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Association of visceral adiposity index (VAI) with prognosis in patients with metabolic syndrome and heart failure with reduced ejection fraction

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Abstract

Background Visceral Adiposity Index (VAI) is an effective predictor of metabolic syndrome (MetS) and serves as a marker of visceral adiposity. The association between the VAI index and poor prognosis in patients with MetS and Heart failure with reduced ejection fraction (HFrEF) remains unclear. The aim of this study is to evaluate the relationship between VAI and endpoint events in patients with metabolic syndrome and HFrEF.

Methods This study was a single-center retrospective cohort study. A total of 809 patients with MetS and HFrEF admitted to Hangzhou Hospital of Zhejiang Medical Group from January 2014 to September 2021 were consecutively included. The VAI index was calculated based on anthropometric measurements and laboratory examination results at admission, and patients were grouped according to tertiles of VAI index. All patients were followed for 24 months, and the incidence of cardiac death and readmission for heart failure was recorded.

Results For different clinical endpoint events, there were significant differences in event-free survival between tertiles of VAI index. The risk of cardiac death [hazard ratio (HR):3.402, 95%CI:2.123–5.449, $P<0.001$] and heart failure readmission (HR:4.862, 95%CI:3.605–6.557, $P<0.001$) increased with the increase of tertile of VAI index. Multivariate COX regression analysis adjusted for other confounding factors showed that VAI was an independent predictor of clinical adverse endpoint events. The predictive value of VAI for cardiac death [Area under curve (AUC):0.649, 95%CI:0.602–0.697, $P<0.001$] and heart failure readmission (AUC:0.693, 95%CI:0.656–0.729, $P<0.001$) was higher than that of other variables.

Conclusions In patients with HFrEF at risk for comorbid metabolic diseases, baseline VAI levels on admission were associated with the occurrence of adverse outcomes during follow-up.

Keywords Visceral adiposity index, Heart failure with reduced ejection fraction, Metabolic syndrome

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Introduction

The diagnosis and severity of heart failure can be differentiated on the basis of left ventricular ejection fraction. Heart failure with reduced ejection fraction (HFrEF) is a common phenotype of heart failure, and patients often present with end-stage heart failure and a significant reduction in cardiac systolic function. Each category of heart failure differs in risk factors, pathophysiology, and treatment options. HFrEF is often detected in the later stages of the disease and faces worse clinical outcomes. Despite advances in the treatment of patients with heart failure, both pharmacologic and device therapies, the majority of patients continue to have a high mortality rate after hospitalization and a significant number of patients are admitted to the hospital repeatedly for heart failure episodes [1, 2]. Studies have shown that patients with heart failure often have a variety of non-cardiovascular comorbidities, which vary according to the type of heart failure [3]. These comorbidities also often influence patients' treatment decisions. Half of the reasons for readmission in heart failure patients were for reasons other than heart failure, indicating a high comorbidity burden.

Obesity and obesity-related complications are not only associated with abnormalities in the patient's cardio metabolism, but also promote the development of heart failure [4]. Even in the absence of heart failure, obesity itself increases ventricular burden [5, 6]. Metabolic syndrome (MetS) is a group of metabolic disorders including obesity, involving a variety of diseases and metabolic processes, which work together to affect cardiovascular health [7]. Studies related to the National Health and Nutrition Examination Survey have shown that the prevalence of metabolic syndrome is as high as 34.2% among adults in the United States [8]. The incidence of metabolic syndrome is on the rise globally, and studies in Korea have shown a 1.68% increase in the prevalence of metabolic syndrome over a 4-year period, with a significant impact on increased cardiovascular risk [9].

About one-third of the Chinese population has metabolic syndrome, and there are marked differences in prevalence by age and gender, with a significant increase in prevalence with age [10]. The presence of MetS in heart failure patients reflects the risk of aggregation of various metabolic risk factors, and the risk of cardiovascular death is significantly increased in patients with MetS compared with non-MetS patients [11]. The metabolic derangements of metabolic syndrome lead to abnormal myocardial metabolism and increased sensitivity to ischemia. Cardiac lipid accumulation due to obesity results in structural and functional damage and cardiac dysfunction [12].

Obesity is receiving increasing attention as a major manifestation of the metabolic syndrome. Adipose accumulation, especially ectopic adipose tissue, is increased in obese patients. Adipose tissue plays an important role in the regulation of systemic metabolic homeostasis, and obesity-associated adipose tissue dysfunction promotes an inflammatory response that leads to insulin resistance and various metabolic disorders [13].

The obesity epidemic has increased the burden of related diseases, and obesity is strongly associated with visceral adiposity, which is thought to be directly related to the metabolic syndrome given that patients with visceral obesity have a significantly increased risk of insulin resistance.

Framingham study suggests that visceral fat is a better predictor of cardiovascular disease risk than measures such as waist circumference (WC) [14], and therefore targeted reduction of visceral fat may be more effective in providing positive cardiovascular protection. However, accurate assessment of body composition is complex in clinical settings and is not included in routine clinical testing [15]. VAI is thought to be associated with visceral fat dysfunction and can be used in the assessment of visceral obesity. Amato et al. [16] demonstrated that VAI is an effective marker for predicting MetS in a multicenter cross-sectional study in southwest China. The correlation between obesity and HFrEF has not been commonly studied. This study aimed to elucidate the relationship between VAI and the prognosis of patients with MetS and HFrEF, given the lack of previous research on VAI and HFrEF.

Methods

Criteria for including and excluding study subjects

This is a single-center retrospective study. We consecutively included patients with MetS and HFrEF who attended Zhejiang Medical and Healthcare Group Hangzhou Hospital from January 2014 to September 2021. HFrEF was defined as ejection fraction less than 40% on echocardiography. The diagnostic criteria for metabolic syndrome were three of the following five characteristics [17]: WC ≥ 80 cm in women and ≥ 85 in men. Triglyceride (TG) levels ≥ 150 mg/dl. HDL-C levels below 40 mg/dl in men and below 50 mg/dl in women. Systolic blood pressure (SBP) ≥ 130 mm Hg and/or diastolic blood pressure (DBP) ≥ 85 mmHg or on antihypertensive therapy. Fasting plasma glucose (FPG) ≥ 100 mg/dl or on hypoglycemic therapy. Exclusion criteria: severe heart valve disease, heart failure due to non-cardiac factors, severe hepatic or renal impairment, malignant tumors, familial hypercholesterolemia, patients with incomplete clinical information.

Data collection

Trained investigators collected basic clinical data of the patients. The included patients were fasted for at least

12 h after admission and fasting blood was collected. Blood glucose and lipid indices were tested by Hangzhou Hospital Testing Center. Patients underwent echocardiography within 24 h after admission, and the Simpson method was used to evaluate the ejection fraction of the patients and record it. Drinking or smoking was defined as daily drinking or smoking for at least 1 year. Blood samples were collected 12 h after admission and processed by the central laboratory for measurement of serum creatinine, fasting plasma glucose (FPG), total cholesterol (TC), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and brain natriuretic peptide (BNP). Estimated glomerular filtration rate (eGFR) was calculated using the Cockcroft-Gault equation [14]. Anthropometric indicators such as height, weight, and waist circumference (WC) were measured according to standard methods. Body mass index (BMI) was computed by dividing weight (kg) by height (m) squared. VAI was calculated using the formula [WC/39.68+ (1.88 × BMI)] × [TG/1.03] × [1.31/HDL-C] for men and [WC/36.58 + (1.89 × BMI)] × [TG/0.81] × [1.52/HDL-C] for women. eGFR was calculated using the Cockroft-Gault formula. eGFR < 60 was considered to be the presence of chronic kidney disease (CKD).

Follow-up

All patients included in the study underwent a 24-month follow-up, which was obtained by trained specialists by surveying inpatient and outpatient medical records and contacting patients and their families by telephone. The primary endpoint of the study was cardiac death and the secondary endpoint was readmission for heart failure. If multiple events occurred during follow-up, the most serious endpoint events was selected for analysis.

Statistical analysis

Continuous variables were presented as means ± standard deviations if normally distributed, and as medians with interquartile ranges if not. Continuous variables were compared by analysis of variance or rank sum test. Categorical variables were represented as frequencies and analyzed using the chi-square test. Kaplan-Meier event-free survival curves for VAI index tertiles were compared using the log-rank test. Cox proportional hazards regression models, both univariate and multivariate, were employed to examine the association between VAI and clinical endpoint events. Model 1 was adjusted for both sex and age. Model 2 was adjusted for sex, age, smoking, drinking, and myocardial infarction (MI). Model 3 was adjusted for sex, age, smoking, drinking, MI, B-type natriuretic peptide (BNP), estimated glomerular filtration rate (eGFR), and left ventricular ejection fraction (LVEF). The predictive value of BMI, WC, TG, HDL-C, and VAI for clinical endpoint events was assessed using the area under the ROC curve (AUC). $P < 0.05$ was considered significant. All analyses were performed using SPSS 25.0 and R.

Results

Out of 922 patients included in the study, 113 were lost to follow-up over a 24-month period, resulting in a 12.3% loss rate. The final number of patients who completed the 24-month follow-up was 809. The mean age was 65 ± 10 years, with a gender distribution of 586 (72.4%) males and 223 (27.5%) females. Table 1 presents the clinical baseline characteristics of the study population categorized by VAI index tertiles. Significant differences were observed in sex, age, diabetes, hypertension, BMI, FPG, TG, TC, HDL-C, LDL-C, and LVEF among patients categorized by varying VAI levels (Table 1).Through 24 months of follow-up, cardiac death occurred in 137 patients, whereas 334 patients were readmitted for heart failure. Kaplan-Meier survival analyses demonstrated significantly lower cumulative patient survival in higher VAI tertile subgroups regardless of whether the endpoint event was cardiogenic shock or readmission for heart failure (P log-rank < 0.001) (Fig. 1).

Table 2 displays the Cox proportional hazards regression analysis outcomes. In unadjusted Cox models, the VAI indices of tertile 2 and tertile 3 increased the risk of cardiac death and readmission for heart failure compared with tertile 1. Model 1 was adjusted for sex and age. Model 2 included additional adjustments for smoking, drinking, and MI. Model 3 further incorporated adjustments for BNP, eGFR, and LVEF. After adjusting for these confounders, Multivariate-adjusted HR increased with increasing levels of the VAI index. Meanwhile, the VAI index as a continuous variable was significantly associated with an increased risk of cardiac death (HR:1.092, 95% CI:1.056–1.130, $P < 0.001$) and an increased risk of readmission for heart failure (HR:1.130, 95% CI:1.102–1.158, $P < 0.001$). Regardless of the adverse outcome, the VAI index had the highest HR compared to single indicators such as BMI, WC, TG, and HDL-C (Table 3).

ROC analyzed the predictive value of BMI, WC, TG, HCL-C, and VAI for different types of endpoint events. The results showed that for the prediction of cardiac death, TG, HDL-C, and VAI had some predictive value, and VAI had a greater AUC compared with other variables (AUC:0.649, 95%CI:0.602–0.697, $P < 0.001$). For heart failure readmission, BMI, WC, TG, HCL-C, and VAI all had predictive value, with VAI having the greatest predictive value (AUC:0.693, 95%CI:0.659–0.729, $P < 0.001$) (Table 4, Supplementary Tables 1–2).

Subgroup analyses according to sex were adjusted for relevant confounders. In male patients, the VAI index was significantly linked to both the risk of cardiac death

Table 1 Baseline data of the three groups

	Tertile1 (*n* = 273)	Tertile2 (*n* = 266)	Tertile3 (*n* = 270)	*P*
VAI	1.49(1.24, 1.70)	2.47(2.24, 2.73)	4.32(3.52, 6.11)	< 0.001
Male, n (%)	229(83.9)	196(73.7)	161(59.6)	< 0.001
Age, years	67 ± 9	64 ± 10	65 ± 10	0.001
Smoking, n (%)	117(42.9)	109(41.0)	96(35.6)	0.197
Drinking, n (%)	76(27.9)	78(29.3)	60(22.2)	0.141
Diabetes, n (%)	232(85.0)	193(72.6)	137(50.7)	< 0.001
Hypertension, n (%)	244(89.4)	215(80.8)	223(82.6)	0.015
MI, n (%)	83(30.4)	87(32.7)	84(31.1)	0.347
BMI, kg/m2	25.9 (23.9, 28.5)	26.6 (23.4, 29.0)	26.9 (24.9, 29.3)	0.019
WC, cm	102.0 (90.1, 106.3)	97.4 (91.9, 105.4)	98.8 (90.3, 105.0)	0.634
eGFR, ml/min/1.73m^2	68.8 (47.2, 90.16)	76.2 (51.3, 100.1)	68.7 (43.2, 94.8)	0.074
FPG, mg/dl	126.36 (100.71,170.73)	144.54 (112.28,207.36)	170.19 (117.50,239.58)	< 0.001
TG, mg/dl	81.51(66.45, 97.46)	120.50 (103.66,144.42)	177.20 (141.32,250.30)	< 0.001
TC, mg/dl	117.65 (100.23,144.35)	130.42 (107.49,155,41)	141.26 (112.91,179.18)	< 0.001
HDL-C, mg/dl	36.77 (31.54,43.73)	32.90 (28.15,38.70)	28.25 (23.99,34.83)	< 0.001
LDL-C, mg/dl	75.07 (59.21,94.23)	83.97 (66.45,107.19)	93.07 (67.62,124.32)	< 0.001
LVEF, %	36 ± 4	37 ± 4	37 ± 4	0.001
BNP, pg/ml	3082.0 (1200.0, 6464.0)	3025.5 (1120.0, 6531.0)	2353.5 (829.9, 5566.0)	0.140

VAI: visceral adiposity index, MI: myocardial infarction, BMI: body mass index, WC: waist circumference, eGFR: estimated glomerular filtration rate, FPG: fasting plasma glucose, TG: triglyceride, TC: total cholesterol, HDL-C: high-density lipoprotein cholesterol, LDL-C: low-density lipoprotein cholesterol, LVEF: left ventricular ejection fraction, BNP: brain natriuretic peptide

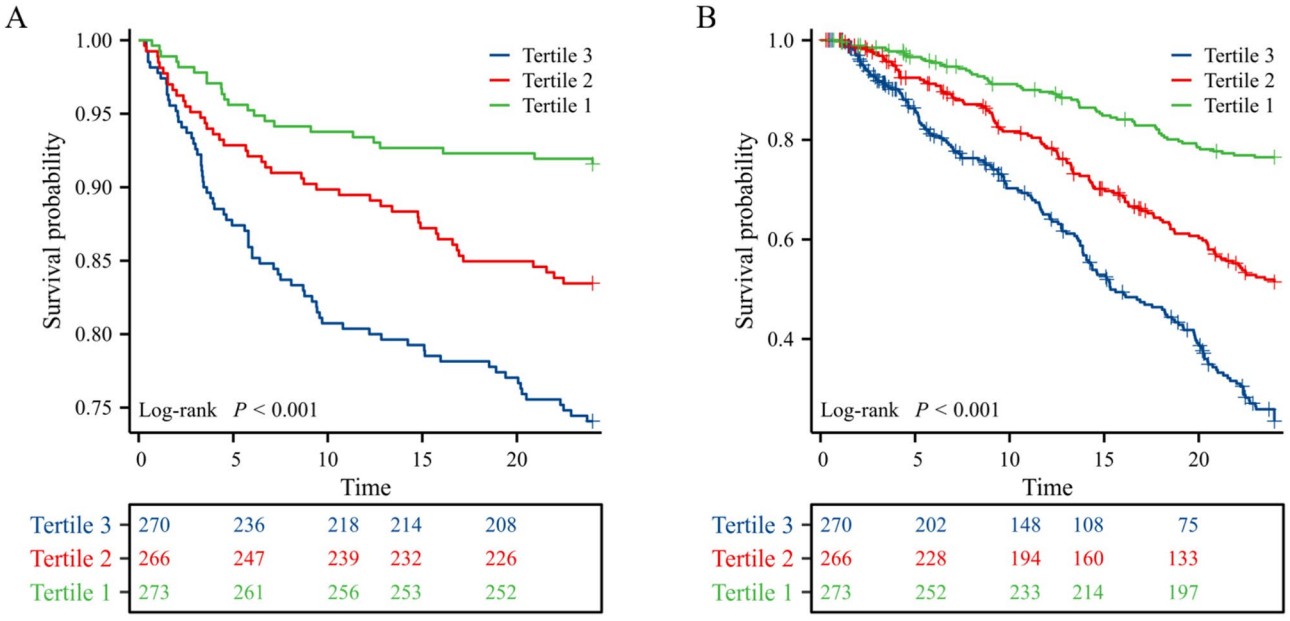

Fig. 1 Kaplan-Meier curves of cardiac death (**A**) and readmission for heart failure (**B**) with different VAI

(HR:1.194, 95% CI:1.138–1.254, $P < 0.001$) and readmission for heart failure (HR:1.194, 95% CI:1.144–1.247, $P < 0.001$).In female patients, the VAI index significantly correlated with heart failure readmission risk (HR:1.122, 95% CI:1.079–1.166, $P < 0.001$).Subgroup analyses according to age were adjusted for relevant confounders. The VAI index in patients was significantly linked to the risk of cardiac death and heart failure readmission, irrespective of whether they were above or below 65 years of age. At the convenience of comorbidities, the VAI index was associated with an increased risk of adverse endpoint events in patients regardless of whether they had concurrent MI or CKD (Table 5).

Discussion

Our findings suggest that in patients with HFrEF combined with metabolic syndrome, increased levels of VAI are associated with the occurrence of adverse endpoint

Table 2 Association between VAI and cardiac death and readmission for heart failure

	Crude model		Model1		Model2		Model3	
	HR (95%CI)	*P*	HR (95%CI)	*P*	HR (95%CI)	*P*	HR (95%CI)	*P*
Cardiac death								
Tertile1	Reference		Reference		Reference		Reference	
Tertile2	2.043(1.234–3.383)	0.002	2.242(1.348–3.729)	0.002	2.216(1.331–3.690)	0.002	2.20(1.334–3.696)	0.002
Tertile3	3.402(2.123–5.449)	< 0.001	4.121(2.544–6.678)	< 0.001	4.056(2.503–6.573)	< 0.001	4.167(2.567–6.763)	< 0.001
	P for trend	< 0.001	P for trend	< 0.001	P for trend	< 0.001	P for trend	< 0.001
Readmission for heart failure								
Tertile1	Reference		Reference		Reference		Reference	
Tertile2	2.448(1.789–3.350)	< 0.001	2.565(1.868–3.522)	< 0.001	2.626(1.907–3.617)	< 0.001	2.630(1.908–3.626)	< 0.001
Tertile3	4.862(3.605–6.557)	< 0.001	5.631(4.126–7.686)	< 0.001	5.774(4.219–7.902)	< 0.001	5.671(4.112–7.819)	< 0.001
	P for trend	< 0.001	P for trend	< 0.001	P for trend	< 0.001	P for trend	< 0.001

Model1: sex, age. Model2: sex, age, smoking, drinking, MI. Model3: sex, age, smoking, drinking, MI, BNP, eGFR, LVEF

Table 3 Relationship between different clinical indicators and adverse endpoint events

	Crude model		Model1		Model2		Model3	
	HR (95%CI)	*P*	HR (95%CI)	*P*	HR (95%CI)	*P*	HR (95%CI)	*P*
Cardiac death								
VAI	1.092 (1.056–1.130)	< 0.001	1.115 (1.076–1.155)	< 0.001	1.115 (1.076–1.155)	< 0.001	1.115 (1.076–1.156)	< 0.001
BMI	1.044 (1.003–1.087)	0.034	1.047 (1.003–1.092)	0.035	1.047 (1.003–1.092)	0.037	1.052 (1.005–1.102)	0.03
WC	1.011 (0.997–1.025)	0.139	1.008 (0.992–1.023)	0.333	1.007 (0.991–1.022)	0.399	1.007 (0.991–1.024)	0.404
TG	1.003 (1.002–1.004)	< 0.001	1.003 (1.002–1.004)	< 0.001	1.003 (1.002–1.004)	< 0.001	1.003 (1.002–1.004)	< 0.001
HDL-C	0.961 (0.943–0.979)	< 0.001	0.962 (0.944–0.981)	< 0.001	0.962 (0.944–0.980)	< 0.001	0.960 (0.942–0.978)	< 0.001
Readmission for heart failure								
VAI	1.130 (1.102–1.158)	< 0.001	1.139 (1.110–1.168)	< 0.001	1.139 (1.110–1.169)	< 0.001	1.140 (1.111–1.170)	< 0.001
BMI	1.080 (1.053–1.109)	< 0.001	1.080 (1.051–1.109)	< 0.001	1.082 (1.053–1.111)	< 0.001	1.093 (1.061–1.126)	< 0.001
WC	1.025 (1.015–1.034)	< 0.001	1.026 (1.016–1.036)	< 0.001	1.027 (1.017–1.037)	< 0.001	1.029 (1.018–1.041)	< 0.001
TG	1.003 (1.002–1.004)	< 0.001	1.003 (1.002–1.004)	< 0.001	1.003 (1.002–1.004)	< 0.001	1.003 (1.002–1.004)	< 0.001
HDL-C	0.953 (0.942–0.965)	< 0.001	0.952 (0.941–0.964)	< 0.001	0.953 (0.941–0.964)	< 0.001	0.953 (0.941–0.965)	< 0.001

VAI: visceral adiposity index, BMI: body mass index, WC: waist circumference, TG: triglyceride, HDL-C: high-density lipoprotein cholesterol. Model1: sex, age. Model2: sex, age, smoking, drinking, MI. Model3: sex, age, smoking, drinking, MI, BNP, eGFR, LVEF

Table 4 Predictive efficacy of VAI for cardiac death and readmission for heart failure

	AUC	95%CI	*P*
Cardiac death			
BMI	0.547	0.492–0.603	0.082
WC	0.534	0.479–0.588	0.210
TG	0.624	0.574–0.673	< 0.001
HDL-C	0.627	0.577–0.676	< 0.001
VAI	0.649	0.602–0.697	< 0.001
Readmission for heart failure			
BMI	0.583	0.544–0.623	< 0.001
WC	0.560	0.520–0.600	0.004
TG	0.631	0.592–0.670	< 0.001
HDL-C	0.633	0.595–0.673	< 0.001
VAI	0.693	0.656–0.729	< 0.001

BMI: body mass index, WC: waist circumference, TG: triglyceride, TC: total cholesterol, HDL-C: high-density lipoprotein cholesterol, VAI: visceral adiposity index

events in patients over 24 months. Regardless of whether the VAI index was used as a continuous or categorical variable, it was significantly associated with the risk of cardiac death and readmission for heart failure in patients after further adjustment for potential influencing factors. Compared with other risk factor indices, VAI had a better predictive value for the prediction of adverse end point events. In patients with HFrEF combined with metabolic syndrome, VAI was strongly associated with patient prognosis.

HFrEF is a growing global epidemic, and its incidence continues to rise worldwide as a complex cardiovascular disease. A multicenter study on heart failure in the UK found that patients with HFrEF accounted for 43.4% of all patients with heart failure [18]. A cross-sectional study from Turkey showed that patients with HFrEF accounted for 51.4% of all patients with HF [19]. Patients with HFrEF are also at high risk of readmission and death, and studies have shown that patients with HFrEF have the highest rates of emergency heart failure readmission (40.8%) and all-cause death (42.7%) in HF [20]. Among these, age, BMI, and diabetes are all influential factors for readmission within 1 year in patients with HFrEF [21]. It has been shown that the poor prognosis of HFrEF patients may be related to factors such as treatment adherence, disease progression, and multiple

Table 5 Association between VAI and cardiac death and readmission for heart failure in different subgroups

	Cardiac death HR (95%CI)	*P*	Readmission for heart failure HR (95%CI)	*P*
Sex				
Male	1.204 (1.146–1.265)	< 0.001	1.194(1.144–1.247)	< 0.001
Female	1.059(0.990–1.132)	0.095	1.122(1.079–1.166)	< 0.001
Age				
> 65	1.095(1.038–1.156)	0.001	1.147(1.107–1.188)	< 0.001
≤ 65	1.146(1.086–1.209)	< 0.001	1.154(1.105–1.205)	< 0.001
MI				
Yes	1.300 (1.155–1.462)	< 0.001	1.257 (1.140–1.386)	< 0.001
No	1.109 (1.063–1.156)	< 0.001	1.132 (1.099–1.165)	< 0.001
eGFR				
≥ 60	1.120 (1.069–1.172)	< 0.001	1.129 (1.092–1.167)	< 0.001
< 60	1.126 (1.060–1.197)	< 0.001	1.171 (1.119–1.225)	< 0.001

MI: myocardial infarction, eGFR: estimated glomerular filtration rate. Adjusted for sex, age, smoking, drinking, MI, BNP, eGFR, LVEF

comorbidities [20]. Patients with HFrEF often have multiple comorbidities, which increase the risk of readmission and death. Relevant studies have shown that atrial fibrillation, chronic kidney disease, diabetes mellitus, and obesity are the common comorbidities in patients with HFrEF [22]. Patients with HFrEF were at higher risk of hospitalization and death compared to other types of HF, resulting in greater healthcare costs and disease burden.

The potential reason for the continued prevalence of HFrEF is due to increasing susceptibility risk factors such as age, obesity and type 2 diabetes. One aspect of this is due to the significant increase in the large number of patients with heart failure who are obese, have type 2 diabetes, and are hypertensive, and the enrichment of these disease factors is positively related to the disease burden of heart failure [23]. Metabolic syndrome concerns a combination of diseases with multiple metabolic risks, and although the diagnostic criteria are not the same at different times and in different institutions, the core features of the disease are very clear. As a collection of serial metabolic dysfunctions, it significantly contributes to the development and progression of cardiovascular disease. Although MetS consists of different diseases, they share many common pathophysiological mechanisms, and insulin resistance (IR) is a central feature of this group of diseases, affecting tissues and organs throughout the body, and is also directly related to heart failure. Because of the presence of myocardial IR, it may have a significant impact on myocardial metabolic activity, resulting in cardiomyocyte damage and myocardial fibrosis [24, 25].

Among the characteristic manifestations of the metabolic syndrome, obesity is strongly associated with the heart failure phenotype, manifesting cardiac dilatation, remodeling, and dysfunction. Nearly half of heart failure patients are overweight or obese. Central output and pulmonary vascular resistance in congestive heart failure correlate with the degree of obesity in patients [26], and obese animal models also exhibit increased myocardial energy demand and cardiac loading, which exacerbate cardiac susceptibility to injury. Elevated blood pressure levels are one of the hallmarks of MetS, and there is an increased risk of increased blood pressure and promotion of hypertension in obese patients. Obesity and hypertension share common features, such as sympathetic overactivation and insulin resistance, which simultaneously increase the risk of metabolic disorders and cardiovascular events [27, 28]. Similar to other metabolic abnormalities, obesity causes increased lipid accumulation, fat deposition that affects myocardial contraction, myocardial toxicity due to high free fatty acids and proinflammatory factors that affect mitochondrial function, and elevated cardiotoxins such as ceramides [29, 30]. Obesity affects myocardial systolic and diastolic function in a number of ways, including metabolism, inflammation, and hormonal regulation, contributing to the development of heart failure. In addition, there is a close relationship between obesity and the different ejection fraction phenotypes in heart failure, where obesity causes an increase in myocardial energy demand as well as a deficit in myocardial energy reserve [31]. Weight, BMI, waist circumference, hip circumference, or lipid indices are commonly used to assess the severity of obesity, but the role of different fat types and their metabolic effects are completely different [32]. Currently, most of the indicators for assessing obesity can only be roughly assessed or can only reflect the overall situation, but cannot reflect the metabolic characteristics. Visceral obesity may be a more relevant indicator of disease because abdominal obesity significantly increases metabolic risk and the risk of left ventricular systolic dysfunction compared with general obesity [33].

Adipose tissue balances metabolic homeostasis and meets energy needs through anabolic and secretory functions, but the metabolic functions of visceral and subcutaneous fat may be different, and an increased proportion of visceral fat increases the likelihood of insulin resistance and the risk of cardiovascular disease even in normal individuals. By identifying those at risk early, it can help develop plans to modify risk factors and help delay the onset and progression of MetS in later life. Visceral obesity as a specific metabolic risk factor increases the risk of disease in cardiovascular individuals and should

be further evaluated. Previous studies have also confirmed that increased visceral adiposity is associated with disease toxicity, but studies often use CT to assess adipose tissue. CT cannot be routinely used to assess visceral fat in the general patient population. Considering the additional financial cost and convenience of CT examination, it may not be applicable to the assessment of obesity in the general patient population. Given that previous indices could not readily differentiate between visceral and subcutaneous fat and could only generalize the degree of abdominal obesity, and that these indices may interact with each other to influence the assessment of results, the VAI score was used to assess the severity of visceral obesity.

VAI is a tool for assessing visceral adiposity that takes into account not only body measurements but also laboratory tests, and is calculated differently for different genders. In these respects, the VAI is superior to single measures and provides a more comprehensive assessment of metabolic risk in a population, whereas BMI alone does not reflect the distribution of fat based on height and weight and is limited in its use in different populations [34]. Measurement of WC in the actual clinical setting is influenced by many factors such as body size and measurement method, as well as different distributions among different genders and races, which may be highly heterogeneous. Fluctuations in TG levels have been associated with the risk of cardiovascular disease [35], but TG needs to be measured periodically and is susceptible to many influences such as diet and medications in the short term. Reduced HDL-C levels are thought to be associated with an increased risk of cardiovascular disease, but HDL-C continues to be the subject of much controversy in its clinical application, with some studies suggesting that increased HDL-C levels do not reduce the risk of cardiovascular events [36]. Therefore, although these indicators are associated with cardiovascular disease risk, a single indicator provides limited value. VAI integrates the metabolic risk of the patient and has a high sensitivity and specificity [37].

The VAI is considered to be a novel marker of cardiovascular metabolic risk. Studies have shown that VAI is closely associated with various components in the MetS and can be utilized to reflect insulin resistance and metabolic disorders [38–40], especially in diabetic patients, where VAI has been found to be closely associated with cardiovascular disease risk [41]. In our study, even after adjusting for other confounders, the HR for adverse endpoint events increased with increasing levels of VAI. We found that for different types of adverse endpoint events, VAI had the greatest discriminatory power. As a composite index, VAI predicted efficacy over WC, BMI, TG, and HDL-C. Metabolic profiles are also dependent on sex and age, and sex-age interactions play an important role in metabolic diseases, with significant changes in fat distribution and metabolic levels with age, as well as significant differences in fat distribution patterns and dietary habits between men and women [42]. Meanwhile, men are more likely than women to abuse alcohol in their daily lives. Excessive alcohol consumption significantly increases the risk of MetS [43]. Our findings indicate that in patients with MetS and HFrEF, VAI independently correlates with the risk of cardiac death and heart failure readmission in males, and with the risk of heart failure readmission in females. In contrast, in patients of all ages, the VAI index was independently associated with the risk of adverse end point events. Considering the correlation between VAI and disease prognosis and the relative simplicity of its calculation, VAI can be applied in clinical practice as a reliable tool for prognostic risk assessment in patients with MetS and HFrEF.

Our study also has some limitations. As a retrospective cohort study, our consideration of patients' other comorbidities was limited, and there may have been some potential confounders that were not excluded. We performed the calculation of VAI only from the baseline measurements, and during the follow-up period, the patients' dietary profile and therapeutic medications may cause changes in the measurements, which may affect the calculation of the VAI index. It is unclear whether changes in VAI during follow-up affect the prediction of cardiovascular outcomes. The causal relationship between VAI and future adverse endpoint events in MS patients with comorbid HFrEF needs to be further elucidated in a multicenter prospective study.

Conclusion

VAI can be considered as a risk factor for assessing cardiometabolic risk as an indicator of visceral obesity. Our study determined that VAI levels independently correlate with the risk of adverse cardiovascular events, including cardiac death and heart failure readmission, in patients with MetS and HFrEF. VAI was more effective in predicting prognosis in patients with MetS and HFrEF than traditional anthropometric parameters or laboratory indicators. In HF patients with metabolic disorders, VAI serves as an indicator of metabolic risk and can be used for risk stratification and prognostic assessment of patients.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12872-025-04591-1 .

Supplementary Material 1

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Author contributions
M-Y W and D-M G contributed to the conception and design, acquisition and drafting of the manuscript or critical revision for important intellectual content. W-L L and XH contributed to interpretation of the data and analysis. Q-R W and Y-S-Z Z contributed to the conception and design and reviewing of the manuscript or critical revision for important intellectual content. All authors approved the final version, and agree to be accountable for all aspects of the work.

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Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was an observational study, and the results of the study did not involve the personal characteristics of the patients and did not pose any risk to the patients, so the informed consent of the patients was waived. Clinical trial number: not applicable. This study followed the Declaration of Helsinki. Approved by the Ethics Committee of Hangzhou Hospital of Zhejiang Medical and Health Group (Ls20240005).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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