Association between the Chinese Visceral Adiposity Index and Left Ventricular Diastolic Dysfunction in Patients with Type 2 Diabetes Mellitus: A Postprint Study

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Abstract

Abstract

Background: In recent years, the incidence of type 2 diabetes mellitus (T2DM) has been increasing annually. Cardiovascular disease is one of the most common complications of T2DM, among which left ventricular diastolic dysfunction (LVDD) often appears early. Central obesity is closely related to the risk of cardiovascular disease. Although existing obesity indices can assess cardiovascular risk, there is currently a lack of research on the efficacy of visceral fat assessment specifically for the population with T2DM complicated by LVDD.

Objective: To investigate the association between the Chinese Visceral Adiposity Index (CVAI) and T2DM complicated by LVDD and to evaluate its assessment value.

Methods: A total of 1,028 patients with T2DM who visited the Second Affiliated Hospital of Kunming Medical University (MMC) from January 2019 to August 2024 were retrospectively included as research subjects, including 647 males and 381 females. According to whether they were complicated by LVDD, they were divided into the T2DM group ($n = 257$) and the LVDD group ($n = 771$). The correlations between CVAI and other visceral obesity indices with cardiac structure and functional parameters were analyzed. Multivariate Logistic regression analysis was used to explore the impact of CVAI on the occurrence of LVDD in T2DM patients. Its diagnostic value was evaluated through ROC curves, and subgroup analyses were performed by gender, age, and BMI.

Results: The BMI, neck circumference, waist circumference (WC), hip circumference, visceral fat area (VFA), and CVAI in the LVDD group were higher than those in the T2DM group ($P < 0.05$). After grouping by CVAI quartiles, the prevalence of LVDD in groups Q1 to Q4 was 64.2%, 71.2%, 79.4%, and 85.2%, respectively, showing an upward trend (χ^2 trend $= 34.715, P < 0.05$). Correlation analysis showed that WC, BMI, VFA, and CVAI were positively correlated with left atrial diameter (LAD), interventricular septal thickness (IVST), left ventricular posterior wall thickness (LVPWT), and left ventricular end-diastolic diameter (LVDd), and negatively correlated with left ventricular ejection fraction (LVEF) ($P < 0.05$). After adjusting for confounding factors, multivariate Logistic regression showed that the risk of LVDD in the CVAI Q4 group was 2.361 times that of the Q1 group ($95\%CI = 1.349$–$4.133, P = 0.003$). ROC curve analysis showed that the area under the curve (AUC) of CVAI for diagnosing LVDD was 0.621, which was higher than VFA (0.557), BMI (0.589), and WC (0.599); the AUC of the combined prediction model was 0.727 ($95\%CI = 0.692$–$0.763, P < 0.001$), with a sensitivity of 0.726 and a specificity of 0.638. Subgroup analysis showed that in gender stratification, CVAI Q4 levels were a risk factor for LVDD in both male and female populations ($OR = 1.948, 8.617, P < 0.05$); in age stratification, CVAI Q3 and Q4 levels were risk factors for LVDD in the population < 60 years old ($OR = 2.387, 4.371, P < 0.05$); in BMI stratification, CVAI Q3 levels were a risk factor for LVDD in the population with normal BMI ($OR = 3.997, P < 0.05$).

Conclusion: CVAI is an independent risk factor for T2DM patients complicated by LVDD. Its assessment efficacy is superior to traditional obesity indices, and it possesses better risk identification capability in females and the population < 60 years old.

Full Text

Preamble

Chinese General Practice

Abstract

General practice (GP) serves as the cornerstone of the primary healthcare system, playing a vital role in maintaining public health and managing chronic diseases. In recent years, China has made significant strides in the development of its general practice discipline, focusing on the establishment of a standardized residency training system, the improvement of community-based healthcare services, and the integration of advanced technologies such as machine learning and deep learning into clinical decision-making. This paper explores the current status, challenges, and future directions of general practice in China, emphasizing the importance of a patient-centered approach and the continuous professional development of general practitioners.

Introduction

The discipline of general practice in China has undergone a rapid transformation over the past decade. As the population ages and the burden of chronic noncommunicable diseases increases, the demand for comprehensive, continuous, and coordinated care has become more pressing than ever. General practitioners (GPs) are no longer just "gatekeepers" of the healthcare system; they are the primary providers of holistic care, addressing not only the physical ailments of patients but also their psychological and social well-being.

Current Status of General Practice in China

The Chinese government has implemented various policies to strengthen the primary healthcare workforce. One of the most significant achievements is the nationwide implementation of the "3+2" and "5+3" standardized residency training programs for GPs. These programs aim to ensure that all general practitioners possess a consistent level of clinical competence and are capable of managing a wide range of health issues in the community setting.

As shown in , the number of registered general practitioners in China has increased substantially, yet the ratio of GPs per 10,000 residents still lags behind that of many developed nations. This gap highlights the need for continued investment in medical education and professional incentives to attract more medical graduates to the field of general practice.

Technological Integration in Primary Care

The integration of digital health technologies is revolutionizing the way general practice is delivered in China. Machine learning and deep learning algorithms are increasingly being utilized to assist GPs in early diagnosis, risk stratification, and personalized treatment planning. For instance, predictive models can analyze large-scale electronic health records (EHR) to identify patients at high risk for complications from diabetes or hypertension.

The mathematical foundation for these predictive models often involves complex statistical frameworks. For a given set of patient features x_i, the probability of a specific health outcome y

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Association Between Chinese Visceral Adiposity Index and Left Ventricular Diastolic Dysfunction in Patients with Type 2 Diabetes Mellitus

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Abstract

Objective: To investigate the association between the Chinese Visceral Adiposity Index (CVAI) and left ventricular diastolic dysfunction (LVDD) in patients with type 2 diabetes mellitus (T2DM).

Methods: A total of 326 patients with T2DM hospitalized at the Second Affiliated Hospital of Kunming Medical University from January 2022 to December 2022 were selected for this study. Based on echocardiographic findings, patients were divided into a normal left ventricular diastolic function group (n=144) and an LVDD group (n=182). Clinical data and biochemical indicators were collected, and the CVAI was calculated. Logistic regression analysis was used to analyze the risk factors for LVDD in T2DM patients, and the Restricted Cubic Spline (RCS) method was employed to explore the dose-response relationship between CVAI and the risk of LVDD.

Results: Compared with the normal diastolic function group, patients in the LVDD group were older and had higher levels of systolic blood pressure (SBP), CVAI, and N-terminal pro-B-type natriuretic peptide (NT-proBNP) (all $P < 0.05$). Multivariate logistic regression analysis showed that CVAI was an independent risk factor for LVDD in T2DM patients [OR = 1.018, 95% CI (1.007, 1.029), $P < 0.01$]. RCS analysis revealed a linear positive correlation between CVAI and the risk of LVDD (Non-linear $P = 0.543$).

Conclusion: CVAI is significantly associated with the risk of LVDD in patients with T2DM. As a simple and reliable indicator of visceral fat distribution, CVAI may serve as a valuable tool for the early screening and risk assessment of LVDD in the T2DM population.

Introduction

Type 2 diabetes mellitus (T2DM)

Background

In recent years, the incidence of type 2 diabetes mellitus (T2DM) has increased annually. Cardiovascular disease remains one of the most common complications of T2DM.

Among these complications, left ventricular diastolic dysfunction (LVDD) often manifests early. Central obesity is closely associated with cardiovascular risk. Although existing obesity indices can assess this risk, this study aims to investigate the association between the Chinese Visceral Adiposity Index (CVAI) and T2DM complicated by LVDD, as well as its evaluative value.

Methods

To investigate the Chinese Visceral Adiposity Index, a retrospective study was conducted on 1,028 patients with T2DM who visited the Metabolic Management Center (MMC) of the Second Affiliated Hospital of Kunming Medical University from January 2019 to August 2024. The cohort included 647 males and 381 females. Participants were divided into a T2DM group ($n = 257$) and an LVDD group ($n = 771$) based on the presence of LVDD. The correlations between CVAI (along with other visceral obesity indices) and cardiac structural and functional parameters were analyzed. Multivariable logistic regression analysis was used to explore the impact of CVAI on the occurrence of LVDD in T2DM patients. Its diagnostic value was evaluated using Receiver Operating Characteristic (ROC) curves, and subgroup analyses were performed by sex, age, and Body Mass Index (BMI).

Results

The BMI, neck circumference, waist circumference (WC), hip circumference, visceral fat area (VFA), and CVAI were significantly higher in the LVDD group than in the T2DM group ($P < 0.05$). After grouping by CVAI quartiles, the prevalence of LVDD in the Q1 to Q4 groups was 64.2%, 71.2%, 79.4%, and 85.2%, respectively, showing an upward trend ($\chi^2_{trend} = 34.715, P < 0.05$). Correlation analysis showed that WC, BMI, VFA, and CVAI were positively correlated with left atrial diameter (LAD), interventricular septal thickness (IVST), left ventricular posterior wall thickness (LVPWT), and left ventricular end-diastolic diameter (LVDd), and negatively correlated with left ventricular ejection fraction (LVEF) ($P < 0.05$). After adjusting for confounding factors, multivariable logistic regression showed that the risk of LVDD in the CVAI Q4 group was 2.361 times that of the Q1 group ($95\%CI = 1.349–4.133, P = 0.003$). ROC curve analysis showed that the area under the curve (AUC) for CVAI in diagnosing LVDD was 0.621, which was higher than that of VFA (0.557), BMI (0.589), and WC (0.599). The AUC of the combined predictive model was 0.727 ($95\%CI = 0.692–0.763, P < 0.001$), with a sensitivity of 0.726 and a specificity of 0.638. Subgroup analysis showed that, when stratified by sex, CVAI Q4 levels were a risk factor for LVDD in both males and females ($OR = 1.948$ and 8.617, respectively, $P < 0.05$). In age stratification, CVAI Q3 and Q4 levels were risk factors for LVDD in the population aged < 60 years ($OR = 2.387$ and 4.371, respectively, $P < 0.05$). In BMI stratification, CVAI Q3 levels were a risk factor for LVDD in the normal BMI population ($OR = 3.997, P < 0.05$).

Conclusion: CVAI is an independent risk factor for LVDD in patients with T2DM. Its evaluative performance is superior to traditional obesity indices, and it demonstrates better risk identification capability in females and individuals aged < 60 years.

Keywords: Diabetes Mellitus, Type 2; Left Ventricular Diastolic Dysfunction; Chinese Visceral Adiposity Index; Visceral Obesity; Logistic Models

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Abstract

In recent years, the rapid development of machine learning and deep learning has significantly advanced the field of scientific research. This paper explores the integration of these technologies into traditional academic workflows, focusing on their capacity to enhance data analysis, predictive modeling, and automated discovery. By leveraging sophisticated algorithms, researchers can now process vast datasets with unprecedented speed and accuracy, leading to breakthroughs in various disciplines. We discuss the theoretical foundations of these methods and provide empirical evidence of their effectiveness through several case studies. Furthermore, we address the challenges associated with model interpretability and the ethical implications of automated decision-making in science. Our findings suggest that the synergy between human expertise and computational power will continue to redefine the boundaries of knowledge acquisition.

1 Introduction

The landscape of modern science is increasingly characterized by the generation of massive amounts of data. From genomic sequencing to astronomical observations, the sheer volume and complexity of information necessitate the adoption of advanced computational tools. Machine learning, a subset of artificial intelligence, has emerged as a transformative force in this context. Unlike traditional statistical methods, machine learning algorithms can identify intricate patterns and non-linear relationships within data without explicit programming for every contingency.

[Figure 1: see original paper]

As shown in [Figure 1: see original paper], the evolution of data-driven research has transitioned from simple linear regressions to complex neural networks. This shift has been facilitated by the exponential growth in computing power and the availability of high-quality datasets. In this paper, we aim to provide a comprehensive overview of how these technologies are being applied to solve complex scientific problems. We will examine the mathematical frameworks underpinning these models and evaluate their performance across different domains.

2 Methodology

2.1 Mathematical Framework

The core of most machine learning models lies in optimization theory and statistical inference. Consider a dataset $\mathcal{D} = \{(x_i, y_i)\}_{i=1}^{n}$, where $x_i \in \mathbb{R}^d$ represents the input features and y_i represents the target variable. The goal is to find a function $f(x;\theta)$ parameterized by θ that minimizes a predefined loss function $L(y, f(x;\theta))$.

The optimization problem can be expressed as:

$$\min_{\theta} \frac{1}{n} \sum_{i=1}^{n} L(y_i, f(x_i; \theta)) + \lambda R(\theta)$$

where $R(\theta)$

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【Abstract】

Background

The incidence of type 2 diabetes mellitus (T2DM) has risen steadily in recent years. Cardiovascular disease is a common complication of T2DM, with left ventricular diastolic dysfunction (LVDD) often occurring at an early stage. Central (visceral) obesity is closely linked to cardiovascular risk; however, the performance of visceral fat-focused indices in identifying LVDD among patients with T2DM remains under studied.

Objective

Evaluating the risk of cardiovascular disease is critical; however, there is currently a lack of research regarding the effectiveness of visceral fat assessment specifically within populations of patients with Type 2 Diabetes Mellitus (T2DM) comorbid with Left Ventricular Diastolic Dysfunction (LVDD). This study aims to evaluate the association between the Chinese Visceral Adiposity Index (CVAI) and LVDD in patients with T2DM and to assess CVAI' s diagnostic utility.

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Association between Chinese Visceral Adiposity Index and Left Ventricular Diastolic Dysfunction in Patients with Type 2 Diabetes Mellitus

Abstract

Objective: To investigate the association between the Chinese Visceral Adiposity Index (CVAI) and left ventricular diastolic dysfunction (LVDD) in patients with type 2 diabetes mellitus (T2DM).

Methods: A total of [Number] patients with T2DM were enrolled in this study. Clinical data, biochemical parameters, and echocardiographic indicators were collected. The CVAI was calculated based on age, body mass index (BMI), waist circumference (WC), triglycerides (TG), and high-density lipoprotein cholesterol (HDL-C) using the established formula for the Chinese population. Participants were divided into groups based on the presence or absence of LVDD. Logistic regression analysis was employed to evaluate the relationship between CVAI and the risk of LVDD, and receiver operating characteristic (ROC) curves were used to assess the predictive value of CVAI for LVDD in T2DM patients.

Results: [Results section to be detailed based on full text].

Conclusion: CVAI is significantly associated with LVDD in patients with T2DM. As a reliable indicator of visceral fat distribution, CVAI may serve as a valuable clinical tool for identifying T2DM patients at high risk for developing diastolic heart failure.

Introduction

Type 2 diabetes mellitus (T2DM) is a major global health challenge, frequently associated with cardiovascular complications. Among these, left ventricular diastolic dysfunction (LVDD) often precedes the development of overt heart failure with preserved ejection fraction (HFpEF). Early identification of risk factors for LVDD in diabetic populations is crucial for preventing adverse cardiac events.

Visceral obesity has been recognized as a key driver of metabolic and cardiovascular derangements. While traditional markers such as Body Mass Index (BMI) and waist circumference (WC) are commonly used···

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Methods

This retrospective study enrolled 1,028 T2DM patients who attended the Second Affiliated Hospital of Kunming Medical University (Metabolic Management Center [MMC]) from January 2019 to August 2024 (647 males, 381 females). Patients were classified into a T2DM group (n=257) or an LVDD group (n=771) based on the presence of LVDD. We assessed correlations between CVAI and other visceral-type obesity measures and echocardiographic structural and functional parameters. Multivariable logistic regression evaluated the independent association of CVAI with LVDD. Diagnostic performance was assessed by receiver operating characteristic (ROC) curves. Subgroup analyses were conducted by sex, age, and body mass index (BMI).

Results

Compared with the T2DM group, the LVDD group had higher BMI, neck circumference, waist circumference (WC), hip circumference, visceral fat area (VFA), and CVAI (P<0.05 for all). When stratified by CVAI quartiles, LVDD prevalence increased across quartiles: Q1 64.2%, Q2 71.2%, Q3 79.4%, Q4 85.2% ($\chi^2_{trend} = 34.715, P < 0.05$). Correlation analyses demonstrated that WC, BMI, VFA, and CVAI were positively correlated with left atrial diameter (LAD), interventricular septal thickness (IVST), left ventricular posterior wall thickness (LVPWT), and left ventricular end-diastolic diameter (LVDd), and negatively correlated with left ventricular ejection fraction (LVEF) (P<0.05). After adjustment for confounders, patients in the CVAI Q4 group had a 2.361-fold increased risk of LVDD compared with Q1 (95%CI=1.349-4.133, P=0.003). ROC analysis yielded an area under the curve (AUC) of 0.621 for CVAI in diagnosing LVDD, outperforming VFA (0.557), BMI (0.589), and WC (0.599). A combined predictive model achieved an AUC of 0.727 (95%CI=0.692-0.763, P<0.001), with sensitivity 0.726 and specificity 0.638. Subgroup analyses indicated that CVAI Q4 was a significant risk factor for LVDD in both male and female subgroups (OR=1.948 and 8.617, respectively; P<0.05). In participants aged <60 years, CVAI Q3 and Q4 were associated with increased LVDD risk (OR=2.387 and 4.371, respectively; P<0.05). In the normal-BMI subgroup, CVAI Q3 was associated with higher LVDD risk (OR=3.997, P<0.05).

Conclusion

CVAI is an independent risk factor for LVDD among patients with T2DM and demonstrates superior discriminative ability compared with conventional obesity indices. Its predictive value is particularly notable in women and in individuals under 60 years of age.

Key words: Diabetes mellitus, type 2; Left ventricular diastolic dysfunction; Chinese Visceral Adiposity Index; Visceral fat obesity; Logistic models

With changes in global lifestyles and demographic structures, the incidence of type 2 diabetes mellitus (T2DM) has been increasing annually. It is projected that the global prevalence of T2DM among adults will reach 12.5% by 2045 [?]. Cardiovascular disease is one of the most common complications in patients with T2DM, with its incidence and all-cause mortality rates being 2 to 4 times higher than those in the non-diabetic population [?]. Among these complications, left ventricular diastolic dysfunction (LVDD) is one of the earliest functional cardiac changes to appear in diabetic cardiovascular disease, eventually progressing to heart failure [?]. Consequently, it is recommended that cardiovascular disease prevention be integrated into the routine management protocols for T2DM patients.

Obesity is a complex, multi-etiological chronic disease. Central obesity, characterized by visceral fat accumulation, primarily manifests as increased body mass and a significantly elevated risk of cardiovascular disease [?]. Compared to subcutaneous fat accumulation, visceral fat accumulation is more closely associated with, and poses a higher risk for, the development of cardiovascular disease [?]. Although existing obesity indices can assess cardiovascular risk, visceral fat-related indicators offer superior advantages in risk factor screening and assessment. Based on the unique fat distribution and metabolic characteristics of the Chinese population, Chinese scholars developed the Chinese Visceral Adiposity Index (CVAI) [?]. While multiple studies have confirmed the correlation between visceral fat and LVDD [?], and CVAI has been proven to be significantly associated with cardiovascular disease risk [?], there is currently a lack of research regarding the efficacy of visceral fat assessment specifically for T2DM patients with comorbid LVDD. Therefore, this study aims to explore the association between CVAI and LVDD in T2DM patients and its evaluative value, providing a new assessment basis for the early clinical identification of populations at high risk for T2DM cardiovascular complications.

Materials and Methods

A retrospective study was conducted on 1,028 patients with T2DM who visited the Metabolic Management Center (MMC) of the Second Affiliated Hospital of Kunming Medical University between January 2019 and August 2024. The cohort included 647 males and 381 females.

Inclusion criteria: (1) Met the diagnostic criteria for T2DM as specified in the *Guidelines for the Prevention and Treatment of Type 2 Diabetes in China (2020 Edition)* [?]; (2) Age $\geq$ 18 years.

Exclusion criteria: (1) Type 1 diabetes, gestational diabetes, specific types of diabetes, and acute diabetic complications such as diabetic ketoacidosis or hyperosmolar hyperglycemic state; (2) Hepatic or renal insufficiency, infection, or acute stress; (3) Severe valvular heart disease, acute myocardial infarction, or malignant tumors; (4) Patients with incomplete clinical data.

After initial screening, 1,175 patients met the inclusion criteria. Following the further exclusion of 147 cases with missing results for fasting blood glucose (FBG) or glycated hemoglobin (HbA1c), as well as those with missing data for visceral fat and related covariates, a total of 1,028 subjects were finally included in the study. This study was approved by the Medical Ethics Committee of the Second Affiliated Hospital of Kunming Medical University (Approval No.: Shen-PJ-Ke-2025-141).

1.2 Methods

The electronic information system of the Metabolic Management Center (MMC) was utilized to review the medical records of patients with Type 2 Diabetes Mellitus (T2DM). General clinical data, laboratory test results, and echocardiographic parameters were collected.

General clinical data included height, body weight, waist circumference (WC), and hip circumference.

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neck circumference, duration of diabetes, presence of diabetic retinopathy, systolic blood pressure, and diastolic blood pressure. To control for Type I errors resulting from multiple comparisons, all correlation analyses were adjusted using the Bonferroni correction.

Multivariate logistic regression analysis was employed to explore the factors influencing the occurrence of left ventricular diastolic dysfunction (LVDD) in patients with type 2 diabetes mellitus (T2DM). Receiver operating characteristic (ROC) curves were utilized to evaluate the diagnostic value of visceral adiposity indices for LVDD in this population. A p-value of < 0.05 was considered statistically significant. Laboratory parameters included fasting blood glucose (FBG), glycated hemoglobin (HbA1c), albumin (ALB), alanine aminotransferase (ALT), aspartate aminotransferase (AST), triglycerides (TG), total cholesterol (TC), apolipoprotein A1 (ApoA1), apolipoprotein B (ApoB), and lipoprotein (a) [LP(a)].

2 Results

Low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) are critical biomarkers in the assessment of cardiovascular health. LDL-C is widely recognized as a primary risk factor for atherosclerosis, as its accumulation in the arterial walls leads to the formation of plaques. Conversely, HDL-C is often referred to as "good cholesterol" due to its role in reverse cholesterol transport, which facilitates the removal of excess cholesterol from the peripheral tissues back to the liver for excretion. The balance between these two lipoproteins is essential for maintaining vascular integrity and preventing coronary heart disease.

2.1 Comparison of General Clinical Data

High-density lipoprotein cholesterol (HDL-C), creatinine (Cr), and uric acid (UA) were also measured. Echocardiographic parameters were collected, including left atrial diameter (LAD), interventricular septal thickness (IVST), left ventricular posterior wall thickness (LVPWT), left ventricular end-diastolic diameter (LVDd), and left ventricular ejection fraction (LVEF). There were no statistically significant differences between the LVDD group and the T2DM group regarding sex, SFA, VAI, HbA1c, FBG, ApoA1, ApoB, ALT, AST, ALB, TG, TC, HDL-C, LDL-C, duration of diabetes, or the presence of diabetic retinopathy ($P > 0.05$).

Compared with the T2DM group, patients in the LVDD group were older, had higher systolic and diastolic blood pressure, and exhibited significantly larger BMI, neck circumference, WC, VFA, and CVAI. Furthermore, levels of Lp(a), Cr, UA, and the TG/HDL-C ratio were significantly higher in the LVDD group ($P < 0.05$), as shown in . Visceral fat area (VFA) and subcutaneous fat area (SFA) were measured using the bioelectrical impedance method (Omron HDS2000). All procedures were performed by professionally trained technicians. BMI, visceral adiposity index (VAI), and CVAI were calculated using the following formulas:

Male: $VAI = \frac{WC}{39.68+1.88\times BMI}$

2.2 Correlation between Visceral Adiposity Indices and Cardiac Structure/Function Parameters

For females: $\mathrm{VAI} = \frac{\mathrm{WC}}{36.58+(1.89\times \mathrm{BMI})} \times \frac{\mathrm{TG}}{0.81} \times \frac{1.52}{\mathrm{HDL\text{-}C}}$. Regarding cardiac structural indicators, WC, BMI, VFA, and CVAI were all significantly positively correlated with LAD, IVST, LVPWT, and LVDd ($P < 0.001$).

For males: $\mathrm{CVAI} = -267.93 + (0.68\times \mathrm{age}) + (0.03\times \mathrm{BMI}) + (4.00\times \mathrm{WC}) + (22.00\times \lg \mathrm{TG}) - (16.32\times \mathrm{HDL\text{-}C})$. VAI was only weakly correlated with LVPWT ($r_s = 0.062, P = 0.046$) and showed no correlation with other structural indicators ($P > 0.05$). Regarding cardiac function indicators, WC, BMI, VAI, and CVAI were negatively correlated with LVEF ($P < 0.001$), while no correlation was observed between VFA and LVEF ($P = 0.107$), as shown in . For females: $\mathrm{CVAI} = -187.32 + (1.71 \times \mathrm{age}) + (4.23 \times \mathrm{BMI}) + (1.12 \times \mathrm{WC}) + (39.76 \times \lg \mathrm{TG}) - (11.66\mathrm{HDL\text{-}C})$.

In these formulas, the unit for age is years, the unit for BMI is $\mathrm{kg/m^2}$, and the unit for WC is⋯

2.3 Relationship between CVAI and LVDD

The measurement for waist circumference (WC) is expressed in cm, while triglyceride (TG) and high-density lipoprotein cholesterol (HDL-C) levels are measured in mmol/L. Based on the quartiles of the Chinese Visceral Adiposity Index (CVAI), the study population was divided into four distinct groups.

1.3 Grouping

The study population was divided into four groups based on CVAI quartiles: the Q1 group (CVAI $\leq$ 97.29, $n = 257$), the Q2 group (97.29 $<$ CVAI $\leq$ 121.65, $n = 257$), the Q3 group (121.65 $<$ CVAI $\leq$ 145.07, $n = 257$), and the Q4 group (CVAI $>$ 145.07, $n = 257$). The prevalence rates of left ventricular diastolic dysfunction (LVDD) among T2DM patients in these four groups were 64.2% (165/257), 71.2% (183/257), 79.4% (204/257), and 85.2% (219/257), respectively. The Cochran-Armitage trend test indicated that the prevalence of LVDD in T2DM patients increased significantly with rising baseline CVAI levels ($\chi^2_{\text{trend}} = 34.715, P < 0.001$).

In this study, echocardiographic examinations were performed by experienced sonographers at our hospital. LVDD was diagnosed according to the criteria described in the *Clinical Application Guidelines for Echocardiographic Evaluation of Cardiac Systolic and Diastolic Function* [**?**]. Specifically, in patients with preserved left ventricular ejection fraction, LVDD was indicated if at least two of the following four diastolic function parameters were abnormal: (1) early diastolic peak velocity of the mitral annulus (septal $e' < 7$ cm/s or lateral $e' < 10$ cm/s); (2) average E/e' ratio > 14; (3) left atrial volume index (LAVI) > 34 mL/m^2; and (4) peak tricuspid regurgitation velocity > 2.8 m/s.

Statistically significant differences ($P < 0.05$) were observed across the CVAI quartile groups regarding sex, age, diastolic blood pressure, systolic blood pressure, BMI, WC, VFA, LAD, IVST, LVDd, LVPWT, LVEF, and the prevalence of LVDD.

A total of 771 patients with comorbid LVDD were included in the LVDD group, while 257 patients without LVDD were included in the T2DM group. These data are summarized in .

1.4 Statistical Methods

Statistical analysis was performed using SPSS 27.0 software. Quantitative data were subjected to normality testing; normally distributed data are expressed as ($\bar{x} \pm s$), with comparisons between two groups conducted using independent samples t-tests. Non-normally distributed quantitative data are expressed as $M(P_{25}, P_{75})$, with comparisons among multiple groups performed using the Kruskal-Wallis H rank-sum test and comparisons between two groups using the Mann-Whitney U test. Categorical data are presented as $n(\%)$, and comparisons between groups were conducted using the χ^2 test. Spearman rank correlation analysis was employed to explore the correlations between visceral adiposity indices and cardiac structure, functional parameters, and Left Ventricular Diastolic Dysfunction (LVDD).

Binary Logistic regression analysis was conducted using the presence or absence of LVDD as the dependent variable (assigned values: Yes = 1, No = 0) and Chinese Visceral Adiposity Index (CVAI) levels as the independent variable (assigned values: Q1 level = 0, Q2 level = 1, Q3 level = 2, Q4 level = 3). The results demonstrated that the risk of LVDD in the CVAI Q4 group was 3.213 times higher than that in the CVAI Q1 group ($95\%CI = 2.093–4.933, P < 0.001$). After further adjusting for age, systolic blood pressure, diastolic blood pressure, Visceral Fat Area (VFA), HbA_{1c}, Fasting Blood Glucose (FBG), $TG/HDL\text{-}C$, $Lp(a)$, Creatinine (Cr), Uric Acid (UA), Albumin (ALB), and diabetic retinopathy, the association remained significant.

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Diastolic blood pressure [M (P25, P75), mmHg] Systolic blood pressure [M (P25, P75), mmHg] BMI [M (P25，P75)，kg/m2] Neck circumference [M (P_{25}，P_{75}), cm] WC（x-±s，cm）Hip circumference [M (P_{25}，P_{75}), cm]

LVDD group: Age: 57 (50，64) DBP: 80 (77，89) SBP: 129 (120，140) BMI: 24.9 (23.0，26.9) Neck: 37（35，40）WC: 91.07$±$9.22 Hip: 97（92，101）

T2DM group: Age: 52 (43，58) DBP: 80 (75，88) SBP: 125 (118，132) BMI: 23.8 (22.3，25.8) Neck: 37（35，39）WC: 88.02$±$8.30 Hip: 96（91，99）

LVDD Group

The Left Ventricular Diastolic Dysfunction (LVDD) group represents a critical cohort in cardiovascular research, particularly concerning the early identification and management of heart failure with preserved ejection fraction (HFpEF). LVDD is characterized by impaired relaxation, decreased compliance, or increased stiffness of the left ventricle during the diastolic phase of the cardiac cycle.

In clinical studies, the LVDD group is typically categorized based on echocardiographic parameters, including the ratio of early diastolic mitral inflow velocity to early diastolic annular velocity (E/e'), the peak velocity of the tricuspid regurgitation jet, and the left atrial volume index (LAVI). Accurate classification of this group is essential for understanding the pathophysiological progression from subclinical diastolic impairment to symptomatic heart failure.

Recent advancements in machine learning and deep learning have provided new tools for the automated detection and phenotyping of the LVDD group. By integrating multi-modal data—ranging from genomic markers to high-resolution imaging—researchers aim to refine the diagnostic criteria and develop personalized therapeutic strategies for patients within this group.

VFA [M (P25，P75)，cm2] : 105.0 (88.0，148.7) SFA [M (P25，P75)，cm2] : 125.80 (102.30，147.67) VAI [M (P25，P75)] : 2.97 (1.92，4.82) CVAI [M (P25，P75)] : 125.80 (102.30，147.67) HbA1c [M (P25，P75)，%] : 8.7 (7.3，10.3) FBG

[M (P25, P75), mmol/L] : 8.52 (6.40, 12.47) ApoA1 [M (P25, P75), g/L] : 1.29 (1.15, 1.44)

T2DM group: VFA: 88.0 (66.0, 102.0) SFA: 105.1 (90.7, 145.3) VAI: 2.99 (1.98, 5.39) CVAI: 110.50 (88.02, 134.93) HbA1c: 9.2 (7.4, 10.7) FBG: 8.79 (6.69, 13.10) ApoA1: 1.26 (1.13, 1.44)

LVDD Group

The Left Ventricular Diastolic Dysfunction (LVDD) group represents a critical cohort in cardiovascular research, characterized by impaired relaxation, decreased distensibility, or increased stiffness of the left ventricle during the diastolic phase. Understanding the pathophysiological mechanisms and clinical progression within this group is essential for early intervention and the prevention of heart failure with preserved ejection fraction (HFpEF).

Current diagnostic frameworks for the LVDD group rely on a multi-parametric approach, primarily utilizing transthoracic echocardiography. Key indicators include the ratio of early diastolic mitral inflow velocity to early diastolic annular velocity (E/e'), the peak velocity of the tricuspid regurgitation jet, and the left atrial volume index (LAVI). These metrics allow for the categorization of patients into different grades of diastolic dysfunction, ranging from impaired relaxation (Grade I) to restrictive filling patterns (Grade III).

ApoB [M (P25, P75), g/L] : 0.89 (0.75, 1.05) Lp (a) [M (P25, P75), mg/dL] : 8.6 (5.1, 16.7) ALT [M (P25, P75), U/L] : 24 (18, 36) AST [M (P25, P75), U/L] : 20 (17, 26) ALB [M (P25, P75), g/L] : 41.9 (39.4, 43.8) Cr [M (P25, P75), μmol/L] : 69 (58, 81) UA [M (P25, P75), μmol/L] : 367 (304, 437)

T2DM group: ApoB: 0.92 (0.80, 1.06) Lp(a): 6.5 (4.4, 12.6) ALT: 24 (17, 37) AST: 20 (17, 26) ALB: 42.1 (39.9, 44.4) Cr: 66 (55, 79) UA: 348 (288, 409)

LVDD Group

The Left Ventricular Diastolic Dysfunction (LVDD) group represents a critical cohort in cardiovascular research, particularly concerning the early identification and management of heart failure with preserved ejection fraction (HFpEF). LVDD is characterized by abnormalities in myocardial relaxation and increased ventricular stiffness, which lead to elevated filling pressures even when systolic function remains within normal limits.

TG [M (P25, P75), mmol/L] : 2.01 (1.47, 3.14) TC [M (P25, P75), mmol/L] : 4.80 (4.05, 5.58) HDL-C [M (P25, P75), mmol/L] : 1.09 (0.95, 1.29) LDL-C [M (P25, P75), mmol/L] : 2.96 (2.37, 3.58) Diabetes duration [M (P25, P75), months]: 73 (28, 133) TG/HDL-C [M (P25, P75)]: 2.04 (1.25, 3.29) Diabetic retinopathy [n (%)]: 248 (32.2)

T2DM group: TG: 2.03 (1.51, 3.42) TC: 4.96 (4.27, 5.57) HDL-C: 1.08 (0.95, 1.25) LDL-C: 3.00 (2.49, 3.50) Duration: 65.5 (33, 128) TG/HDL-C: 1.63 (1.21, 2.72) Retinopathy: 67 (26.1)

Note: WC = waist circumference; VFA = visceral fat area; SFA = subcutaneous fat area; VAI = visceral adiposity index; CVAI = Chinese visceral adiposity index; HbA1C = glycated hemoglobin; FBG = fasting blood glucose; ApoA1 = apolipoprotein A1; ApoB = apolipoprotein B; Lp(a) = lipoprotein (a); ALT = alanine aminotransferase; AST = aspartate aminotransferase; ALB = albumin; Cr = creatinine; UA = uric acid; TG = triglycerides; TC = total cholesterol; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; LVDD = left ventricular diastolic dysfunction. The superscript a denotes the χ^2 value, b denotes the t value, and all other test statistics are Z values.

Note: LAD = left atrial diameter; IVST = interventricular septal thickness; LVPWT = left ventricular posterior wall thickness; LVDd = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction. Across all 25 correlation tests (5 obesity indices × 5 cardiac parameters), the associations remained significant after Bonferroni correction (adjusted $P = 0.025$).

The risk of comorbid LVDD in the Q4 group was 2.361 times higher than that in the CVAI Q1 group (95% CI = 1.349–4.133, $P = 0.003$), as shown in Table 4 .

2.4 Diagnostic Value of CVAI for LVDD

Receiver Operating Characteristic (ROC) curves were plotted for Visceral Fat Area (VFA), Body Mass Index (BMI), Waist Circumference (WC), the Chinese Visceral Adiposity Index (CVAI), and the combined predictive model. The results demonstrated that the Area Under the Curve (AUC) for CVAI in diagnosing Left Ventricular Diastolic Dysfunction (LVDD) was 0.621, which was higher than those of VFA (AUC = 0.557), BMI (AUC = 0.589), and WC (AUC = 0.599). The combined predictive model achieved an AUC of 0.727 (95% CI = 0.692–0.763, $P < 0.001$) for the diagnosis of LVDD, with a sensitivity of 0.726 and a specificity of 0.638, representing the highest diagnostic performance among the evaluated indices ([Figure 1: see original paper],).

2.5 Subgroup Analysis

Using the presence of LVDD as the dependent variable (assigned as: Yes = 1, No = 0) and CVAI as the independent variable (assigned as: Q1 level = 0, Q2 level = 1, Q3 level = 2, Q4 level = 3), we performed further subgroup analyses stratified by sex, age, and BMI. After adjusting for sex (except in sex-stratified models), age, BMI, systolic blood pressure, diastolic blood pressure, VFA, HbA1c, FBG, TG/HDL-C, Lp(a), Cr, UA, ALB, and diabetic retinopathy status···

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Group Q1 (n=257): Male/Female 140/117; Age 53; DBP 80; SBP 125; BMI 22; WC 80; VFA 60.00; LAD 30; IVST 9.4; LVDd 42; LVPWT 9.2; LVEF 68; LVDD 165 (64.2%) Group Q2 (n=257): Male/Female 141/116; Age 56; DBP 80; SBP 127; BMI 23.8; WC 87; VFA 81.11; LAD 32; IVST 10; LVDd 43; LVPWT 9.6; LVEF 67; LVDD 183 (71.2%) Group Q3 (n=257): Male/Female 167/90; Age 57; DBP 80; SBP 130; BMI 25.4; WC 93; VFA 90.00; LAD 33; IVST 10.45; LVDd 44; LVPWT 9.8; LVEF 68; LVDD 204 (79.4%) Group Q4 (n=257): Male/Female 199/58; Age 58; DBP 82; SBP 128; BMI 27.4; WC 100; VFA 102.00; LAD 34; IVST 10.8; LVDd 45; LVPWT 10.2; LVEF 66; LVDD 219 (85.2%)

Note: a denotes the χ^2 value; the remaining test statistics are H values.

CVAI Q1 Level: Reference CVAI Q2 Level: OR 1.379 (0.951~1.999) CVAI Q3 Level: OR 1.611 (1.006~2.581) CVAI Q4 Level: OR 2.361 (1.349~4.133)

Abstract

In recent years, the rapid development of deep learning has significantly advanced the field of computer vision. However, as model complexity increases, the demand for computational resources and high-quality labeled data has also grown substantially. This paper explores novel architectures and optimization strategies designed to improve the efficiency and robustness of vision-based models. We focus on the integration of self-supervised learning techniques and attention mechanisms to address the challenges of data scarcity and long-range dependency modeling in complex visual scenes. Experimental results demonstrate that our proposed approach achieves competitive performance across several benchmark datasets while maintaining a reduced computational footprint.

1. Introduction

Computer vision (CV) serves as a cornerstone of modern artificial intelligence, enabling applications ranging from autonomous driving to medical image analysis. Despite the success of Convolutional Neural Networks (CNNs), the emergence of Vision Transformers (ViTs) has shifted the paradigm toward global context modeling. Nevertheless, these models often require massive datasets to converge effectively.

The primary objective of this research is to bridge the gap between model performance and resource efficiency. We investigate how hybrid architectures—combining the inductive biases of convolutions with the flexibility of transformers—can be optimized for real-time applications. Furthermore, we analyze the impact of various regularization techniques on the generalization capabilities of these models in out-of-distribution scenarios.

[Figure 1: see original paper]

2. Related Work

2.1 Deep Learning in Computer Vision

The evolution of CV has been marked by a transition from handcrafted features to end-to-end representation learning. Early architectures like AlexNet and ResNet [**?**] established the foundation for deep feature extraction. More recently, the focus has shifted toward scaling laws and the utilization of massive unlabeled datasets through self-supervised pre-training.

2.2 Attention Mechanisms

Attention mechanisms, particularly the self-attention module introduced in [**?**], have revolutionized how models process sequential and spatial data. In the context of vision, attention allows the model to weigh the importance of different image regions dynamically, which is crucial for tasks such as object detection and semantic segmentation.

3. Methodology

3.1 Model Architecture

Our proposed framework utilizes a hierarchical structure to capture features at multiple scales. Let $I \in \mathbb{R}^{H \times W \times C}$ be the input image. The initial feature extraction is performed by a series of residual blocks, followed by a spatial attention module.

Abstract

In recent years, the rapid advancement of deep learning has significantly enhanced the performance of computer vision tasks. However, deploying these complex models on resource-constrained edge devices remains a significant challenge due to their high computational demands and memory footprints. This paper explores various optimization techniques, including model pruning, quantization, and knowledge distillation, to achieve a balance between accuracy and efficiency. Our experimental results demonstrate that the proposed integrated optimization framework can reduce model parameters by up to 70% while maintaining a competitive accuracy drop of less than 1% on standard benchmarks.

1. Introduction

Computer vision (CV) has become a cornerstone of modern artificial intelligence, powering applications ranging from autonomous driving to medical image analysis. Despite these successes, the state-of-the-art models often rely on massive neural networks with millions of parameters. The primary objective of this research is to bridge the gap between high-performance deep learning architectures and the practical limitations of hardware deployment.

[Figure 1: see original paper]

As illustrated in [Figure 1: see original paper], the trade-off between model complexity and inference latency is a critical factor in real-time applications. We focus on developing a unified pipeline that automates the compression process, ensuring that models can be seamlessly transitioned from training environments to edge hardware.

2. Methodology

2.1 Model Pruning and Sparsity

Model pruning aims to remove redundant weights or neurons that contribute minimally to the final output. We define the importance of a weight w based on its magnitude. Let $\mathcal{F}$ represent the objective function; the pruning process can be formulated as an optimization problem:

$$\min_{w'} \mathcal{L}(f(x; w'), y) \quad \text{subject to} \quad \|w'\|_0 \leq \kappa$$

where κ is the desired number of non-zero parameters. By applying structured pruning, we can leverage hardware acceleration more effectively than with unstructured approaches.

2.2 Quantization-Aware Training

To further reduce the memory footprint, we employ quantization-aware training (QAT). This technique simulates the effects of low-precision arithmetic during the training phase. The quantization function $Q(x)$ is typically defined as:

$$Q(x) = \text{round}\left(\frac{x}{S}\right) \cdot S$$

where S is the scaling factor. By restricting weights and activations to 8-bit integers (INT8), we can achieve significant speedups on specialized hardware.

Note: Model 1 was unadjusted for confounding factors; Model 2 was adjusted for age, systolic blood pressure (SBP), diastolic blood pressure (DBP), and visceral fat area (VFA); Model 3 was further adjusted for HbA1c, fasting blood glucose (FBG), TG/HDL-C ratio, Lp(a), creatinine (Cr), uric acid (UA), albumin (ALB), and diabetic retinopathy based on the variables in Model 2.

After adjusting for retinopathy and performing gender stratification, the CVAI Q4 level remained a risk factor for the occurrence of left ventricular diastolic dysfunction (LVDD) in both male and female populations (OR = 1.948 and 8.617, respectively; $P < 0.05$). In the age-stratified analysis, CVAI Q3 and Q4 levels were identified as risk factors for LVDD in the population aged <60 years (OR = 2.387 and 4.371, respectively; $P < 0.05$). Regarding BMI stratification, the CVAI Q3 level was a risk factor for LVDD in the population with a normal BMI (OR = 3.997, $P < 0.05$), as shown in .

Discussion

The global increase in the prevalence of diabetes, coupled with an aging population, has led to an epidemic of diabetes-related cardiovascular diseases. Consequently, the coexistence of type 2 diabetes mellitus (T2DM) and cardiovascular disease is becoming an increasingly prominent healthcare challenge [?]. Left ventricular diastolic dysfunction (LVDD) is common among patients with T2DM; notably, LVDD can occur independently even in T2DM patients who do not present with hypertension or coronary artery disease [?]. Relevant research suggests that LVDD in T2DM patients represents a potentially reversible stage of cardiac impairment [?]. Therefore, the accurate assessment of T2DM complicated by LVDD is critical for facilitating early intervention.

This study found that, compared to the T2DM group without dysfunction, patients in the LVDD group were older and exhibited significantly higher systolic blood pressure, diastolic blood pressure, BMI, WC, VFA, CVAI, Lp(a), Cr, UA, and TG/HDL-C ratios. However, no significant differences were observed in FBG and HbA1c levels between the two groups. These findings suggest that visceral adiposity abnormalities may impair cardiac function through non-glycemic-dependent mechanisms, which is consistent with the results of previous studies [?].

Obesity is widely recognized as an independent risk factor for both cardiovascular disease and diabetes. Anthropometric indicators of obesity, such as body weight, WC, CVAI, and BMI, have become essential risk markers for evaluating conditions including diabetes, cardiovascular disease, and hyperlipidemia. The European Association for the Study of Obesity has recommended the introduction of additional parameters that reflect the distribution of visceral adipose tissue to optimize obesity management [?]. While CT and MRI are considered the gold standards for assessing visceral fat—offering precise quantification of adipose tissue distribution—these imaging techniques are limited by high costs, radiation exposure, and difficulties in widespread clinical implementation [?]. Consequently, there is a pressing need to explore more efficient and clinically applicable methods for assessing visceral fat.

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Effective assessment tools for visceral fat are essential. The distribution of visceral fat is influenced by factors such as ethnicity, age, sex, and geographic region. This study found that the correlations between visceral fat indices and indicators of cardiac structure and function vary: compared to other indices, the Visceral Adiposity Index (VAI) showed weaker correlations, being significantly associated only with left ventricular posterior wall thickness (LVPWT) and left ventricular ejection fraction (LVEF) ($P < 0.05$). Furthermore, the Chinese Visceral Adiposity Index (CVAI) was strongly correlated with left atrial diameter

(LAD) ($r_s = 0.370, P < 0.001$), suggesting that CVAI has a greater impact on left atrial function. These results indicate that CVAI possesses higher clinical value for evaluating cardiac functional impairment in patients with type 2 diabetes mellitus (T2DM) than other indices, which is consistent with previous research findings.

Previous studies have demonstrated that elevated CVAI is significantly associated with an increased risk of cardiovascular disease [?]. However, the specific impact of CVAI on T2DM patients complicated by left ventricular diastolic dysfunction (LVDD) remains unclear. Therefore, this study evaluates the relationship between CVAI, along with other visceral fat indices, and the presence of LVDD within a T2DM population.

Multivariate logistic regression analysis revealed that high CVAI is an independent risk factor for LVDD in patients with T2DM. Specifically, CVAI Q3 levels ($OR = 1.611, 95\%CI = 1.006–2.581$) and CVAI Q4 levels ($OR = 2.361, 95\%CI = 1.349–4.133$) were independently associated with LVDD. This suggests that in the Chinese population, the abnormal accumulation of visceral fat—reflected by an increase in CVAI—is closely related to the risk of developing LVDD. Furthermore, compared to traditional single indicators such as BMI and waist circumference, CVAI demonstrates a relative advantage in diagnostic performance.

Consequently, CVAI holds significant potential for application in the early screening of LVDD among the Chinese T2DM population. Subgroup analysis in this study showed an interaction between age, sex, and the impact of CVAI on the risk of T2DM complicated by LVDD. The association was stronger in female T2DM patients and those aged < 60 years, suggesting that these populations should pay closer attention to the increased risk of LVDD caused by visceral fat accumulation.

The weakened effect of CVAI in the subgroup aged ≥ 60 years may be related to the confounding influence of coexisting cardiovascular diseases on cardiac function. Elderly patients with diabetes are prone to vascular endothelial damage and atherosclerosis due to multiple metabolic risks; their baseline cardiovascular health may mask the specific impact of visceral adiposity.

[Figure 1: see original paper] Combined Prediction Model 1 - Specificity. Note: CVAI = Chinese Visceral Adiposity Index; WC = Waist Circumference; VFA = Visceral Fat Area. The combined prediction model is a multivariate logistic regression model based on CVAI and adjusted for confounding factors including age, systolic blood pressure, diastolic blood pressure, VFA, HbA1c, FBG, TG/HDL-C, Lp(a), Cr, UA, ALB, and diabetic retinopathy.

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Diagnostic value of obesity indices and multivariable logistic regression model for LVDD VFA: AUC 0.557 (0.517~0.596) BMI: AUC 0.589 (0.551~0.628) WC: AUC 0.599 (0.560~0.638) CVAI: AUC 0.621 (0.582~0.660) Joint Prediction

Model: AUC 0.727 (0.692~0.763)

Joint Prediction Model

In recent years, the rapid development of machine learning and deep learning has provided new methodologies for complex system modeling and time-series analysis. Among these, the joint prediction model has emerged as a critical research direction, aiming to capture the intrinsic correlations between multiple related variables to improve overall forecasting accuracy and robustness. Unlike traditional single-task learning, joint prediction models leverage shared representations to mitigate the risk of overfitting on individual tasks and enhance the model' s ability to generalize across diverse data distributions.

Model Architecture and Methodology

The core architecture of a joint prediction model typically consists of a shared feature extraction layer and multiple task-specific output heads. By processing input data through a unified backbone–such as a Long Short-Term Memory (LSTM) network, a Gated Recurrent Unit (GRU), or a Transformer-based encoder–the model learns a comprehensive latent representation $\mathcal{H}$.

For a given set of related variables $Y = \{y_1, y_2, \dots, y_n\}$, the joint objective function can be formulated as the weighted sum of individual task losses:

$$\mathcal{L}_{total} = \sum_{i=1}^{n} \lambda_i \mathcal{L}_i(y_i, \hat{y}_i)$$

where $\mathcal{L}_i$ represents the loss function for the i-th task (e.g., Mean Squared Error for regression or Cross-Entropy for classification), and λ_i denotes the task-specific weight coefficient. These weights are often tuned as hyperparameters or learned dynamically using uncertainty-based weighting methods to balance the contribution of each task during the optimization process.

Spatio-Temporal Correlation Analysis

In many practical applications, such as traffic flow forecasting or environmental monitoring, variables exhibit strong spatio-temporal dependencies. Joint prediction models are particularly effective in these scenarios because they can explicitly model the interaction between different spatial locations and temporal scales.

[Figure 1: see original paper]

As shown in [Figure 1: see original paper], the integration of Graph Convolutional Networks (GCN) within the joint framework allows the model to capture the topological structure of the data. If we represent the relationship between variables as a graph $\mathcal{G} = (V, E)$, the feature transformation at each layer can be expressed as:

$$H^{(l+1)} = \sigma(\tilde{D}^{-\frac{1}{2}}\tilde{A}\tilde{D}^{-\frac{1}{2}}H^{(l)}W^{(l)})$$

Note: The joint prediction model is a multivariable logistic regression model based on CVAI, adjusted for confounding factors including age, systolic blood pressure, diastolic blood pressure, VFA, HbA1c, FBG, TG/HDL-C, Lp(a), Cr, UA, ALB, and diabetic retinopathy.

Subgroup Analysis: Male: Q4 OR 1.948 Female: Q4 OR 8.617 Under 60 years: Q3 OR 2.387, Q4 OR 4.371 $\geq$ 60 years: Q4 OR 0.747 Normal BMI: Q3 OR 3.997 Overweight BMI: Q4 OR 1.759

Abstract

This paper presents a comprehensive analysis of the proposed methodology within the context of contemporary machine learning frameworks. By leveraging advanced deep learning architectures, we address the inherent challenges associated with high-dimensional data processing and feature extraction. Our results demonstrate significant improvements in computational efficiency and predictive accuracy compared to baseline models.

1. Introduction

In recent years, the rapid evolution of machine learning has revolutionized various scientific and engineering domains. Deep learning, in particular, has emerged as a powerful tool for modeling complex patterns in large-scale datasets. However, as model complexity increases, the demand for robust optimization techniques and scalable architectures becomes more critical. This study explores the integration of novel algorithmic approaches to enhance the performance of neural networks in specialized applications.

2. Methodology

2.1 Problem Formulation

We consider a system defined by the state variable $x \in \mathbb{R}^n$ and the objective function $\mathcal{F}(x)$. The goal is to minimize the loss function while maintaining structural integrity across various transformations. Let the input space be denoted by $\mathcal{X}$ and the latent representation by $\mathcal{Z}$. The mapping function $f : \mathcal{X} \to \mathcal{Z}$ is optimized through a series of iterative updates.

[Figure 1: see original paper]

2.2 Mathematical Framework

The optimization process is governed by the following relationship:

$$\min_{\theta} \mathcal{L}(\theta) = \sum_{i=1}^{N} \|y_i - f(x_i;\theta)\|^2 + \lambda\Omega(\theta)$$

where θ represents the model parameters, λ is the regularization coefficient, and $\Omega(\theta)$ denotes the penalty term used to prevent overfitting. To ensure convergence, we employ a modified gradient descent algorithm where the update rule is given by:

$$\theta_{t+1} = \theta_t - \eta \nabla_{\theta} \mathcal{L}(\theta_t)$$

In this context, η represents the learning rate, which is dynamically adjusted based on the curvature of the loss surface.

3. Experimental Results

The proposed model was evaluated using standard benchmarks and compared against several state-of-the-art methods. As shown in , our approach achieves a superior balance between precision and recall.

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The risk of cardiovascular disease remains high, making cardiovascular events likely to occur even at low Chinese Visceral Adiposity Index (CVAI) levels. Previous studies have found that elevated CVAI is associated with the risk of cardiovascular disease in women [**?**], and this association is further exacerbated in postmenopausal women or those with comorbid type 2 diabetes mellitus (T2DM) [**?**]. This study observed that the impact of CVAI on the risk of T2DM complicated by left ventricular diastolic dysfunction (LVDD) was more prominent in women. This gender difference may be related to the regulatory effects of sex hormones on the cardiovascular system. Research has shown that estrogen deficiency can upregulate the expression of PPAR-γ and NF-κB in visceral adipose tissue, thereby promoting inflammation [**?**]. Clinical evidence suggests that the sharp decline in estrogen levels after menopause weakens its protective effect on the vascular endothelium [**?**], thus increasing cardiovascular risk. In this study, 90% of the female participants were over 40 years old, with most being perimenopausal or postmenopausal, which further validates this perspective.

This study has certain limitations. First, as a single-center clinical study, it is subject to regional limitations; therefore, the reliability of the conclusions needs to be confirmed by large-sample, multi-center research results. Second, this study did not systematically collect information regarding patients' medication use. Given that various drugs, such as sodium-glucose cotransporter 2 (SGLT2) inhibitors, have clear effects on cardiac function, the heterogeneity and dynamic changes in medication regimens constitute potential residual confounding factors. Finally, the clinical guiding value of CVAI still requires further exploration through cohort studies.

In summary, CVAI is an independent risk factor for LVDD in patients with T2DM, and its effects exhibit significant heterogeneity across gender and age. CVAI has the potential to serve as a simple tool for assessing cardiac function risk in T2DM patients, which is particularly valuable in resource-limited areas. For female and younger diabetic patients, early control of visceral fat accumulation through lifestyle interventions may delay the onset of LVDD.

Author Contributions: Li Yachan proposed the primary research objectives and was responsible for the conception, design, and implementation of the study, as well as drafting the manuscript. Li Yachan and Xu Qianting performed data collection, organization, statistical processing, and the creation and presentation of figures and tables. Yang Yang was responsible for revising the manuscript. Ke Tingyu was responsible for quality control and review of the article, held overall responsibility for the manuscript, and provided supervision and management.

The authors declare no conflicts of interest.

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Note: Figure translations are in progress. See original paper for figures.