

Association Between Pericoronary Fat Attenuation Index as Evaluated by Coronary Artery CT Angiography and Clinical Interventions in Lipid Management Among Patients with Coronary Artery Disease

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Objective: This study aims to evaluate the relationship between the pericoronary fat attenuation index (FAI), derived from coronary artery computed tomography angiography, and post-lipid management levels of low-density lipoprotein cholesterol in patients with coronary artery disease (CAD). Additionally, the study investigates coronary inflammation across different lipid management strategies.

Methods: We selected a cohort comprising 521 CAD patients who met the inclusion criteria. Patients were categorized into well-managed (LDL-C < 2.6 mmol/L) and poorly managed (LDL-C ≥ 2.6 mmol/L) groups based on lipid management efficacy. We collected anthropometric measures (height, weight, body mass index, and body surface area) and clinical indicators, including Gensini score, and FAI-related parameters for coronary atherosclerotic lesions. We analyzed the interrelations along these parameters and lipid management using statistical methods and assessed diagnostic value via receiver operating characteristic (ROC) curve analysis of these parameters was assessed through.

Results: The poorly managed group exhibited significantly higher levels of total cholesterol, triglycerides, and lower levels of high-density lipoprotein compared to the well-managed group ($P < 0.05$). Significant differences were observed between the groups in terms of lesion length in the proximal segment of the left anterior descending artery, FAI value in the proximal segment of lesions in the right coronary artery (RCA), volume thickness in the middle segment of RCA lesions, and lesion length in the distal segment of RCA ($P < 0.05$). ROC curve analysis revealed areas under the curve ranging from 0.484 to 0.660 for the parameters, indicating limited diagnostic efficacy.

Conclusion: The FAI in the RCA varies with lipid management strategies, suggesting it as a valuable metric for monitoring both perivascular inflammation and lipid status in CAD patients. However, its current diagnostic efficacy is limited, indicating the need for further research to improve its clinical utility.

Keywords: coronary artery CT angiography, coronary atherosclerotic heart disease, coronary inflammation, lipids, low-density lipoprotein cholesterol, pericoronary fat attenuation index

Introduction

Coronary artery disease (CAD) represents a prevalent cardiovascular condition. In urban China, CAD exhibits a mortality rate of 126.91 per 100,000, a concerning trend marked by escalating prevalence and mortality rates, thereby posing

substantial health hazards.¹ Low-density lipoprotein cholesterol (LDL-C) is a pathogenic risk factor and primary target for intervention in CAD. The mechanism of action of cLDL in coronary heart disease is that the antioxidant content of small and dense low-density lipoprotein in cLDL is low, which is very easy to oxidize, difficult to clear from plasma, and easy to adhere to the vascular wall.² It has been confirmed that it can be used as an independent risk factor for predicting atherosclerosis, and has been included in the National Cholesterol Education Plan of the United States.³ However, the treatment rate for LDL-C among patients at high risk of atherosclerotic cardiovascular disease (ASCVD) in China stands at a modest 42.9%.⁴ While lipid-lowering therapies have demonstrated efficacy in slowing and even reversing the progression of coronary atherosclerosis, apprehensions about safety emerge when LDL-C levels are excessively low, potentially resulting in intracranial hemorrhage.^{5,6} Pericoronary inflammation (referred to as coronary inflammation) plays a key role in different stages of the development of coronary atherosclerotic plaque, affecting the formation and stability of plaque.^{7,8} Severe inflammation can easily cause significant vascular stenosis and unstable plaques, leading to adverse events. Consequently, there is a critical need to assess the inflammatory status of coronary arteries post LDL-C management. Recently, the quantitative assessment of the pericoronary fat attenuation index (FAI) using coronary artery computed tomography (CT) angiography imaging has gained widespread recognition as a novel surrogate biomarker for coronary inflammation. Previous studies have shown that FAI is a non-invasive examination method that can warn the level of coronary artery inflammation related to CAD in the early stage of disease and provide basis for early clinical treatment. The FAI provides a reliable means to monitor changes in the content and size of pericoronary lipids, providing insight into changes in fat density driven by paracrine mechanisms of coronary inflammation.⁹⁻¹¹ In this study, we investigated the correlation between FAI as observed in coronary artery CT angiography and LDL-C levels following lipid management interventions in patients with CAD. The primary objectives are to discern the CAD status and associated FAI under diverse LDL-C management scenarios, as well as to analyze the state of coronary inflammation in the context of varied lipid management strategies.

Data and Methods

Study Participants and Grouping

A retrospective analysis was conducted encompassing 521 patients diagnosed with CAD who received treatment at the cardiology departments of Yan'an Hospital Affiliated to Kunming Medical University, Wenshan Prefecture First People's Hospital, and The People's Hospital of Lincang between January and December 2022. Patients were categorized clinically based on lipid management indicators, specifically LDL-C, into two groups: the well-managed group (LDL-C < 2.6 mmol/L) and the poorly managed group (LDL-C \geq 2.6 mmol/L), including traditional Chinese medicine treatment, Miao medicine, Yi medicine treatment, other nonclinical guideline treatment plans, and comprehensive multiple treatment plans, and patients who refuse treatment. The informed consent was obtained from all participants.

Inclusion and Exclusion Criteria

Inclusion criteria: 1. CAD patients: Coronary atherosclerotic heart disease refers to a common cardiovascular disease caused by coronary artery stenosis or occlusion, resulting in myocardial ischemia, hypoxia or necrosis; 2. Aged 18 years and above; 3. Cardio-gated coronary artery scan was performed with Gensini score greater than 0;¹² 4. Complete liver function examination (including LDL-C) and have complete clinical data; 5. Clinical manifestations were angina pectoris; 6. Patients who have not undergone coronary stent implantation or DSA, or do not need coronary stent implantation for the time being; 7. Coronary artery CTA examination indicates the presence of stenosis in the coronary artery and the degree is from 50% to 70%.

Exclusion criteria: 1. Diabetic patients; 2. Patients with severe heart, liver and renal insufficiency; 3. Patients who had undergone heart surgery prior to the examination.

Methods

Research Methods

General Data Collection

The collected data included the height, weight, body mass index (BMI), and body surface area of enrolled patients. Liver function tests included total cholesterol (TC), triglycerides (TG), LDL-C, and high-density lipoprotein cholesterol (HDL-

C). BMI was calculated as weight (kg) divided by height (m) squared. The formula for body surface area was $0.61 \times \text{height(m)} + 0.0128 \times \text{weight(kg)} - 0.1529$.

Coronary CT Angiography Enhancement Examination

Imaging procedures were performed using the Siemens Flash 128 dual-source spiral CT scanner, including both plain and enhanced scans. The scan parameters were a tube voltage of 120 kV with automatic milliamperage technology. The detector configurations were either $2 \times 128 \times 0.6$ mm or $2 \times 64 \times 0.6$ mm, with a pitch of 1.5. The reconstruction layer thickness was 1.0 mm, with a 0.6 mm interval. Non-ionic iohexol (350 mgI/mL) was used as the contrast agent, administered via a dual-barrel high-pressure injector into the median cubital vein at a rate of 3–4 mL/s. A total of 60–80 mL of contrast agent was followed by a 20–30 mL saline flush at the same rate. The bolus tracking technique, was employed with the aortic chamber as the target vessel for monitoring. Scanning began when the enhancement threshold CT value of 120 hU was reached, with the patient holding their breath. The scanning range extended from 2 cm above the aortic arch to below the apex of the heart. The acquired images were then transferred to a workstation for reconstruction using multiplanar reconstruction (MPR), curved planar reconstruction (CPR), maximum intensity projection (MIP), and volume rendering (VR). These reconstructed images were analyzed alongside axial images.

FAI Image Analysis

All results from coronary CT enhancement examinations were transferred to the Perivascular Analysis Tool software workstation, developed by Shukun Technology (Shukun (Beijing) Network Technology Co., Ltd.), for post-processing.

The main coronary artery FAI were calculated automatically.^{13,14} After data import, the system measured the length of the three primary coronary arteries, their respective FAI values, and the volume of pericoronary fat. A fat partition threshold of -190 to -30 hU was used to calculate the target fat within a 40 mm range extending outward from the outer edge of the vessel wall. For the left anterior descending artery (LAD) and the left circumflex artery (LCX), the measurement range began at the origin and extended to 4 mm distally, while for the right coronary artery (RCA), it started 10 mm from the coronary ostium and extended to 50 mm distally (see Figure 1).



Figure 1 Female, 46 years old, localized non-calcified plaque in mid-segment (segment 3) of the right coronary artery causing mild luminal stenosis (approximately 45% narrowing), Gensini score of 2. (A) Proximal section of LAD (start=40 mm), FAI value of -88 hU, volume of 2591 mm³, thickness approximately 4.00 mm; (B) Proximal section of LCX (start=40 mm), FAI value of -82 hU, volume of 2071 mm³, thickness approximately 4.00 mm; (C) Proximal section of RCA (start=40 mm), FAI value of -83 hU, volume of 2693 mm³, thickness approximately 4.00 mm; (D) Localized non-calcified plaque in the mid-segment (segment 3) of the right coronary artery causing mild stenosis around FAI parameters: FAI value of -81 hU, length approximately 7 mm, volume about 402 mm³.

For the measurement of FAI in areas of coronary atherosclerosis, the measurement region was centered at the plaque site of interest. The radial distance was manually adjusted to match the diameter of the vessel, and the software automatically computed the length of the plaque, the FAI value, and the volume of pericoronary fat surrounding it.

Image Analysis

Image interpretation was independently performed by two physicians, each with over 10 years of experience in cardiovascular imaging diagnosis. In cases of disagreement, a collaborative discussion was conducted to reach a consensus. The analysis focused primarily on lesions within the main coronary artery, with an emphasis on plaque characteristics categorized as non-calcified, calcified, or mixed. Soft plaque, with a CT value < 50 hU, and fibrous plaque with a CT value between 50 and 120 hU, were collectively classified as non-calcified plaques. The analysis also included an assessment of plaque extent, degree of luminal stenosis, identification of vulnerable plaques, and Gensini scoring. The Gensini scoring system assigns scores based on the degree of coronary lumen narrowing: < 25% scored 1 point, 25–50% scored 2 points, 51–75% scored 4 points, 76–90% scored 8 points, 91–99% scored 16 points, and 100% occlusion scored 32 points. Varied weighting coefficients were applied depending on the location of the narrowing, with a coefficient of 5 for the left main coronary artery, 2.5 for the proximal segments of the LAD and left circumflex artery (LCX), 1.5 for the mid-segment of the LAD, 1 for the RCA, posterior descending artery (PDA), distal segments of the LAD, diagonal branch (D1), obtuse marginal artery (OM), and distal segments of the LCX, and 0.5 for the remaining vessels. The Gensini score for each patient was derived as the sum of scores across all branches.

Statistical Methods

Data analysis was performed using SPSS 19.0 statistical software. Quantitative data following a normal distribution are presented as mean \pm standard deviation, and inter-group comparisons were conducted using independent sample *t*-tests. Categorical data are expressed as the number of cases (%) and compared between-group using the chi-squared test and Fisher's exact test, depending on the distribution characteristics. Non-normally distributed quantitative data are represented as the median (interquartile range) and compared using the non-parametric rank sum test. A $P < 0.05$ was considered statistically significant. These findings enable clinical physicians to assess pericoronary inflammation in patients without complete lipid status, allowing for appropriate adjustments in medication and the development of more suitable coronary CT follow-up schedule.

Results

General Information

The study included 521 patients with a mean age of (62.98 ± 11.37) years (range: 26 to 97 years). Of these, 204 were females (39.2%) and 317 were males (60.8%). All patients underwent lipid management according to the "Chinese Adult Guidelines for the Prevention and Treatment of Abnormal Blood Lipids (2016 Revised)." The well-managed group consisted of 211 patients (40.5%), while the poorly managed group included 310 patients (59.5%).

In the poorly managed group, levels of TC, TG, and HDL were significantly higher than those in the well-managed group ($P < 0.05$). However, no statistically significant differences were observed in weight, height, body surface area, or BMI between the two groups ($P > 0.05$), as revealed in [Table 1](#).

Differences in FAI Between the Well-Managed and Poorly Managed Groups at the LAD, LCX, and RCA Proximal Segments

As shown in [Table 1](#) and [Figure 1](#), there were statistically significant differences between the poorly managed and well-managed groups in terms of the FAI values and volumes in the proximal segments of the LAD, LCX, and RCA ($P < 0.05$).

Table 1 Differences in Proximal FAI Parameters and General Data Between the Well-Managed and Poorly Managed Groups

Variable	Well-Managed Group (n=211)	Poorly Managed Group (n=310)	P-value
Male	127 (60.19%)	190 (61.29%)	0.614
Age	64.920±11.623	61.850±11.052	0.003
FAI volume of PLA of LAD	1747.0 (774.5)	1742.0 (707.5)	0.613
FAI value of the PLA of LAD	-79.832±9.606	-79.682±8.519	0.882
FAI volume of PLA of LCX	1215.0 (737.0)	1122.0 (743.0)	0.293
FAI value of PLA of LCX	-75.863±9.28	-75.897±7.624	0.97
FAI volume of PLA of RCA	1913.0 (937.5)	1904.0 (839.0)	0.626
FAI value of the PLA of RCA	-76.588±10.037	-78.185±9.356	0.143
Body surface area	1.63 (0.291)	1.642 (0.355)	0.198
Weight	62.0 (16.5)	62.0 (18.5)	0.348
TC (mmol/L)	3.65 (0.91)	5.11 (1.23)	< 0.001*
TG (mmol/L)	1.34 (1.175)	1.7 (1.195)	< 0.001*
BMI	23.389 (6.64)	23.335 (5.564)	0.612
Height	1.6 (0.145)	1.62 (0.15)	0.59
Calcification score	43.12 (252.92)	34.17 (174.935)	0.304
Gensini score	7.5 (12.5)	10.0 (12.75)	0.032*
HDL (mmol/L)	1.09 (0.49)	1.14 (0.39)	0.006*

*Note: When variables follow a normal distribution, the reported value is the mean ± standard deviation. In the case of non-normal variables, the median (interquartile range) is used. $P < 0.05$.

Abbreviations: FAI, fat attenuation index; LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery; PLA, proximal lesion area; TC, total cholesterol; TG, triglyceride; BMI, Body mass index; HDL, high density lipoprotein.

Differences in FAI in Coronary Atherosclerosis Areas Between the Well-Managed and Poorly-Managed Groups

Table 2 presents statistically significant differences between the groups concerning lesion length in the proximal segment of the LAD, FAI value in the proximal segment of the RCA, volume thickness in the mid-segment of the RCA, and lesion length in the distal segment of the RCA ($P < 0.05$).

Table 2 Differences in FAI Parameters of Coronary Atherosclerosis Areas Between Well-Managed and Poorly-Managed Groups

	Variable	Well-Managed group	Poorly Managed group	P-value
PLA of LAD	FAI value	-74.099 (8.651)	-74.099 (7.901)	0.519
	Volume	699.88 (138.0)	699.88 (295.0)	0.093
	Thickness of volume	4.0 (3.404)	4.0 (3.404)	0.356
	Length	16.018 (4.0)	16.018 (5.018)	0.012*
MLA of LAD	FAI value	-83.691 (0.0)	-83.691 (1.0)	0.874
	Volume	1051.387 (30.387)	1051.387 (293.387)	0.356
	Thickness of volume	5.347 (2.347)	4.0 (2.347)	0.081
	Length	22.758 (0.569)	22.758 (4.258)	0.581
DLA of LAD	FAI value	-75.0 (0.0)	-75.0 (0.0)	0.071
	Volume	452.308 (0.0)	452.308 (0.0)	0.071
	Thickness of volume	33.923 (0.0)	33.923 (0.0)	0.617
	Length	4.077 (0.0)	4.077 (0.0)	0.802

(Continued)

Table 2 (Continued).

	Variable	Well-Managed group	Poorly Managed group	P-value
PLA of LCX	FAI value	-71.736 (0.0)	-71.736 (0.0)	0.267
	Volume	498.34 (0.0)	498.34 (0.0)	0.146
	Thickness of volume	3.329 (0.0)	3.329 (0.0)	0.453
	Length	17.014 (0.0)	17.014 (0.0)	0.104
DLA of LCX	FAI value	-72.676 (0.0)	-72.676 (0.0)	0.22
	Volume	497.866 (0.0)	497.866 (0.0)	0.772
	Thickness of volume	3.179 (0.0)	3.179 (0.0)	0.562
	Length	16.821 (0.0)	16.821 (0.0)	0.09
PLA of RCA	FAI value	-75.165 (1.165)	-75.165 (1.835)	0.038*
	Volume	736.375 (21.875)	736.375 (86.375)	0.515
	Thickness of volume	3.714 (0.286)	3.714 (0.286)	0.735
	Length	17.008 (2.008)	17.008 (0.008)	0.507
MLA in RCA	FAI value	-79.009 (0.0)	-79.009 (0.0)	0.376
	Volume	1048.844 (168.594)	1048.844 (0.0)	0.126
	Thickness of volume	3.0 (0.0)	3.0 (1.0)	0.031*
	Length	22.716 (2.466)	22.716 (0.0)	0.458
DLA in RCA	FAI value	-71.0 (0.0)	-71.0 (0.0)	0.157
	Volume	549.488 (0.0)	549.488 (0.0)	0.998
	Thickness of volume	3.346 (0.0)	3.346 (0.0)	0.115
	Length	19.707 (0.0)	19.707 (0.0)	0.036*

*Note: $p < 0.05$. Variables conforming to normal distribution are presented as mean \pm standard deviation; non-normal distributions are presented as median (interquartile range).

Abbreviations: FAI, fat attenuation index; LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery; PLA, proximal lesion area; MLA, mid-segment lesion area; DLA, distal lesion area.

Differences in Coronary Gensini Scores Between the Well-Managed and Poorly Managed Groups

The present research revealed a statistically significant difference ($P < 0.05$) in the overall distribution of Gensini scores between the well-managed and poorly-managed groups. Regarding the calcification scores, however, no statistically significant distinction existed between the two groups ($P > 0.05$), as indicated in [Table 1](#).

ROC Curve Analysis of Parameters with Statistical Differences Between the Two Groups

ROC curve analysis was performed using parameters that showed statistically significant differences between the two groups. The AUC for these parameters ranged from 0.484 to 0.660. Specifically, the AUCs for lesion length in the proximal segment of the LAD, volume thickness in the mid-segment of the RCA, lesion length in the distal segment of RCA, FAI value in the proximal segment of RCA, and Gensini score were 0.484, 0.573, 0.685, 0.533, and 0.660, respectively. The optimal cut-off values, along with their corresponding sensitivity and specificity, were as follows: 15.5 (45.20%, 54.80%), 3.5 (58.10%, 41.90%), 21 (22.60%, 77.40%), -78.5 (68.40%, 48.40%), and 20.25 (78.90%, 51.60%). The diagnostic efficacy of these parameters, as indicated by their AUC, was generally below 0.700, as detailed in [Table 3](#) and illustrated in [Figure 2](#).

Table 3 Diagnostic Efficacy Assessment Using the ROC Curve for Parameters Indicating Statistical Differences Between the Two Groups

Item	AUC	P-value	Threshold Value	Youden's Index	Sensitivity	Specificity
Length of PLA of LAD	0.484	0.087	15.50	0.075	45.20%	54.80%
Volume thickness of MLA of RCA	0.573	0.083	3.50	0.156	58.10%	41.90%
Length of DLA of RCA	0.685	0.082	21.00	0.353	22.60%	77.40%
FAI value of PLA of RCA	0.533	0.087	-78.50	0.168	68.40%	48.40%
Gensini Score	0.660	0.081	20.25	0.306	78.90%	51.60%

Abbreviations: FAI, fat attenuation index; LAD, left anterior descending artery; RCA, right coronary artery; PLA, proximal lesion area; MLA, mid-segment lesion area; DLA, distal lesion area.

Discussion

Differences in General Conditions Between the Well-Managed and Poorly Managed Groups

CAD remains a significant health concern, with increasing prevalence in China. LDL-C stands out as a pathogenic risk factor for CAD. In the United States, a decline in CAD mortality has been largely attributed to improved risk factor control, including a notable 24% reduction in TC.¹⁵ Our study highlights a significant disparity in the overall distribution of TC between well-managed and poorly-managed CAD patients, emphasizing the critical role of effective TC management. Consistent with broader literature trends, our findings show an increase in TC, LDL-C, and triglycerides (TG) among Chinese patients, alongside a decrease in HDL-C.^{16,17} This underscores the urgent need to enhance awareness and management of dyslipidemia in CAD patients. The study supports existing literature that identifies HDL-C and the LDL/HDL ratio as important predictors of CAD, reinforcing the need for comprehensive lipid management.¹⁸

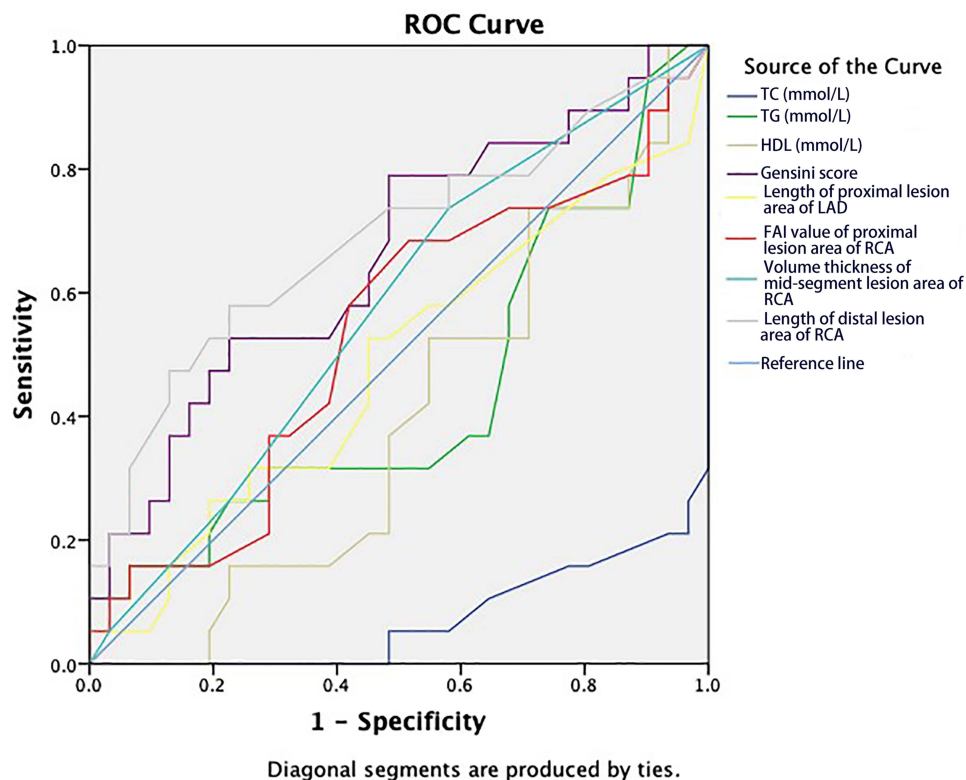


Figure 2 ROC curve analysis for parameters that differ significantly between the two groups.

Correlation Between Coronary Artery CT Angiography, Gensini Score, and Lipid Management Intervention in Patients with CAD

Cardiovascular diseases, including CAD, are the leading cause of mortality worldwide¹⁹ Myocardial ischemia due to coronary artery stenosis is a major concern, and the Gensini score is used to assess the severity of CAD.²⁰ Research indicates that each 1 mmol/L reduction in LDL-C corresponds to a 20–23% decrease in adverse cardiovascular events.^{21–23} Atherosclerosis is driven by a concentration gradient that results in the deposition and retention of ApoB-containing lipoproteins in the subendothelial space.²⁴ All ApoB-containing lipoprotein particles contribute to atherosclerosis, with 95% of LDL-C comprised of ApoB100. Our study found that Gensini scores varied significantly between well-managed and poorly managed CAD patients, with poorly managed patients exhibiting higher scores. This aligns with previous studies suggesting that severe narrowing is associated with elevated Gensini scores.⁹ Elevated LDL-C is a primary risk factor for atherosclerosis across genetic, animal, and epidemiological studies,^{25–29} and reducing LDL-C improves CAD outcomes.^{26,30,31} Our findings reinforce the importance of LDL-C management in improving CAD prognosis.

Correlation Between Pericoronary FAI Based on Coronary Artery CT Angiography and Lipid Management Intervention in Patients with CAD

Pericoronary adipose tissue, rich in saturated fats, influences the inflammatory environment around coronary vessels.³² The pericoronary FAI, reflecting fat density and inflammation, is a novel marker for coronary inflammation.³³ Our study revealed that poorly managed CAD patients had more adverse pericoronary FAI conditions compared to well-managed patients. This suggests that inadequate lipid management accelerates pericoronary inflammation, which is consistent with research indicating RCA-FAI as a potential independent risk factor for atherosclerosis.³² Increased attenuation of pericoronary fat correlates with coronary inflammation and mortality,³⁴ and FAI offers a valuable, non-invasive marker for assessing coronary inflammation.³⁵ Our results support the use of FAI in conjunction with lipid management to better assess and manage CAD.

Research Limitations

The study's uneven age distribution may introduce bias, highlighting the need for more balanced data in future research. Additionally, the lack of detailed categorization of lipid management interventions and analysis of treatment plans limits the depth of our findings. Future studies should include a more granular classification of treatment and consider the impact of calcified plaques and potential artifacts on coronary assessments. Other confounding factors, such as dyslipidemia duration and ethnic differences, were not addressed. The absence of a healthy control group also underscores the need for additional comparative studies.

Conclusion

In summary, as a novel inflammatory biomarker, FAI may serve as a valuable tool for assessing the lipid profiles and the state of inflammation of patients around coronary arteries, but its diagnostic efficacy needs to be improved. Subsequent combined diagnosis with other inflammatory factor parameters is expected to improve diagnostic efficacy. Notably, the results of this study indicate that RCA-FAI varies with lipid management strategies. Therefore, FAI may have the potential to be employed in monitoring perivascular inflammation and lipid status in CAD.

Abbreviations

CAD, coronary atherosclerotic heart disease; LDL-C, low-density lipoprotein cholesterol; FAI, fat attenuation index; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.

Data Sharing Statement

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

This study was conducted with approval from the Ethics Committee of Kunming Yan'an Hospital. This study was conducted by the declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for Publication

All participants signed a document of informed consent.

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Disclosure

The authors declare that they have no competing interests.

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