive value for coronary artery stenosis, can detect quantitative and qualitative characteristics of plaques, and predict the risk of future cardiovascular events, thus becoming the first-line non-invasive examination for the diagnosis of coronary artery disease (CAD) [2]. However, the blooming effect and beam-hardening artifacts caused by coronary artery calcification (CAC) affect diagnostic accuracy. Hardening artifacts from calcified plaques and metallic stents interfere with the assessment of coronary artery luminal stenosis, leading to overestimation or inability to evaluate the degree of stenosis [3]. Dual-energy CT has been widely used in clinical practice. Multi-energy spectral imaging techniques enable more accurate material decomposition (e.g., calcium, iodine, uric acid), enhancing the ability to analyse plaque components, quantify myocardial perfusion, and perform virtual non-contrast/decalcification imaging [4].

The pericoronary adipose tissue attenuation measured by CCTA, *i.e.*, the fat attenuation index (FAI), is an emerging inflammatory biomarker for predicting major adverse cardiovascular events (MACE) [5]. However, severe coronary calcification produces beam-hardening and blooming artifacts that may affect the accuracy of FAI measurement, and standard reconstruction methods have limited ability to suppress these artifacts [6]. Dual-energy subtraction technique removes calcified components and theoretically reduces artifact interference, thereby improving FAI measurement. Currently, direct comparisons of the ability of the two methods to predict MACE in severely calcified populations are lacking.

This study aims to remove calcified plaques by dual-energy coronary scanning and post-processing, compare dual-energy subtraction CTA with conventional CTA reconstruction and with CAG, and explore the application value of dual-energy subtraction CTA in assessing plaque stenosis severity and pericoronary adipose tissue attenuation measurement in patients with severe coronary calcification.

## 2. CLINICAL DATA

Fifty-three patients with suspected or confirmed CAD who visited Jining No. 1 People's Hospital from April 2022 to September 2023 were enrolled. All patients underwent dual-energy CCTA (DE-CCTA) and invasive CAG within 60 days. There were 42 males and 11 females, aged 40 - 84 years. According to the Coronary Artery Calcium Score Risk Classification Guidelines of the American College of Cardiology Foundation and the American Heart Association [7], patients with a calcium score > 400 (severe calcification) were included. The study was approved by the Ethics Committee of Jining No. 1 People's Hospital (approval No. KYLL202308-127).

Exclusion criteria: ① Poor CT image quality; ② Other severe cardiovascular diseases such as aortic dissection or congenital heart disease; ③ Presence of coronary stents.

Patients underwent telephone follow-up for 2 years after CCTA to document the occurrence of MACE, including cardiac death, stroke, non-fatal myocardial infarction, rehospitalisation for unstable angina or heart failure, and unplanned revascularisation.

## 3. METHODS

### 3.1. Dual-Energy CCTA Examination

A Siemens Somatom Definition Flash CT scanner was used. Patients were placed in the supine position. Oral metoprolol was administered to control heart rate (60 - 80 bpm), and breathing training was performed.

Scanning ranged from below the tracheal carina to the diaphragmatic surface of the heart.

Dual-energy mode was used for the coronary CTA scan. Scan parameters: tube voltages 100 kV and Sn150 kV, automatic tube current modulation, retrospective ECG gating, and images reconstructed at optimal diastolic and systolic phases. Contrast medium (iohexol 350 mgI/ml, 50 - 70 ml) was injected at 4.5 - 5.5 ml/s via an antecubital vein, followed by 40 ml of saline. The scan was triggered automatically using a bolus-tracking technique (threshold > 100 HU). Scanning ranged from below the tracheal carina to the diaphragmatic surface of the heart. From each patient's single dual-energy CCTA acquisition, two sets of images were reconstructed: Group A—standard reconstruction using optimal phase fusion images, and Group B—dual-energy subtraction images obtained by loading the dual-energy data into dedicated software for bone and calcium subtraction. Luminal diameter stenosis was calculated for both reconstruction types. Thus, each patient served as their own control in a paired within-patient comparison. Coronary segments were classified according to the 18-segment model of the coronary tree recommended by the American College of Cardiology [8], and only segments of LAD, LCX, and RCA with diameter ≥ 1.5 mm and calcified wall with luminal stenosis were evaluated. Coronary artery stenosis was graded as: minimal (0% - 24%), mild (25% - 49%), moderate (50% - 69%), severe (70% - 99%), and occlusion (100%). The CT attenuation range for adipose tissue was set from −190 HU to −30 HU. The software automatically calculated the mean attenuation of fat tissue in the region of interest around the coronary artery branch with the most severe stenosis, *i.e.*, the FAI.

### 3.2. Coronary Angiography (CAG)

A GE Innova 3100-IQ angiography system was used. The Seldinger technique was performed via the right femoral or radial artery. Images were acquired from multiple angles, and images with good contrast filling were analysed. Coronary artery stenosis was graded as: minimal (0% - 24%), mild (25% - 49%), moderate (50% - 69%), severe (70% - 99%), and occlusion (100%).

### 3.3. Blinding

CCTA images were interpreted independently by two radiologists (>8 years of experience) who were blinded to the results of invasive CAG, the type of reconstruction (standard vs. dual-energy subtraction), and all clinical outcomes. CAG images were interpreted by two experienced cardiologists who were blinded to CCTA findings and reconstruction methods. Disagreements in either modality were resolved by consensus.

### 3.4. Image Quality Scoring

Image quality was assessed using the Likert scale: 0 = poor quality, vessel wall excessively removed, severe artifacts, non-diagnostic; 1 = fair, vessel wall not clearly displayed, local artifacts, difficult for diagnosis; 2 = good, vessel wall relatively clearly displayed, individual slices with artifacts but most slices diagnostic; 3 = excellent, vessel wall continuous, no artifacts. Cases with a score < 2 were excluded from statistical analysis.

### 3.5. Statistical Analysis

SPSS 25.0 was used. Categorical data were expressed as n (%). Kappa test was used to evaluate consistency between the two experimental groups and CAG results, where consistency was classified as high (0.75 - 1.00), good (0.60 - 0.74), moderate (0.40 - 0.59), or poor (<0.40). To assess agreement between each reconstruction method and CAG for ordinal stenosis grading, we used weighted kappa with quadratic weights. Diagnostic performance for stenosis caused by calcified plaques was evaluated. Univariate binary logistic regression was used to evaluate the relationship between the pericoronary fat parameters measured by standard reconstruction and dual-energy subtraction methods and MACE events, and odds ratios (OR) with 95% confidence intervals (CI) were calculated. $P < 0.05$ was considered statistically significant.

## 4. RESULTS

Among the 159 coronary arteries of the 53 patients, after dual-energy subtraction bone removal reconstruction, the diagnostic satisfactory rates for the right coronary artery (RCA), left anterior descending artery (LAD), and left circumflex artery (LCX) were 94.3%, 90.6%, and 92.4%, respectively (**Table 1**). The overall satisfactory rate for all coronary images was 92.5% (**Table 1**).

**Table 1. Image quality scores for each coronary segment.**

| Segment | Score | | | | Total | Satisfactory rate (%) |
|---|---|---|---|---|---|---|
| | 3 | 2 | 1 | 0 | | |
| RCA | 22 | 28 | 1 | 2 | 53 | 94.3 |
| LAD | 29 | 19 | 3 | 2 | 53 | 90.6 |
| LCX | 27 | 22 | 2 | 2 | 53 | 92.4 |
| Total | 78 | 69 | 6 | 6 | 159 | 92.5 |

A total of 159 coronary arteries (RCA, LAD, LCX from 53 patients) were evaluated. According to the Likert scale (**Table 1**), 147 vessels (92.5%) achieved a score of 2 or 3, indicating diagnostically acceptable image quality for dual-energy CTA. Among these 147 vessels, one did not undergo invasive CAG (procedure failure). Thus, 146 vessels had both high-quality CCTA and CAG results available.

Of these 146 vessels, CAG identified 12 vessels with no appreciable plaque or stenosis (<30% diameter stenosis), 37 with mild stenosis (30% - 49%), 32 with moderate stenosis (50% - 69%), 53 with severe stenosis (70% - 99%), and 8 with occlusion (100%). The 12 vessels without significant stenosis showed no measurable luminal narrowing on either CCTA or CAG.

Because the primary objective was to evaluate the diagnostic performance for haemodynamically significant stenosis (CAG ≥ 70% or occlusion) in the presence of calcification, the 12 non-stenotic vessels were initially excluded to avoid overestimation of specificity driven by an abundance of true negatives. Consequently, 134 vessels (all with CAG stenosis ≥ 30%) constituted the main analysis set for diagnostic accuracy.

CAG diagnosed 4 segments with minimal stenosis, 37 with mild stenosis, 32 with moderate stenosis, 53 with severe stenosis, and 8 with occlusion. Standard post-processing diagnosed 1 minimal, 12 mild, 35 moderate, 72 severe, and 14 occluded segments. Dual-energy subtraction post-processing diagnosed 8 minimal, 30 mild, 39 moderate, 55 severe, and 2 occluded segments (**Figure 1**). Coronary artery stenosis was measured as a continuous percentage of luminal diameter narrowing (0% - 100%) based on quantitative assessment. Using CAG as the reference standard, Pearson correlation analysis showed that the standard reconstruction method was moderately correlated with CAG ($r = 0.429$, $P < 0.001$), whereas the dual-energy subtraction method demonstrated a strong correlation with CAG ($r = 0.763$, $P < 0.001$). The correlation between the two reconstruction methods was also significant ($r = 0.686$, $P < 0.001$). These results indicate that the dual-energy subtraction method more closely approximates the continuous stenosis measurements obtained by invasive CAG. Using CAG-diagnosed severe stenosis or occlusion as the reference, the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the standard post-processing group were 86.9% (53/61), 54.8% (40/73), 61.6% (53/86), and 68.8% (33/48), respectively, with an area under the ROC curve (AUC) of 0.708 (95% CI: 0.62 - 0.797). The corresponding values for the dual-energy subtraction group were 82% (50/61), 93.2% (68/73), 90.9% (50/55), and 86.1% (68/79), with an AUC of 0.876 (95% CI: 0.809 - 0.942) (**Figure 2**). The Kappa value between the standard post-processing group and CAG for coronary stenosis detection was 0.204 ($P < 0.001$), indicating poor consistency; between the dual-energy subtraction group and CAG the Kappa was 0.63 ($P < 0.001$), indicating good consistency.

Among the 53 enrolled patients, the mean age was 66.4 ± 9.2 years, and 42 (79.2%) were male. Cardiovascular risk factors included hypertension in 38 patients (71.7%), diabetes mellitus in 21 (39.6%), dyslipidemia in 32 (60.4%), and current smoking in 19 (35.8%). Regarding symptom status, 28 patients

(52.8%) presented with typical stable angina, 15 (28.3%) with atypical chest pain, and 10 (18.9%) were asymptomatic but had a high calcium score (≥400). Medication use at the time of CCTA included aspirin in 35 patients (66.0%), statins in 40 (75.5%), and beta-blockers in 22 (41.5%).

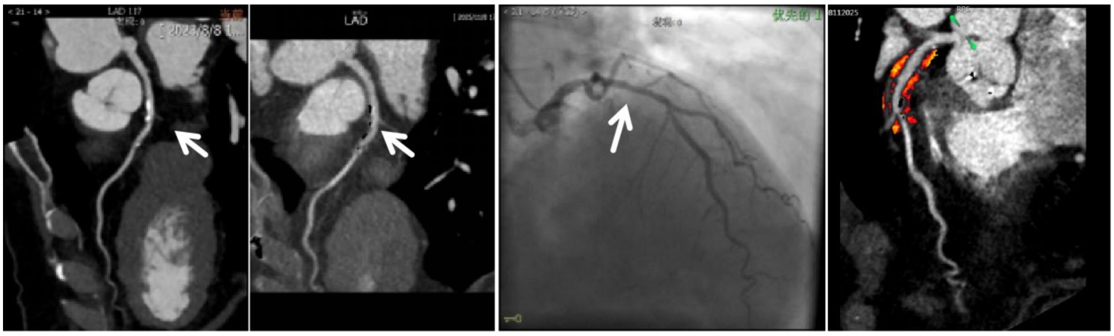


**Figure 1. A 74-year-old female patient. Standard post-processed CCTA revealed moderate stenosis in the proximal LAD (FAI = −69.72 HU), whereas dual-energy subtraction CCTA demonstrated mild luminal stenosis (FAI = −60.72 HU), which was consistent with the CAG results.**

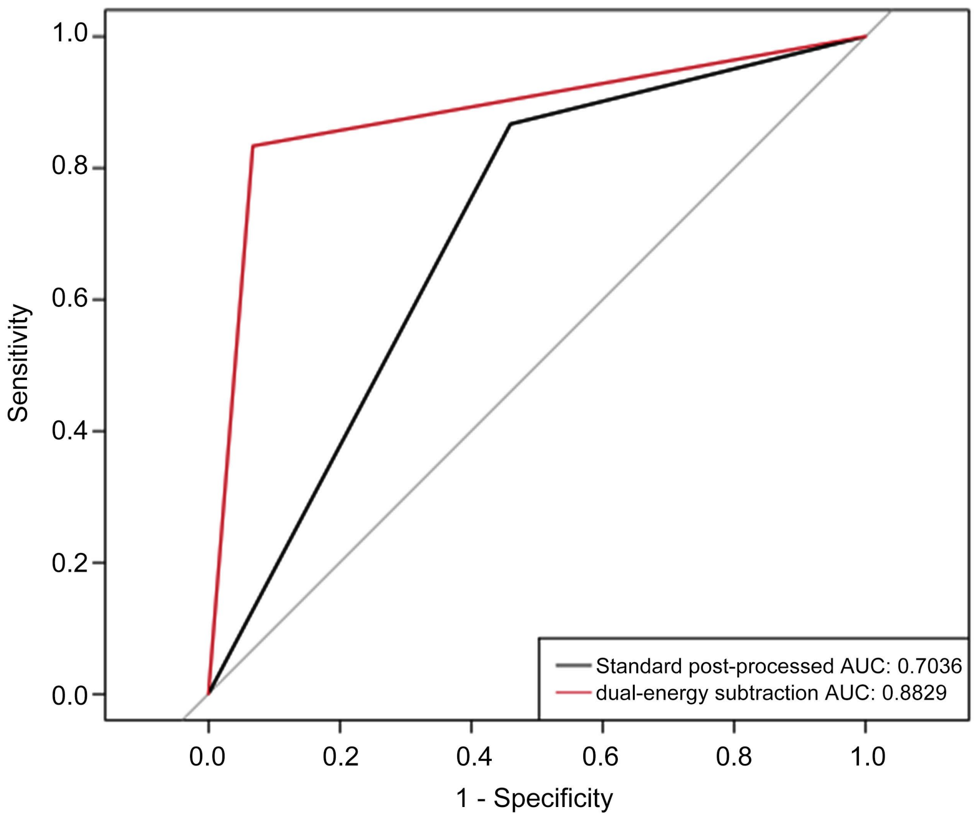


**Figure 2. ROC curves of the standard reconstruction group and the dual-energy subtraction group for predicting severe stenosis or occlusion.**

All 53 patients completed the 2-year follow-up for MACE events (follow-up rate 100%). The median interval between CCTA and invasive CAG was 14 days (interquartile range: 7 - 28 days). No coronary revascularization (percutaneous or surgical) or acute cardiovascular event (e.g., myocardial infarction, unstable angina requiring hospitalization) occurred between the two examinations. A total of 53 patients were included, and 17 (32.1%) experienced MACE events. The FAI measured by standard reconstruction was −69.72 ± 6.88 HU, and by dual-energy subtraction was −68.63 ± 7.53 HU. Univariate logistic regression showed that the pericoronary fat parameter measured by dual-energy subtraction was significantly associated with MACE (OR = 1.110, 95% CI: 1.015 - 1.213, P = 0.022), whereas the standard reconstruction method showed no significant association (OR = 1.053, 95% CI: 0.964 - 1.151, P = 0.252) (Table 2). ROC analysis gave an AUC of 0.670 (95% CI: 0.506 - 0.834, P = 0.048) for the dual-energy subtraction method, which was significantly better than the AUC of 0.593 (95% CI: 0.421 - 0.765, P = 0.277) for the standard reconstruction method (Figure 3).

**Table 2.** Comparison of FAI and predictive performance between the two reconstruction methods

| Method | OR (95% CI) | P value (OR) | AUC (95% CI) | P value (AUC) | Nagelkerke $R^2$ |
|---|---|---|---|---|---|
| Standard reconstruction | 1.053 (0.964 - 1.151) | 0.252 | 0.593 (0.421 - 0.765) | 0.277 | 0.036 |
| Dual-energy subtraction | 1.110 (1.015 - 1.213) | 0.022 | 0.670 (0.506 - 0.834) | 0.048 | 0.148 |

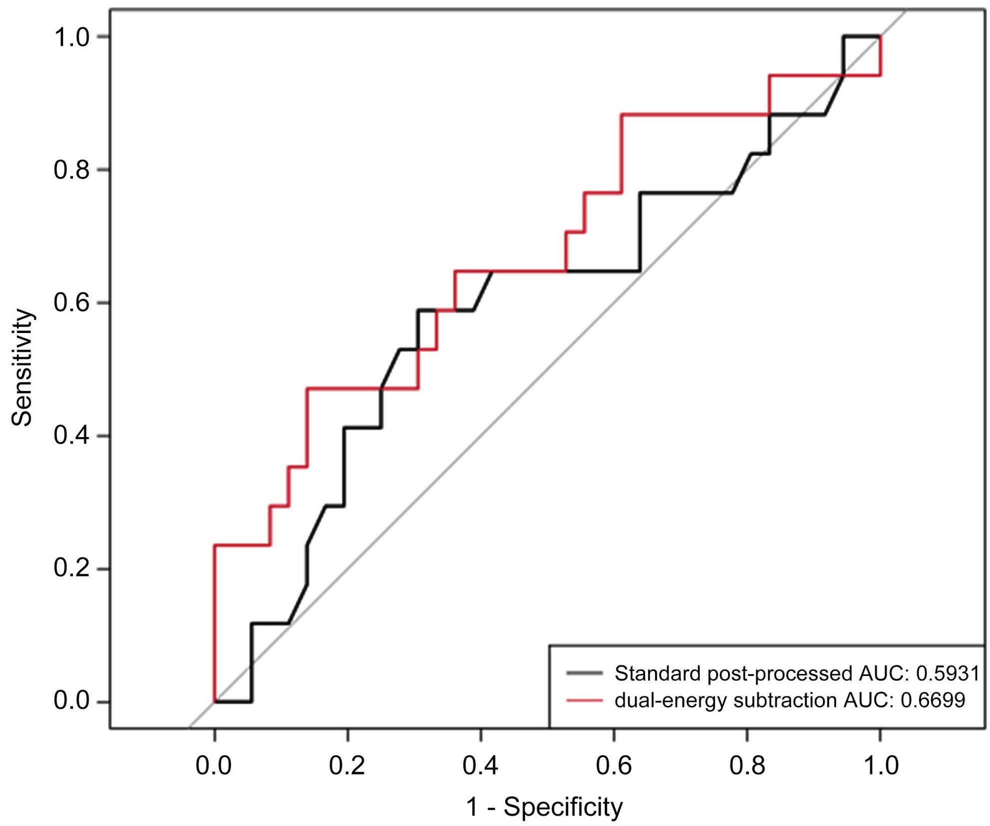


**Figure 3.** ROC curves of the standard reconstruction group and the dual-energy subtraction group for predicting MACE events.

## 5. DISCUSSION

In recent years, various dual-energy CT scanners have been developed. Dual-energy CT imaging exploits the difference in X-ray attenuation coefficients of different materials at different energies, enabling material decomposition and separation of different substances, removing calcium from the vessel wall while preserving iodine contrast, thus allowing more accurate quantification of stenosis [9-11]. Subtraction coronary CT angiography has the advantages of high image quality and the ability to eliminate beam-hardening artifacts. By removing calcified plaques and metallic stents, it provides better visualisation of the vessel lumen and significantly improves the image quality and diagnostic accuracy of coronary imaging [12].

In this study, subtraction technology was used to obtain images with calcified plaques removed. The overall satisfactory image quality rate for all 159 vessels was 92.5%, meeting routine clinical requirements. Among the different coronary branches, the RCA had the highest satisfactory rate (94.3%), while the LAD and LCX had slightly lower rates, similar to previous findings [3]. Previous studies have shown that the incidence of misregistration increases distally [13]. The anatomical course of the RCA along the atrioventricular groove leads to larger motion amplitude, and the asynchronous motion of the atria and ventricles may contribute to the higher incidence of misregistration in the RCA [14]. Moreover, some coronary segments can still be clearly visualised at different R-R intervals (RCA 40%; LCX 50%; LAD 60% - 70%). In this study, the 75% R-R interval was selected as the phase reference, which is more suitable for the LAD [15]. Further studies are needed to reduce reconstruction artifacts and improve the success rate of dual-energy subtraction.

Previous literature reported that about 38.7% - 50% of segments with severe calcified plaques were judged as non-diagnostic on standard reconstruction CTA [13]. By subtraction technology, high-density areas beyond contrast-enhanced regions and associated artifacts are removed, making vessel lumen assessment easier [16]. Our study confirmed that the diagnostic accuracy and specificity of the dual-energy subtraction group for severe stenosis or occlusion were 82% and 93.2%, respectively, with specificity significantly better than that of the standard group. The standard reconstruction showed a serious problem of false positives, *i.e.*, it tended to overdiagnose mild or moderate stenosis as severe stenosis or occlusion, a problem that was well resolved by dual-energy reconstruction. The consistency and correlation results in this study showed that the dual-energy subtraction group was superior to the standard reconstruction group, indicating that coronary dual-energy subtraction technology has good application value in diagnosing luminal stenosis and can help improve physicians' diagnostic confidence.

Our finding that the dual-energy subtraction technique outperformed standard reconstruction in predicting MACE may be explained by the differential impact of calcification artifacts on FAI measurement. Standard reconstruction is susceptible to blooming artifacts from calcifications [17], which can alter the measured attenuation of adjacent adipose tissue. In contrast, dual-energy techniques can reduce calcification-related interference [6], thereby restoring the predictive value of FAI parameters. This is consistent with the JACC review highlighting that beam-hardening artifacts from calcifications remain a major pitfall in FAI assessment [18].

In conclusion, this study demonstrates that coronary CT dual-energy subtraction technique can, to some extent, resolve the problems of inaccurate stenosis assessment and pericoronary fat measurement caused by calcified plaques in patients with severe coronary artery calcification, thereby providing good application value for the precise diagnosis of coronary artery stenosis. Additionally, it offers initial, exploratory evidence that dual-energy subtraction-based FAI measurement may be associated with future MACE events, warranting further investigation.

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## CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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