



OPEN The correlation between the atherogenic index of plasma and the severity of coronary artery disease in acute myocardial infarction patients under different glucose metabolic states

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The atherogenic index of plasma (AIP) is a recent biomarker linked to atherosclerosis that has been validated as a novel indicator for myocardial infarction (MI). However, the relationship between AIP and the severity of coronary artery disease (CAD) in MI patients is still ambiguous, particularly among individuals with different glucose metabolic conditions. A total of 741 participants who were immediately assessed with coronary angiography upon admission and diagnosed with acute MI were recruited. The severity of CAD was assessed based on the number of narrowed vessels. AIP tertiles were used to divide the patients into three groups (T1: AIP < 0.030; T2: 0.030 ≤ AIP ≤ 0.316; T3: AIP > 0.316). The American Diabetes Association's guidelines define three types of glucose metabolic state: diabetes mellitus (DM), prediabetes (Pre-DM), and normal glucose regulation (NGR). Logistic regression analysis was utilized to confirm an association between AIP and CAD severity in MI patients. ROC curves were employed to evaluate the diagnostic utility of AIP for CAD severity in MI patients. In MI patients, a statistically significant correlation was found between AIP and the severity of CAD, with logistic regression analysis revealing a strong association (OR: 2.055; 95% CI: 1.189–3.550; $P = 0.009$). Following adjustments for risk factors in the logistic regression model, AIP remained an independent predictor of multi-vessel CAD (OR: 2.902; 95% CI: 1.555–5.521; $P < 0.001$). Moreover, compared with the T1 group, the odds ratios for multi-vessel CAD in the T2 and T3 groups were 2.039 (95% CI: 1.321–3.175; $P = 0.001$) and 2.087 (95% CI: 1.317–3.340; $P = 0.001$), respectively. The area under the curve for predicting CAD severity with AIP was 0.568 (95% CI: 0.520–0.616; $p = 0.006$). In addition, a significant association was observed between AIP and an increased risk of multi-vessel CAD in the Pre-DM group. In MI patients, AIP is closely associated with the risk of multi-vessel CAD and the prediction of the severity of CAD. In Pre-DM patients, AIP is clearly associated with the severity of CAD, whereas this association is absent in the NGR and DM groups.

Keywords Atherogenic index of plasma, Coronary artery disease, Myocardial infarction, The severity of coronary artery disease, Glucose metabolic states

Abbreviations

AIP Atherogenic index of plasma
CAD coronary artery disease

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MI	myocardial infarction
CAG	coronary angiography
NGR	normal glucose regulation
Pre-DM	prediabetes mellitus
DM	diabetes mellitus
ROC	receiver operating characteristic
AUC	area under the ROC curve
IR	insulin resistance
T2DM	type 2 diabetes mellitus
TC	total cholesterol
TG	triglycerides
HDL-C	high-density lipoprotein cholesterol
LDL-C	low-density lipoprotein cholesterol
HbA1c	glycated hemoglobin
HB	hemoglobin
PLT	platelet count
eGFR	estimated glomerular filtration rate
LAD	left atrial diameter
LVED	left ventricular end-diastolic diameter
LVEF	left ventricular ejection fraction

Acute myocardial infarction (MI) represents a critical clinical manifestation of cardiovascular disease; despite satisfactory outcomes from targeted efforts in recent years, it still poses a serious public health burden¹. Research indicates that MI patients frequently exhibit multi-vessel coronary artery disease (CAD), and in comparison to individuals with single-vessel CAD, they experience elevated mortality rates and a higher incidence of major adverse cardiovascular events^{2,3}. Moreover, with the increasing incidence of insulin resistance (IR) and type 2 diabetes mellitus (T2DM)^{4,5}, elevated blood glucose levels, inflammatory states, endothelial dysfunction, and dysregulated lipoprotein metabolism exacerbate not only the risk of myocardial infarction but also worsen the clinical prognosis for MI patients^{6–8}.

Atherogenic index of plasma (AIP) serves as a measure of lipid metabolism, calculated as the logarithm of the ratio of triglycerides (TG) to high-density lipoprotein cholesterol (HDL-C)⁹. Research shows that an elevated AIP may reflect the severity of IR and is closely linked to the occurrence of IR and T2DM¹⁰. Compared with LDL-C, AIP can more comprehensively represent the overall lipid profile in diabetes mellitus (DM) patients¹¹, and AIP is closely associated with both the reversion from pre-diabetes mellitus (pre-DM) to normal glucose regulation (NGR) and the progression from Pre-DM to DM¹². Higher AIP levels and poorly managed AIP levels are linked to an increased risk of cardiovascular disease in populations with impaired glucose metabolism¹³. Recent studies suggest that AIP could serve as a prospective biomarker for the early diagnosis of MI¹⁴, is closely linked to the incidence of MI¹⁵, and in patients with coronary artery disease, it is significantly associated with cardiovascular outcomes¹⁶.

In addition, the AIP level is significantly correlated with the severity of CAD in patients with coronary heart disease (CHD)^{17,18}. However, to our knowledge, no studies have specifically evaluated the association between AIP and the severity of CAD among MI patients with varying glucose metabolic statuses.

Methods

Study design and population

This retrospective study conforms to the Declaration of Helsinki and was approved by the Ethics Committee of the Sinopharm Dongfeng General Hospital (LW-2024-052). 1010 patients diagnosed with acute MI were hospitalized at Sinopharm Dongfeng General Hospital from January 2022 to December 2023. We excluded 152 patients without coronary angiography (CAG) data, 41 patients diagnosed with MI with nonobstructive coronary arteries following CAG, 27 patients lacking TG and HDL-C data, and 49 patients with severe infections, severe hepatic or renal dysfunction, or cancer. A total of 741 patients were included in the final statistical analysis to investigate the relationship between the AIP and the severity of CAD. Patients were divided into three groups based on the tertiles of the AIP index as follows: T1 group, AIP < 0.030; T2 group, 0.030 ≤ AIP ≤ 0.316; T3 group, AIP > 0.316 (Fig. 1).

Data collection and definitions

Sociodemographic characteristics (age, gender, Body Mass Index (BMI), smoking and drinking status), medical history (hypertension, diabetes, CHD), and blood analysis results are recorded using digital medical record systems.

Fasting venous blood samples are collected in the morning after at least 8 h of fasting, analyzed by the central laboratory, and recorded for glycated hemoglobin (HbA1c), total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), hemoglobin (HB), platelet count (PLT), and estimated glomerular filtration rate (eGFR). Blood pressure is measured immediately after medical contact for all patients, and within 24 h, a bedside echocardiography is performed by experienced ultrasonologist to measure and record the left atrial diameter (LAD), left ventricular end-diastolic diameter (LVED), and left ventricular ejection fraction (LVEF).

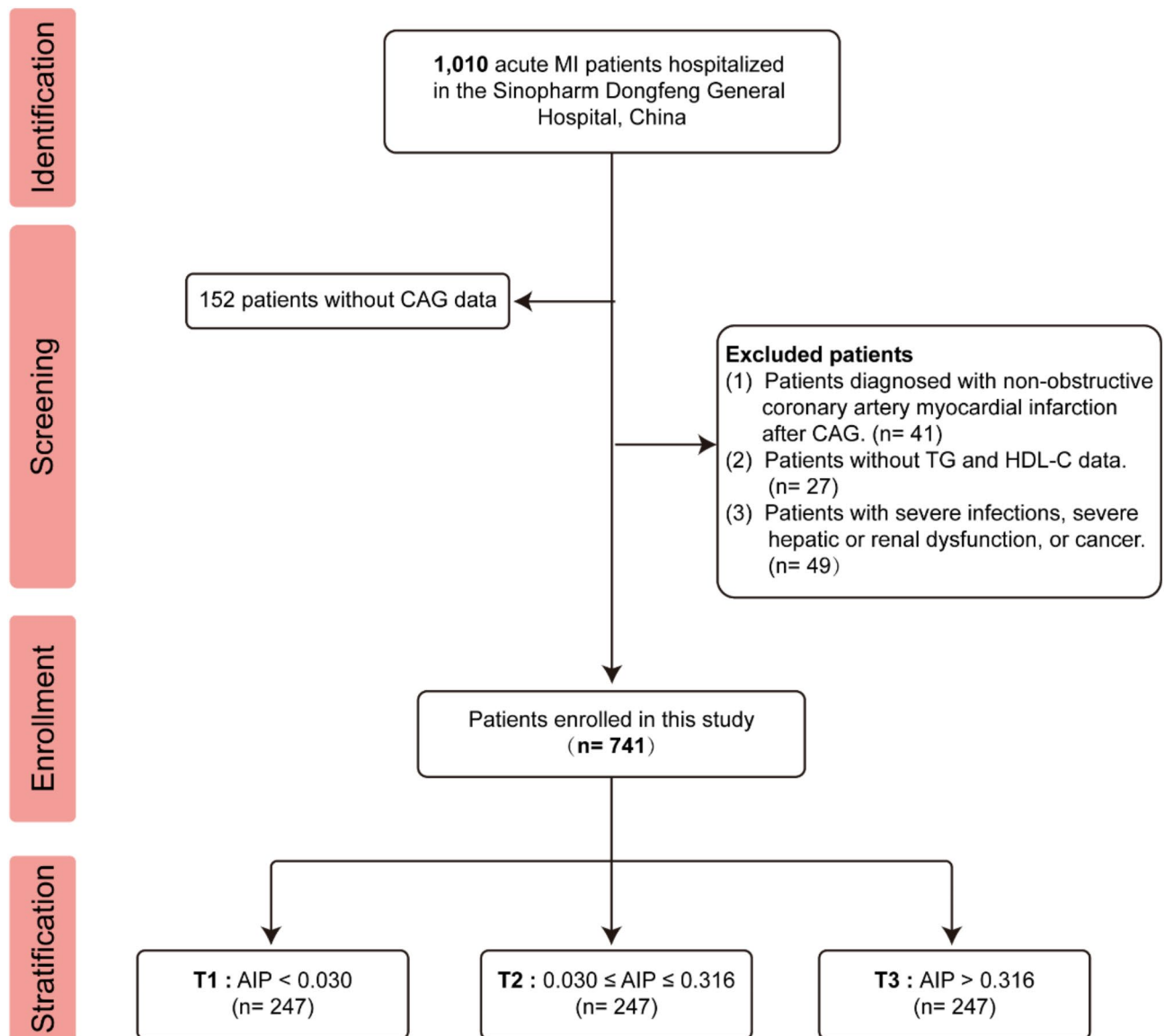


Fig. 1. Flow chart of patient recruitment. *MI* myocardial infarction, *CAG* coronary angiography, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol, *AIP* atherogenic index of plasma.

The severity of CAD is determined by the number of coronary arteries with $\geq 50\%$ stenosis (multi-vessel CAD is defined as two or more coronary arteries with $\geq 50\%$ stenosis). A $\geq 50\%$ luminal narrowing of the left main coronary artery is also considered to be multi-vessel CAD¹⁹.

The AIP was calculated using the following equation: $\log_{10} \left(\frac{\text{TG [mol/L]}}{\text{HDL-C [mol/L]}} \right)$.

Based on the standards set by the American Diabetes Association, glucose metabolic states are classified into: NGR, pre-DM, and DM groups²⁰. If the patient has no history of diabetes, the NGR group is defined as $\text{HbA1c} < 5.7\%$, and the pre-DM group as $5.7\% \leq \text{HbA1c} < 6.5\%$. Individuals who have a history of diabetes or a HbA1c level of 6.5% or higher are classified in the DM group.

Statistical analysis

Continuous variables are described as medians and interquartile ranges (25–75%), while categorical variables are represented by counts or percentages. To compare continuous variables between groups, one-way ANOVA or Kruskal-Wallis tests were used, while the chi-square test was employed to compare categorical variables among groups.

To analyze the association between AIP and CAD severity in MI patients, logistic regression models including odds ratios (OR) and 95% confidence intervals (CI) were established. These models were used to examine the relationship between AIP and multi-vessel CAD across the entire population and under different glucose metabolic statuses in both crude and adjusted models. Model 1 is unadjusted, Model 2 is adjusted for age and gender, and Model 3 further adjusts for smoking, drinking, hypertension, CHD, BMI, HbA1c, LVEF, SBP, DBP, and LDL-C based on the variables in Model 2. Calculate the area under the receiver operating characteristic

(ROC) curve (AUC) and 95% CI to determine the accuracy of AIP in detecting CAD severity in MI patients. Statistical analysis was performed using SPSS 26.0 (IBM, USA) and GraphPad Prism 9.0 (GraphPad Software, USA). The statistical significance threshold was set at $P < 0.05$.

Results

Baseline characteristics

A total of 741 patients with MI were included in this study. The median age was 66 years (IQR, 56–74 years), with a male predominance of 73.55%. Based on the CAG results, single- and multi-vessel CAD were found in 24.02% and 75.98% of patients, respectively. Based on the glucose metabolism status, the patients were divided into the NGR group (34.55%), the pre-DM group (34.82%), and the DM group (30.63%).

Table 1 shows the baseline characteristics of MI patients with single-vessel and multi-vessel CAD. Compared to the single-vessel CAD group, patients in the multi-vessel CAD group are older and have higher levels of HbA1c and TG ($P < 0.05$). Additionally, MI patients with multi-vessel CAD have a higher prevalence of DM and a lower prevalence of CHD ($P < 0.05$).

Table 2 shows the baseline characteristics according to the tertiles of AIP. Compared to the T1 group, T3 group patients are younger, with higher proportions of smoking and DM. In the T3 group, levels of BMI, HbA1c, TC, TG, LDL-C, Hb, and DBP are higher, while HDL-C and eGFR are lower ($P < 0.05$). Furthermore, the T3 group has a higher prevalence of multi-vessel CAD ($P < 0.05$).

Association between AIP and CAD severity in MI patients

Binary logistic regression analysis indicated that, compared with single-vessel CAD, age, HbA1c, and AIP were positively associated with multi-vessel CAD ($P < 0.05$), whereas the prevalence of CHD was negatively associated with multi-vessel CAD ($P < 0.05$) (Table 3).

A multivariable logistic regression model was used to verify the relationship between AIP and CAD severity in MI patients. Whether AIP was treated as a continuous or categorical variable, and whether risk factors were adjusted or not, AIP was significantly associated with CAD severity ($P < 0.05$). When AIP was used as a categorical variable, the incidence of multi-vessel CAD was higher in the T2 and T3 groups compared with the T1 group ($P < 0.05$). After adjusting for all relevant risk factors in Model 3, compared with the T1 group, the odds

Characteristics	Total (n = 741)	Single-vessel CAD (n = 178)	Multi-vessel CAD (n = 563)	P-value
Age(years)	66 (56, 74)	64 (53, 74)	66 (57, 74)	0.033
Male (n, %)	545 (73.55%)	137 (76.97%)	408 (72.47%)	0.276
BMI (kg/m ²)	23.94(21.97,26.26)	24.22 (21.90, 26.76)	23.84 (21.97, 26.09)	0.476
Smoking(n, %)	362 (48.85%)	89 (50.00%)	273 (48.49%)	0.725
Drinking(n, %)	149 (20.11%)	43 (24.16%)	106 (18.83%)	0.122
Hypertension (n, %)	419 (56.55%)	102 (57.30%)	317 (56.31%)	0.815
NGR(n, %)	256 (34.55%)	75(42.13%)	181 (32.15%)	0.019
pre-DM(n, %)	258 (34.82%)	61 (34.27%)	197 (34.99%)	0.932
DM(n, %)	227 (30.63%)	42 (23.60%)	185 (32.86%)	0.025
CHD(n, %)	153 (20.65%)	48 (26.97%)	105 (18.65%)	0.017
SBP (mmHg)	132 (116, 146)	133 (116.25, 143)	131 (116.50, 147)	0.787
DBP (mmHg)	77 (70, 89)	78 (70, 88)	77 (70, 89)	0.850
HbA1c (%)	5.90 (5.50, 6.70)	5.80 (5.50, 6.30)	6.00 (5.50, 6.80)	0.002
TC(mmol/L)	4.13 (3.45, 4.94)	4.02 (3.31, 4.92)	4.17 (3.49, 4.95)	0.083
TG(mmol/L)	1.44 (0.96, 2.16)	1.28 (0.85, 1.88)	1.46 (1.00, 2.25)	0.006
HDL-C(mmol/L)	0.94 (0.79, 1.13)	0.95 (0.81, 1.17)	0.94 (0.79, 1.11)	0.182
LDL-C(mmol/L)	2.36 (1.71, 3.01)	2.295 (1.618, 2.935)	2.38 (1.735, 3.03)	0.087
AIP	0.18 (−0.03, 0.39)	0.11 (−0.06, 0.34)	0.19 (−0.01, 0.41)	0.006
Hb(g/L)	138 (123, 149)	138 (126, 147)	137 (122, 149)	0.405
Plt(*10 ⁹ /L)	205 (167, 247)	199(163, 242)	207 (168.50, 248)	0.204
eGFR	104.08(82.42, 125.54)	104.24 (81.14, 123.55)	104.08 (82.57, 125.59)	0.844
LAD(mm)	36(33, 39)	35 (33, 38)	36 (33, 39)	0.102
LVDd(mm)	47 (43, 50)	47 (43, 49)	47 (43, 50)	0.660
LVEF (%)	58(50, 63)	60 (52, 64)	58 (50, 63)	0.072

Table 1. Baseline characteristics according to single-vessel or multi-vessel CAD in MI patients. CAD coronary artery disease, MI myocardial infarction, BMI body mass index, NGR normal glucose regulation, Pre-DM prediabetes mellitus, DM diabetes mellitus, CHD coronary heart disease, SBP systolic blood pressure, DBP diastolic blood pressure, HbA1c glycated hemoglobin, TC total cholesterol, TG triglycerides, HDL-C high-density lipoprotein cholesterol, LDL-C low-density lipoprotein cholesterol, AIP atherogenic index of plasma, Hb hemoglobin, Plt platelet count, eGFR estimated glomerular filtration rate, LAD left atrial diameter, LVDd left ventricular end-diastolic diameter, LVEF, left ventricular ejection fraction.

Characteristics	Total (n=741)	T1(n=247)	T2(n=247)	T3(n=247)	P-value
Age(years)	66 [56, 74]	70 [61.50, 76]	59 [50, 70.50]	59 [50, 70.50]	<0.001
Male (n, %)	545 (73.5%)	178 (72.06%)	175 (70.85%)	192 (77.73%)	0.180
BMI (kg/m ²)	23.94 [21.97, 26.26]	22.58 [20.60, 24.74]	23.81 [22.14, 26.28]	25.35 [23.41, 27.61]	<0.001
Smoking(n, %)	362 (48.85%)	113 (45.75%)	112 (45.34%)	137 (55.47%)	0.039
Drinking(n, %)	149 (20.11%)	46 (18.62%)	55 (22.27%)	48 (19.43%)	0.570
Hypertension (n, %)	419 (56.55%)	135 (54.66%)	148 (59.92%)	136 (55.06%)	0.422
CHD(n, %)	153 (20.65%)	54 (21.86%)	51 (20.65%)	48 (19.43%)	0.801
NGR(n, %)	256 (34.55%)	107 (43.32%)	77 (31.17%)	72 (29.15%)	0.002
pre-DM(n, %)	258 (34.82%)	89 (36.03%)	87 (35.22%)	82 (33.20%)	0.793
DM(n, %)	227 (30.63%)	51 (20.65%)	83 (33.60%)	93 (37.65%)	<0.001
SBP (mmHg)	132 [116, 146]	132 [115, 145]	131 [117, 147]	132 [116.50, 146.50]	0.923
DBP (mmHg)	77 [70, 89]	76 [68.50, 86]	77 [70, 88]	79 [71, 91]	0.035
HbA1c (%)	5.90 [5.50, 6.70]	5.80 [5.40, 6.20]	6.00 [5.60, 6.75]	6.10 [5.60, 7.15]	<0.001
TC(mmol/L)	4.13 [3.45, 4.94]	3.87 [3.20, 4.60]	4.11 [3.45, 4.90]	4.39 [3.91, 5.28]	<0.001
TG(mmol/L)	1.44 [0.96, 2.16]	0.85 [0.70, 1.00]	1.43 [1.20, 1.65]	2.63 [2.12, 3.70]	<0.001
HDL-C(mmol/L)	0.94 [0.79, 1.13]	1.15 [0.99, 1.35]	0.92 [0.81, 1.08]	0.81 [0.71, 0.93]	<0.001
LDL-C(mmol/L)	2.36 [1.71, 3.01]	2.10 [1.50, 2.76]	2.42 [1.84, 3.06]	2.44 [1.81, 3.08]	<0.001
Hb(g/L)	138 [123, 149]	131 [120, 143.50]	136 [122, 147]	143 [129, 153.50]	<0.001
Plt(*10 ⁹ /L)	205 [167, 247]	206 [157, 242.50]	203 [170, 250]	206 [173.50, 247.50]	0.346
eGFR	104.08 [82.42, 125.54]	108.29 [89.72, 125.65]	100.01 [77.12, 119.96]	103.99 [82.40, 127.73]	0.027
LAD(mm)	36 [33, 39]	36 [33, 39]	36 [33.50, 39]	37 [33, 39]	0.276
LVDd(mm)	47 [43, 50]	46 [42, 49]	47 [42, 51]	47 [43, 50]	0.252
LVEF (%)	58 [50, 63]	58 [50, 63]	58 [50.50, 63]	59 [51, 63]	0.646
Multi-vessel CAD	563 (76.0%)	170 (68.8%)	199 (80.6%)	194 (78.5%)	0.005

Table 2. Baseline characteristics according to the tertiles of AIP. *AIP* atherogenic index of plasma, *BMI* body mass index, *CHD* coronary heart disease, *NGR* normal glucose regulation, *Pre-DM* prediabetes mellitus, *DM* diabetes mellitus, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *HbA1c* glycated hemoglobin, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol, *LDL-C* low-density lipoprotein cholesterol, *Hb* hemoglobin, *Plt* platelet count, *eGFR* estimated glomerular filtration rate, *LAD* left atrial diameter, *LVDd* left ventricular end-diastolic diameter, *LVEF*, left ventricular ejection fraction, *CAD* coronary artery disease.

of multi-vessel CAD in the T2 and T3 groups were 2.039 (95% CI 1.321–3.175; $P=0.001$) and 2.087 (95% CI 1.317–3.340; $P=0.001$), respectively (Table 4).

As shown in Fig. 2, the ROC curve analysis of AIP for predicting multi-vessel CAD in MI patients revealed an AUC of 0.568 (95% CI 0.520–0.616), yielding an optimal cut-off value of 0.035 (Youden index: 0.137) at a sensitivity of 69.27% and a specificity of 44.38% ($p=0.006$).

Relationships among AIP and CAD severity in MI patients with varying levels of glucose metabolism

Our findings indicate that, in the Pre-DM group, AIP (as a continuous variable) is an independent risk factor for multi-vessel CAD ($P<0.05$).Even after adjusting for all relevant risk factors in Model 3, AIP remained significantly associated with CAD severity (OR=5.295, 95% CI 1.545–19.483, $P<0.05$).When considered as a categorical variable, the T2 group had a higher risk of multi-vessel CAD than the T1 group ($P<0.05$).After adjusting all relevant risk factors in Model 3, MI patients in the T2 group had a 2.314-fold higher risk of multi-vessel CAD compared with those in the T1 group (95% CI 1.068–5.202, $P<0.05$).However, in the NGR and DM groups, there was no significant association between AIP levels and CAD severity ($P>0.05$) (Table 5).

Discussion

This study evaluated the relationship among AIP and the severity of CAD in MI patients across different glucose metabolic states. The main findings are: (1) In patients with MI, AIP may be a helpful marker for spotting multi-vessel CAD. (2) Compared to patients with stable CHD, AIP has a stronger correlation with multi-vessel CAD in patients with MI. (3) In the Pre-DM population, there is a strong correlation between AIP and multi-vessel CAD in MI patients, which was not observed in the NGR or DM populations.

MI patients with multi-vessel CAD had a higher complexity in both interventional and surgical treatments than those with single-vessel CAD, and they also have a comparatively worse prognosis². Consequently, MI accompanied by multi-vessel CAD has consistently been the subject of clinical attention. Dyslipidemia is one of the main reasons why arterial diseases start and get worse, holds a prominent position among the high-risk factors for cardiovascular diseases²¹.AIP is considered an important marker in dyslipidemia and atherosclerosis,

Variables	Multi-vessel CAD		
	OR(95%CI)	β	P-value
Age	1.016(1.002–1.030)	0.016	0.022
Sex			
Male	Reference		
Female	1.269 (0.855–1.884)	0.239	0.236
BMI	0.972 (0.924–1.022)	−0.028	0.265
Smoking			
No	Reference		
Yes	0.941 (0.672–1.319)	−0.060	0.725
Drinking			
No	Reference		
Yes	0.728 (0.487–1.090)	−0.317	0.123
Hypertension			
No	Reference		
Yes	0.960(0.683–1.350)	−0.041	0.815
CHD			
No	Reference		
Yes	0.621(0.419–0.920)	−0.477	0.018
SBP	1.003 (0.995–1.010)	0.003	0.477
DBP	0.997 (0.986–1.009)	−0.003	0.664
HbA1c	1.173 (1.034–1.329)	0.159	0.013
TC	1.141 (0.973–1.338)	0.132	0.104
TG	1.080 (0.959–1.218)	0.077	0.204
HDL-C	0.634 (0.343–1.172)	−0.455	0.146
LDL-C	1.087 (0.91–1.298)	0.083	0.357
Hb	0.997 (0.989–1.005)	−0.003	0.432
Plt	1.001 (0.999–1.004)	0.001	0.314
eGFR	1.000(0.999–1.000)	0	0.657
LAD	1.015 (0.981–1.051)	0.015	0.390
LVDd	1.016 (0.988–1.046)	0.016	0.268
LVEF	0.985 (0.968–1.001)	−0.015	0.074
AIP	2.055 (1.189–3.550)	0.720	0.009

Table 3. Relationship between the severity of CAD in MI patients and various risk factors. *CAD* coronary artery disease, *MI* myocardial infarction, *BMI* body mass index, *CHD* coronary heart disease, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *HbA1c* glycated hemoglobin, *TC* total cholesterol, *TG* triglycerides, *HDL-C* high-density lipoprotein cholesterol, *LDL-C* low-density lipoprotein cholesterol, *Hb* hemoglobin, *Plt* platelet count, *eGFR* estimated glomerular filtration rate, *LAD* left atrial diameter, *LVDd* left ventricular end-diastolic diameter, *LVEF*, left ventricular ejection fraction, *AIP* atherogenic index of plasma.

Variables	Multi-vessel CAD					
	Model 1		Model 2		Model 3	
	OR (95% CI)	P-value	OR (95% CI)	P-value	OR(95%CI)	P-value
AIP	2.055 (1.189–3.550)	0.009	2.787(1.555–5.521)	<0.001	2.902(1.555–5.521)	<0.001
T1	Reference		Reference		Reference	
T2	1.878(1.241–2.842)	0.003	2.004(1.320–3.067)	0.001	2.039(1.321–3.175)	0.001
T3	1.658(1.105–2.488)	0.015	2.023(1.318–3.130)	0.001	2.087(1.317–3.340)	0.001

Table 4. Association between AIP and the severity of CAD in MI patients. *AIP* atherogenic index of plasma; *MI* myocardial infarction; *CAD* coronary artery disease; *OR* odds ratios; *CI* confidence interval. T1($AIP < 0.030$), T2($0.030 \leq AIP \leq 0.316$) T3($0.316 < AIP$). Model 1: unadjusted;. Model 2: adjusted for Age and Sex;. Model 3: adjusted for Age, Sex, BMI, Smoking, Drinking, CHD, Hypertension, HbA1c, LVEF, SBP, DBP, LDL-C.

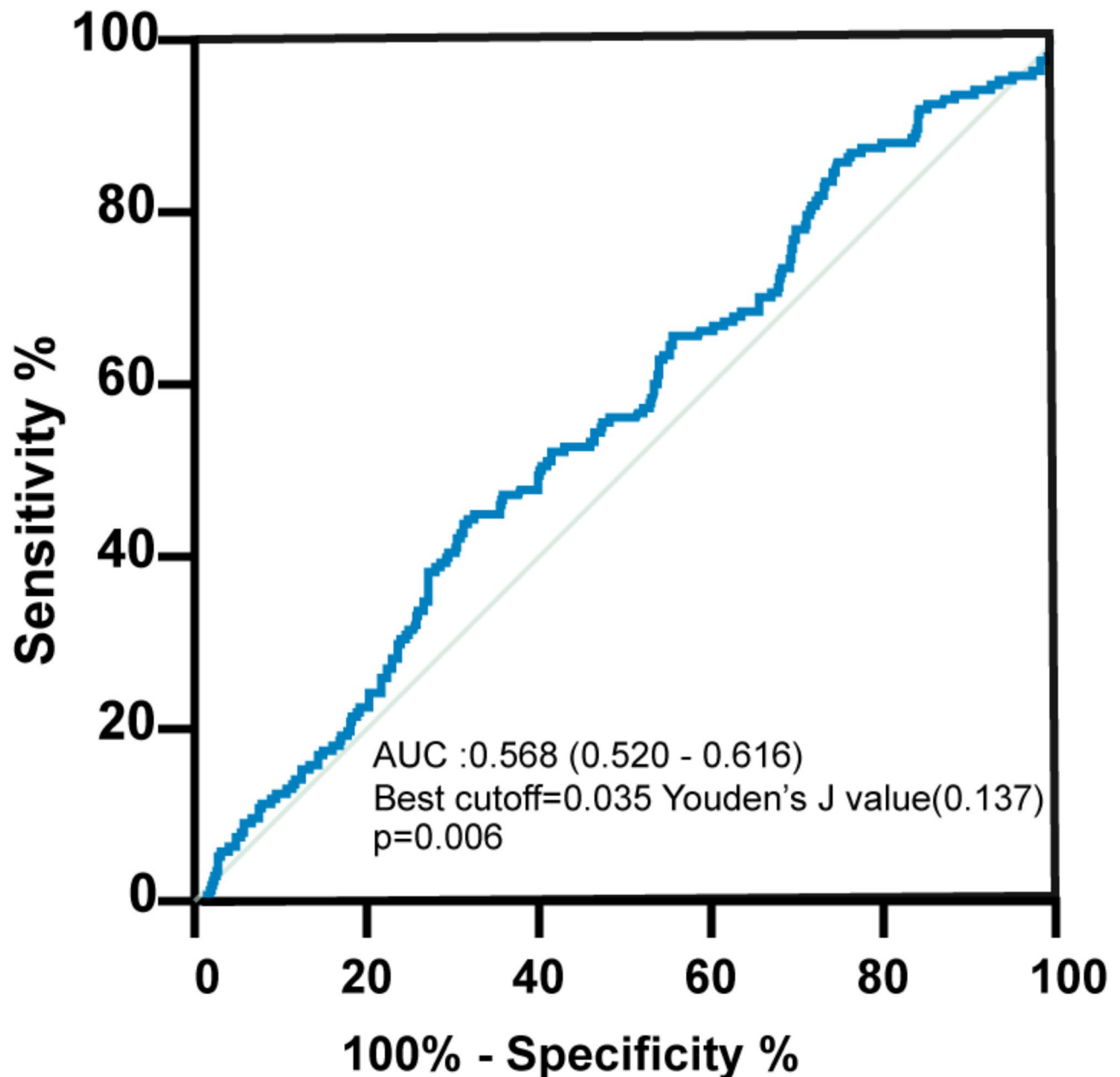


Fig. 2. ROC curve for the use of AIP in the detection of multi-vessel CAD in MI patients. ROC receiver operating characteristic, AIP atherogenic index of plasma, CAD coronary artery disease, MI myocardial infarction.

and compared to individual lipid values, it more comprehensively represents the overall lipid profile¹⁴. Recent studies have shown that baseline of AIP, long-term cumulative AIP exposure and its time course are closely associated with cardiovascular diseases, particularly significant in the role it plays in MI^{22,23}.

In CHD patients, recent research indicates that AIP has a strong connection with CAD severity^{17,18}. To our knowledge, this is the first study that investigates the link between AIP and CAD severity in MI patients (Supplemental Table S1). Unlike previous findings, our study reveals that AIP is statistically significant with CAD severity in MI patients, regardless of adjustments for confounding factors and tertiles of AIP. Compared to the lowest tertile of AIP (T1 group), the highest tertile (T3 group) shows a 1.658-fold and 2.087-fold increased risk of multi-vessel CAD before and after adjusting for confounding variables, respectively. In general, our findings indicate that CAD severity is more strongly correlated with AIP in the MI population than in the CHD population.

Previous studies have shown that AIP is not only closely related to dyslipidemia but also strongly correlated with increased IR and the onset of T2DM¹⁰. Consequently, we conducted a further assessment of the correlation between AIP and CAD severity across different glucose metabolic conditions. Ultimately, it was found that a notable association exists between AIP and CAD severity in the Pre-DM group. However, this correlation

Glucose regulation state	Variables	Multi-vessel CAD					
		Model 1		Model 2		Model 3	
		OR (95% CI)	P-value	OR (95% CI)	P-value	OR(95%CI)	P-value
NGR	AIP	1.593 (0.661–3.841)	0.300	2.467(0.938–6.751)	0.072	2.739(0.942–8.328)	0.069
	T1	Reference		Reference		Reference	
	T2	1.215 (0.642–2.301)	0.549	1.423(0.738–2.797)	0.298	1.443 (0.729–2.910)	0.297
	T3	1.458 (0.747–2.847)	0.269	2.004(0.965–4.297)	0.067	2.093 (0.952–4.758)	0.071
Pre-DM	AIP	3.191(1.128–9.030)	0.029	3.731(1.279–11.416)	0.018	5.295(1.545–19.483)	0.010
	T1	Reference					
	T2	2.520(1.222–5.196)	0.012	2.533(1.245–5.355)	0.012	2.314(1.068–5.202)	0.037
	T3	1.719(0.866–3.411)	0.122	1.803(0.889–3.741)	0.107	1.963(0.877–4.525)	0.106
DM	AIP	1.374(0.518–3.64)	0.523	1.852(0.684–5.317)	0.237	1.903(0.664–5.775)	0.241
	T1	Reference					
	T2	2.024(0.841–4.870)	0.115	2.070(0.850–5.096)	0.108	2.358(0.912–6.191)	0.077
	T3	1.529(0.673–3.474)	0.310	1.850(0.780–4.376)	0.159	1.972(0.781–5.002)	0.149

Table 5. Associations between AIP and the severity of CAD in MI patients according to different glucose metabolism states. OR, odds ratios; CI, confidence interval; AIP, atherogenic index of plasma. T1 (AIP < 0.030) T2 (0.030 ≤ AIP ≤ 0.316) T3 (0.316 < AIP). Model 1: unadjusted;. Model 2: adjusted for Age and Sex;. Model 3: adjusted for Age, Sex, BMI, Smoking, Drinking, CHD, Hypertension, HbA1c, LVEF, SBP, DBP, LDL-C.

was not observed in the NGR and DM groups. This may be attributable to the fact that, during the pre-DM stage, the body typically exhibits early or mild IR, low-grade inflammation, and minor disturbances in glucose and lipid metabolism, and although these responses are weaker compared to the diabetic phase, individuals tend to overlook bodily changes and are less likely to adopt lifestyle or pharmacological interventions²⁴. In addition, during this period, the body is in an intermediate metabolic state where IR has started to develop, but hyperglycemia has not fully manifested, and this chronic, long-term state is crucial in the formation of arteriosclerosis. In recent years, IR indicators (AIP, triglyceride glucose, etc.) have been shown to be closely linked to the risk of multi-vessel CAD as well as mortality and cardiovascular outcomes in patients with chronic coronary syndrome^{18,25}. Meanwhile, studies reveal that in the Pre-DM population, most individuals present with abnormal lipid profiles and/or hypertension. Even though in recent years blood pressure and lipid levels have been effectively controlled, the incidence of MI remains unchanged; compared with Pre-DM patients, those diagnosed with DM have shown more improvement in cardiovascular therapy. Crucially, research has confirmed that even without progressing to DM, Pre-DM is associated with an elevated risk of both microvascular and macrovascular complications²⁶. Previous studies have shown that relative hyperglycemia can trigger microvascular dysfunction in the coronary arteries, regardless of the presence of DM and is closely associated with poor prognosis in patients with MI^{27–29}. This implies that individuals with Pre-DM often experience early atherosclerotic changes prior to full-blown dysregulation of glucose metabolism, and this stage may persist for a long time, thereby increasing the risk of multi-vessel CAD in MI patients. In contrast, in the DM population, the increased use of new antidiabetic drugs such as SGLT2 inhibitors and GLP-1 receptor agonists has been shown to alleviate, to some extent, oxidative stress, inflammatory responses, and the interactions involved in atherosclerosis development, effectively reducing cardiovascular events in DM patients^{30–32}. Moreover, these patients diagnosed with DM often receive or more frequently seek consultations regarding lifestyle modifications and continuous management of cardiovascular risk factors such as blood glucose and blood lipids. In other words, compared to patients with pre-DM, those diagnosed with DM are more likely to receive guideline-recommended cardiovascular pharmacotherapy, potentially undergo more comprehensive care and treatment, and focus on achieving therapeutic goals—changes that may partially reduce their risk of multi-vessel CAD. Overall, a prolonged yet previously undetected pre-DM state may impose greater negative impacts on both microvascular and macrovascular complications, intensifying the association between AIP and the risk of multi-vessel CAD in MI patients. By contrast, individuals with NGR experience a relatively weaker impact due to their stable metabolic status, whereas in diagnosed DM patients, more consistent treatment and heightened disease awareness may weaken the link between AIP and multi-vessel CAD.

It is worth emphasizing that our study revealed an AUC of 0.568 for AIP in predicting multi-vessel CAD in MI patients, indicating potentially limited predictive capability. This may be related to the following factors: multi-vessel CAD are often the result of multiple factors (including lipid metabolism, inflammatory damage, endothelial dysfunction, and various metabolic disorders), and as a lipid-metabolism-related index, AIP alone may not sufficiently capture these complex risk factors and pathological pathways. Moreover, this study was a single-center retrospective investigation with a relatively small sample size, which may have somewhat affected AIP's predictive efficacy. Recent research indicates that pre-DM is a high-risk state for cardiovascular events, closely associated with the risk of MI, all-cause mortality, and outcome risks³³. AIP is closely linked to the risk of pre-DM³⁴, the progression from pre-DM to DM or reversion to NGR¹², and has been shown to be an independent predictor for rapid progression of coronary atherosclerosis and vulnerable plaque formation³⁵. Therefore, even though the AUC value is relatively low, our results suggest that greater attention should still be given to AIP, especially in MI patients with pre-DM, as early decision-making and risk stratification based on AIP levels may

help customize interventions, potentially slowing the progression of coronary lesions and preventing adverse cardiovascular events. Additionally, combining AIP with other biomarkers (such as stress hyperglycemia) and incorporating these into more comprehensive risk prediction models may enhance AIP's ability to predict multi-vessel CAD in MI patients, and we will further investigate this in the future to confirm our hypothesis.

The results of this study provide additional evidence that in patients with MI, elevated AIP levels are strongly linked to multi-vessel CAD. Notably, the association between AIP levels and multi-vessel CAD is most pronounced in pre-DM patients compared to those with NGR and DM, suggesting that AIP levels in this population should be closely monitored. Based on this, AIP is expected to become an effective tool for risk stratification in pre-DM patients, helping clinicians identify high-risk MI patients earlier and develop personalized intervention strategies.

Strengths and limitations

To our knowledge, this is the first study to directly explore the effect of AIP on CAD severity among MI patients under different glucose metabolic statuses. However, this study also has certain limitations. Firstly, the AIP measurement was based on the baseline obtained at patient admission, and due to the absence of long-term follow-up data in this study, we could not assess the predictive value of changes in AIP over time for CAD severity. This deficiency partly constrains our understanding of AIP's role in long-term risk prediction and leaves a gap in elucidating AIP's impact at different stages of disease progression. Future extended follow-ups, incorporating more dynamic data, may prove more valuable for risk stratification of CAD severity. Secondly, we did not collect information on the duration and dosage of antidiabetic, lipid-lowering, and antihypertensive medications used by participants, nor did we have long-term monitoring data for blood pressure, blood glucose, and lipid levels, which may potentially affect our findings. Thirdly, because retrospective studies inherently have unavoidable drawbacks, we could not infer causality in this study. Moreover, although we attempted to adjust for many confounding factors, we cannot completely rule out residual confounding effects—such as diet, exercise, sleep, and stress—which may influence the results. Fourthly, this single-center study involving only the Chinese population may result in admission rate bias and has a relatively small sample size, which may limit the generalizability of the findings to broader populations. Further prospective, large-scale, multicenter randomized controlled trials may make our conclusions more reliable, and future research should account for these factors to enhance the accuracy and validity of the findings.

Conclusion

Our results indicate that AIP is associated with multi-vessel CAD in MI patients, and an elevated AIP can identify MI patients with multi-vessel CAD. In the pre-DM group, there is an association between AIP and the severity of CAD, regardless of adjustments for confounding factors, while no such correlation is observed in the non-DM and DM groups. Monitoring AIP may serve as a risk management strategy for MI patients, particularly in the pre-DM population, offering new preventive strategies for clinical management.

Data availability

The datasets generated and analyzed in this study are not publicly available due to privacy and ethical constraints; however, they can be obtained from the corresponding author.

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Author contributions

KQJ, ZJM and CLZ designed the study, analysed the data, and wrote the manuscript; KQJ, ZJM, CLZ, XTZ, HX, DFL, XWM, HDY, WWW, JXZ collected and interpreted the data; JSC and JC critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

The Ethics Committee of the Sinopharm Dongfeng General Hospital approved this investigation, which was conducted in accordance with the Declaration of Helsinki. Due to the retrospective nature of the study, the Ethics Committee of Sinopharm Dongfeng General Hospital waived the need of obtaining informed consent.

Competing interests

The authors declare no competing interests.

Additional information

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