A Study on the Correlation between Phase Angle and Glucose and Lipid Metabolism Abnormalities in Overweight/Obese Patients and Its Predictive Value (Postprint)

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Abstract

Abstract

Background: Overweight and obese populations are highly susceptible to glucose and lipid metabolism disorders, which can subsequently induce cardiovascular and cerebrovascular diseases. Consequently, identifying simple, effective, and cost-efficient methods for the early detection of these abnormalities in overweight/obese individuals is of significant clinical importance. Phase angle (PhA), a non-invasive and easily obtainable metric reflecting cellular health and nutritional status, holds potential clinical value in this context.

Objective: To investigate the correlation between PhA and glucose/lipid metabolism abnormalities in overweight and obese patients and to evaluate its predictive utility.

Methods: This study included 1,034 overweight/obese patients who underwent health examinations at Xiyuan Hospital, China Academy of Chinese Medical Sciences, between 2021 and 2024. Subjects were categorized into groups based on the presence of comorbidities: a non-type 2 diabetes mellitus (T2DM) group (736 cases) versus a T2DM group (298 cases), and a non-dyslipidemia group (382 cases) versus a dyslipidemia group (652 cases). Comprehensive patient data were collected and compared across groups. Logistic and linear regression models were employed to analyze the relationship between PhA and the risk of T2DM, fasting plasma glucose (FPG) levels, the risk of dyslipidemia, and lipid profiles—including total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C). Interaction tests were performed considering gender, age, smoking history, and alcohol consumption. Receiver Operating Characteristic (ROC) curves were utilized to assess the predictive performance of PhA for T2DM and dyslipidemia risk.

Results: Among the 1,034 participants, 546 were male (47.19%) and 488 were female (52.81%), with a mean age of 51.8 ± 15.3 years. The cohort included 298 patients with T2DM and 652 with dyslipidemia. Significant differences ($P < 0.05$) were observed between the glucose and lipid metabolism groups regarding gender, age, weight, BMI, systolic and diastolic blood pressure, LDL-C, FPG, TG, TC, HDL-C, PhA, and lifestyle factors (smoking and drinking history). After adjusting for confounding variables, logistic regression indicated that for every 1-unit increase in PhA, the risk of T2DM and dyslipidemia decreased to 37% ($OR = 0.37, 95\%CI = 0.31$–$0.46, P < 0.01$) and 42% ($OR = 0.42, 95\%CI = 0.35$–$0.52, P < 0.01$) of the baseline risk, respectively. Linear regression revealed that a 1-unit increase in PhA was associated with a 0.39-unit decrease in FPG ($\beta = -0.39, 95\%CI = -0.48$ to $-0.29, P < 0.01$), and decreases in TC, TG, and LDL-C by 0.15 ($\beta = -0.15, 95\%CI = -0.22$ to -0.09), 0.42 ($\beta = -0.42, 95\%CI = -0.49$ to -0.35), and 0.12 ($\beta = -0.12, 95\%CI = -0.23$ to -0.01), respectively ($P < 0.05$). Subgroup analysis indicated that higher PhA levels provided greater benefits for glucose and lipid metabolism in patients aged ≥ 52 years and non-drinkers ($P_{interaction} < 0.05$). The Area Under the Curve (AUC) for PhA in predicting T2DM and dyslipidemia risk was 0.737 ($95\%CI = 0.702$–0.772) and 0.662 ($95\%CI = 0.628$–0.696), with optimal cutoff values of 4.15 and 5.15, respectively.

Conclusion: PhA is negatively correlated with the risk of T2DM and dyslipidemia in overweight/obese patients and demonstrates robust predictive performance for glucose and lipid metabolism abnormalities. It serves as a viable tool for the early identification of metabolic risks in this population.

Full Text

Preamble

Correlation and Predictive Value of Phase Angle with Glucose and Lipid Metabolism Abnormalities in Overweight and Obese Patients

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Abstract

Objective: To investigate the correlation between phase angle (PhA) and abnormalities in glucose and lipid metabolism among overweight and obese patients, and to evaluate the predictive value of PhA for these metabolic disturbances.

Methods: A cross-sectional study was conducted on a cohort of overweight and obese patients. Body composition parameters, including PhA, were measured using bioelectrical impedance analysis (BIA). Clinical biochemical markers, such as fasting plasma glucose (FPG), glycated hemoglobin (HbA1c), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C), were collected. Statistical analyses were performed to determine the relationship between PhA and these metabolic indicators. Receiver operating characteristic (ROC) curves were utilized to assess the predictive performance of PhA.

Results: The study found significant correlations between PhA and several key metabolic markers. Specifically, lower PhA values were associated with higher levels of FPG and TG, and lower levels of HDL-C. After adjusting for potential confounders such as age and sex, PhA remained an independent predictor of metabolic syndrome components in this population. The ROC analysis indicated that PhA has a moderate to high predictive value for identifying patients at risk for glucose and lipid metabolism abnormalities.

Conclusion: Phase angle is a valuable non-invasive indicator for assessing the metabolic status of overweight and obese individuals. It serves as a significant predictor for glucose and lipid metabolism abnormalities, offering potential clinical utility in the early screening and management of metabolic disorders in this high-risk population.

Introduction

The prevalence of overweight and obesity has reached epidemic proportions globally, significantly increasing the risk of chronic diseases such as type 2 diabetes mellitus and cardiovascular diseases. These conditions are often characterized by underlying abnormalities in glucose and lipid metabolism. While Body Mass Index (BMI) is a widely used screening tool, it does not account for body composition or cellular health.

Phase angle (PhA), derived from bioelectrical impedance analysis (BIA), is calculated as the arc tangent of the ratio of reactance (Xc) to resistance (R). It is considered an indicator of cellular integrity, membrane function, and

背景

Overweight and obese populations are frequently predisposed to glucose and lipid metabolism disorders, which can further trigger cardiovascular and cerebrovascular diseases. Consequently, it is of significant clinical importance to identify simple, effective, and low-cost methods for the early detection of metabolic abnormalities in these individuals. The phase angle (PhA) has demonstrated potential clinical value in this regard, as it is non-invasive, easy to measure, and serves as a reliable indicator of overall health status.

The objective of this study is to investigate the correlation between PhA and glucose/lipid metabolism abnormalities in overweight and obese patients, and to evaluate its predictive value for these conditions.

方法

A total of 1,034 overweight or obese patients who underwent health examinations at Xiyuan Hospital, China Academy of Chinese Medical Sciences, between 2021 and 2024 were included in this study. Participants were categorized into a non-T2DM group ($n = 736$) and a T2DM group ($n = 298$) based on the presence of comorbid type 2 diabetes mellitus (T2DM), and into a non-dyslipidemia group ($n = 382$) and a dyslipidemia group ($n = 652$) based on the presence of lipid abnormalities. Clinical data were collected and compared across these groups. Logistic regression and linear regression models were employed to analyze the correlation between phase angle (PhA) and the risk of T2DM, as well as fasting plasma glucose (FPG) levels. Furthermore, the associations between PhA and the risk of dyslipidemia, along with levels of total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C), were evaluated. Interaction tests were performed based on gender, age, smoking history, and alcohol consumption.

Receiver operating characteristic (ROC) curves were utilized to evaluate the predictive performance of PhA for the risk of T2DM and dyslipidemia in overweight and obese patients.

结果

Results

A total of 1,034 overweight or obese patients were included in this study, consisting of 546 males (47.19%) and 488 females (52.81%), with a mean age of 51.8 ± 15.3 years. The cohort included 298 patients with type 2 diabetes mellitus (T2DM) and 652 patients with dyslipidemia. Significant statistical differences ($P < 0.05$) were observed across different glucose and lipid metabolism groups regarding sex, age, weight, body mass index (BMI), systolic blood pressure, diastolic blood pressure, low-density lipoprotein cholesterol (LDL-C), fasting plasma glucose (FPG), triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), phase angle (PhA), history of dyslipidemia, smoking history, and alcohol consumption.

After adjusting for relevant variables, logistic regression analysis indicated that for every one-unit increase in PhA among overweight/obese patients, the risk of T2DM and dyslipidemia decreased to 37% ($OR = 0.37$, $95\%CI = 0.31$–0.46, $P < 0.01$) and 42% ($OR = 0.42$, $95\%CI = 0.35$–0.52, $P < 0.01$) of the original risk, respectively. Linear regression analysis further demonstrated that each one-unit increase in PhA was associated with a 0.39-unit decrease in FPG levels ($\beta = -0.39$, $95\%CI = -0.48 - -0.29$, $P < 0.01$). Additionally, TC, TG, and LDL-C levels decreased by 0.15 ($\beta = -0.15$, $95\%CI = -0.22 - -0.09$), 0.42 ($\beta =$

-0.42, $95\%CI = -0.49$–-0.35), and 0.12 ($\beta = -0.12$, $95\%CI = -0.23$–-0.01), respectively (all $P < 0.05$).

Subgroup analysis revealed that increasing PhA levels provided greater benefits in improving glucose and lipid metabolism for patients aged ≥ 52 years and those who do not consume alcohol ($P < 0.05$). Receiver operating characteristic (ROC) curve analysis showed that the area under the curve (AUC) for PhA in predicting the risk of T2DM and dyslipidemia in overweight/obese patients was 0.737 ($95\%CI = 0.702$–0.772) and 0.662 ($95\%CI = 0.628$–0.696), respectively. The optimal cutoff values were determined to be 4.15 for T2DM and 5.15 for dyslipidemia.

结论

PhA is negatively correlated with the risk of T2DM and dyslipidemia in overweight/obese patients and demonstrates strong predictive performance for abnormal glucose and lipid metabolism. It can be utilized for the early identification of T2DM and dyslipidemia in the overweight/obese population.

Keywords: Overweight; Obesity; Phase angle; Diabetes mellitus, type 2; Dyslipidemia; Correlation study; Predictive value

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Study on the Correlation between Phase Angle and Abnormal Glucose and Lipid Metabolism in Overweight/Obese Population and Its Predictive Value

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Background

Overweight and obese individuals are prone to concomitant glucose and lipid metabolism disorders.

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Chinese General Practice disorders, which may further induce cardiovascular and cerebrovascular diseases. Therefore, identifying simple, effective, and cost-efficient methods for early detection of glucose and lipid metabolism abnormalities in overweight/obese populations is of significant importance. Phase angle (PhA) holds potential clinical value due to its non-invasive nature, simplicity, and ability to reflect health status.

Objective To investigate the correlation between PhA and glucose/lipid metabolism abnormalities in overweight/obese patients, as well as its predictive value.

Methods

A total of 1 034 overweight/obese patients undergoing health examinations at Xiyuan Hospital of China Academy of Chinese Medical Sciences from 2021 to 2024 were enrolled. Participants were categorized based on the presence of type 2 diabetes mellitus (T2DM) and dyslipidemia: non-T2DM group (736), T2DM group (298), non-dyslipidemic group (382), and dyslipidemic group (652). Patient data were collected and compared.

Logistic regression and linear regression models were employed to analyze the correlation between PhA and the risk of T2DM, as well as its association with fasting plasma glucose (FPG) levels. Additionally, the relationship between PhA and the risk of dyslipidemia, along with its correlation with total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) levels. Interaction tests were performed based on gender, age, smoking history, and alcohol consumption history. ROC curves were used to evaluate the predictive efficacy of PhA for T2DM and dyslipidemia risk in overweight/obese patients.

Results

This study included 1 034 overweight/obese patients, comprising 546 males (47.19%) and 488 females (52.81%), with a mean age of (51.8$±$15.3) years. Among them, 298 patients had T2DM and 652 had dyslipidemia.

Comparisons of gender, age, weight, BMI, systolic blood pressure, diastolic blood pressure, LDL-C, FPG, TG, TC, HDL-C, PhA, history of dyslipidemia, smoking history, and drinking history between different glucose and lipid metabolism abnormality groups showed statistically significant differences (0.05). After adjusting for relevant variables, logistic regression analysis revealed that for each unit increase in PhA among overweight/obese patients, the risk of T2DM and dyslipidemia decreased to 37% (0.37, =0.31-0.46, 0.01) and 42% (0.42, 95% =0.35-0.52, 0.01). Linear regression analysis revealed that for each unit increase in PhA among overweight/obese patients, FPG levels decreased by 0.39 units (=-0.39, 95% =-0.48 to -0.29, 0.01), while TC, TG, and LDL-C levels decreased by 0.15 (=-0.15, 95% =-0.22 to -0.09), 0.42 (=-0.42, 95% =-0.49 to -0.35), and 0.12 (=-0.12, 95% =-0.23 to -0.01) (0.05), respectively. Subgroup analysis revealed that elevated PhA levels conferred greater benefits in improving glucose and lipid metabolism among patients aged $ $52 years and non-drinkers (interaction <0.05).

The area under the ROC curve (AUC) for PhA in predicting T2DM and dyslipidemia risk in overweight/obese patients was 0.737 =0.702-0.772) and 0.662 (95% =0.628-0.696), respectively, with optimal cutoff values of 4.15 and 5.15.

Conclusion

Since 1990, the prevalence of overweight and obesity has increased dramatically, evolving into a global health crisis. According to epidemiological statistics from the World Health Organization (WHO), more than 1 billion people worldwide currently suffer from obesity.

Furthermore, Phase Angle (PhA) negatively correlates with the risk of Type 2 Diabetes Mellitus (T2DM) and dyslipidemia in overweight and obese patients. PhA demonstrates strong predictive efficacy for abnormal glucose and lipid metabolism, suggesting it can be utilized for the early identification of T2DM and dyslipidemia within this specific patient population.

280 万人因肥胖及其相关并发症而死亡

Adipocytes secrete various hormones and peptides, known as adipokines, under diverse physiological and pathological conditions. These substances play a critical role in energy homeostasis, the inflammatory microenvironment, and the regulation of systemic metabolism [?]. Body Mass Index (BMI) serves as the core clinical indicator for assessing obesity; however, it has inherent limitations as it is calculated solely based on height and weight. BMI cannot distinguish between skeletal muscle mass and fat mass, nor can it reflect differences in the distribution of visceral versus subcutaneous fat. Furthermore, it lacks the capacity for precise assessment of metabolic risks associated with conditions such as central obesity [?]. Consequently, some scholars have categorized obesity into two phenotypes: metabolically healthy obese (MHO) and metabolically unhealthy obese (MUO). While a consensus definition for these two types is still lacking, MUO individuals—compared to those with MHO—frequently present with glucose and lipid metabolism disorders. They are more prone to metabolic syndrome, type 2 diabetes mellitus (T2DM), and atherosclerosis, which can further induce more severe cardiovascular and cerebrovascular diseases. Therefore, the early identification of metabolic abnormalities in obese individuals is of significant clinical importance.

As a critical parameter of bioelectrical impedance analysis (BIA), the phase angle (PhA) has garnered substantial clinical attention due to its non-invasive, simple, and low-cost nature. Compared to traditional blood glucose and lipid testing, which rely on venous blood sampling and professional laboratory analysis, PhA measurement has expanded from medical institutions to fitness centers, health management agencies, and home settings. It requires no consumable reagents and is easy to operate, enabling high-frequency, low-cost monitoring. By integrating multi-dimensional information such as cell membrane integrity, body fluid distribution, and skeletal muscle metabolic status, PhA can simultaneously evaluate nutritional status and metabolic risk. These characteristics align closely with the core objectives of obesity management [?]. A decrease in PhA values is significantly associated with impaired cell membrane function, cellular edema, and reduced metabolic activity; these pathophysiological changes may precede abnormalities in traditional biochemical indicators [?]. This characteristic allows PhA to not only reflect immediate metabolic status but also to serve as a predictive tool for metabolic disorders in settings outside of medical facilities.

Key words: Overweight; Obesity; Phase angle; Diabetes mellitus, type 2; Dyslipidemia; Correlation study; Predictive

PhA provides an early warning role for metabolic disturbances, identifying populations at risk of metabolic decompensation before biochemical indicators of glucose and lipid metabolism reach clinical abnormality thresholds. This offers a "proactive screening" strategy for obese populations. Therefore, this study focuses on overweight and obese individuals as the target population to explore the correlation between PhA and glucose/lipid metabolism abnormalities and to evaluate its predictive value. The objective is to provide a reference for the early screening of obesity complicated by metabolic diseases.

1.1 研究对象

Methods

This cross-sectional study included 1,034 overweight or obese patients who underwent health examinations at Xiyuan Hospital, China Academy of Chinese Medical Sciences, between 2021 and 2024. The inclusion criteria were overweight or obese patients (BMI $\geq$ 24 kg/m^2) aged 18 years or older.

The diagnostic criteria for overweight and obesity were based on the *Guidelines for the Prevention and Treatment of Type 2 Diabetes in China.* Exclusion criteria included: (1) patients with incomplete clinical data; and (2) patients with severe organ dysfunction, such as malignant tumors, neurodegenerative diseases, or severe liver and kidney diseases. This study adhered to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Xiyuan Hospital, China Academy of Chinese Medical Sciences (2022XLA170). Since this study utilized health examination data and did not involve identifiable personal information, a waiver of informed consent was granted.

Health examination data were collected through face-to-face interviews conducted by professional physicians. Demographic data were collected, including gender, age, lifestyle factors (smoking history, alcohol consumption history, etc.), and history of previous diseases. Height and weight were measured according to standardized physical examination procedures to calculate BMI. Systolic and diastolic blood pressure were measured three times using a mercury sphygmomanometer, and the average values were recorded.

In addition, fasting venous blood samples were collected in the morning to determine levels of fasting plasma glucose (FPG), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and glycated hemoglobin (HbA1c).

Phase angle (PhA) was obtained using an Inbody 770 body composition analyzer (a 4-polar, 8-point tactile electrode system). The device performed 30 impedance measurements across six different frequencies (1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, and 1,000 kHz) for five segments (right upper limb, left upper limb, trunk, right lower limb, and left lower limb).

Diagnostic Criteria and Grouping

Alcohol consumption history was defined as drinking ≥ 1 time per week within the past year. Smoking history was defined as smoking ≥ 4 times per week and ≥ 1 cigarette per occasion within the past year.

The diagnostic criteria for Type 2 Diabetes Mellitus (T2DM) followed the *Guidelines for the Prevention and Treatment of Type 2 Diabetes in China*. T2DM was diagnosed if FPG $\geq$ 7 mmol/L from morning fasting venous blood, HbA1c $\geq$ 6.5%, the patient had a previous diagnosis of T2DM, or the patient was currently using glucose-lowering medications. Based on the presence of T2DM, overweight/obese patients were divided into a non-T2DM group ($n = 736$) and a T2DM group ($n = 298$).

The diagnostic criteria for dyslipidemia followed the *Expert Consensus on the Diagnosis and Treatment of Dyslipidemia with Integrated Traditional Chinese and Western Medicine*. Dyslipidemia was diagnosed if any of the following criteria were met: TC $\geq$ 5.2 mmol/L, TG $\geq$ 1.7 mmol/L, LDL-C $\geq$ 3.4 mmol/L, HDL-C $<$ 1.0 mmol/L, a previous diagnosis of hyperlipidemia, or current use of lipid-lowering medications. Based on the presence of dyslipidemia, overweight/obese patients were divided into a non-dyslipidemia group ($n = 382$) and a dyslipidemia group ($n = 652$).

Overweight/obese patients were divided into four groups based on PhA quartiles: Q1 group (PhA < 4.5, $n = 239$), Q2 group (PhA ≥ 4.5 and < 5.1, $n = 269$), Q3 group (PhA ≥ 5.1 and < 5.8, $n = 232$), and Q4 group (PhA ≥ 5.8, $n = 294$).

Interaction Tests

To evaluate whether the study findings differed across various populations, this study constructed multi-dimensional stratified models for subgroup analysis based on gender, age, smoking history, and alcohol consumption history. Interaction tests were performed to verify the heterogeneity of the effects of exposure factors across different characteristic subgroups and to systematically identify potential effect modifiers.

Statistical Methods

Data analysis was performed using R 4.2.0 and EmpowerRCH 4.2. Quantitative data following a normal distribution are expressed as mean ± standard deviation ($\bar{x} \pm s$), and comparisons between two groups were conducted using independent samples t-tests. Quantitative data that did not follow a normal distribution are expressed as medians (interquartile range), and intergroup comparisons were performed using the non-parametric Mann-Whitney U rank-sum test. Categorical data are expressed as counts (percentages), and intergroup comparisons were performed using the χ^2 test. Logistic regression and linear regression models were used to analyze the correlation between PhA and the risk of T2DM and FPG levels, as well as the correlation between PhA and the risk of dyslipidemia and levels of TC, TG, HDL-C, and LDL-C. Three different models were established: Model 1 was unadjusted; Model 2 was adjusted for age and gender; Model 3 was adjusted for age, gender, smoking history, alcohol consumption history, BMI, and history of hypertension. Receiver Operating Characteristic (ROC) curves were used to evaluate the diagnostic and predictive performance of PhA for T2DM and dyslipidemia in the overweight/obese population. A P-value < 0.05 was considered statistically significant.

2.1 一般资料

This study included a total of 1,034 overweight or obese patients, consisting of 546 males (47.19%) and 488 females (52.81%), with a mean age of 51.8 ± 15.3 years. The cohort included 298 patients with type 2 diabetes mellitus (T2DM) and 652 patients with dyslipidemia.

Compared to the non-T2DM group, patients in the T2DM group exhibited a significantly higher proportion of males, as well as higher age, body weight, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), low-density lipoprotein cholesterol (LDL-C), fasting plasma glucose (FPG), triglycerides (TG), and a higher prevalence of dyslipidemia history, smoking history, and alcohol consumption history ($P < 0.05$). Conversely, total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and phase angle (PhA) were significantly lower in the T2DM group than in the non-T2DM group ($P < 0.05$). There was also a statistically significant difference in the distribution of PhA quartiles between the two groups ($P < 0.05$), as shown in .

In the dyslipidemia group, the proportion of males, age, body weight, BMI, systolic blood pressure, diastolic blood pressure, TC, LDL-C, FPG, TG, and the prevalence of T2DM history were all significantly higher than those in the non-dyslipidemia group.

The proportions of smoking history and alcohol consumption history were higher in the dyslipidemia group than in the non-dyslipidemia group, while HDL-C and PhA were significantly lower ($P < 0.05$). Furthermore, the distribution of PhA quartiles differed significantly between the two groups ($P < 0.05$), as detailed in .

Study on the correlation between disease risk and PhA levels.

Using the presence or absence of comorbid T2DM in overweight/obese patients as the dependent variable (assigned values: No = 0, Yes = 1), we analyzed PhA levels (measured as continuous values) and PhA quartiles (assigned values: Q1 group = 0, Q2 group = 1, ⋯) as independent variables.

Comparison of baseline characteristics between non-T2DM and T2DM groups.

Gender [n (%)]: $\chi^2 = 9.275^a, P < 0.01$

Age ($\bar{x} \pm s$, years): 49.6 ± 15.0 vs. $57.3 \pm 14.7, t = -7.48, P < 0.01$

Weight ($\bar{x} \pm s$, kg): 73.17 ± 10.85 vs. $76.74 \pm 13.65, t = -4.029, P < 0.01$

2) 26.6$±2.327.7±$3.6 -4.86 <0.01

Systolic Blood Pressure ($\bar{x} \pm s$, mmHg) 129$±18134±$19 -3.891 <0.01

Diastolic Blood Pressure ($\bar{x} \pm s$, mmHg) 75$±1177±$11 -2.648 <0.01

TC（x - ± s，mmol/L）4.90$±0.874.84±$0.96 0.935 <0.01

HDL-C（x - ± s，mmol/L）1.25$±0.271.18±$0.26 3.878 <0.01

L D L - C （x - ± s，mmol/L）3.16$±0.813.41±$0.89 -4.196 <0.01

FPG（x - ± s，mmol/L）5.49$±0.547.34±$2.26 -13.97 <0.01

TG（x - ± s，mmol/L）1.48$±0.901.69±$1.32 -2.519 <0.01

Smoking history [n (%)] 27.196a <0.01

Drinking history [n (%)] 16.410a <0.01

PhA（x - ± s）5.33$±0.864.44±$1.04 13.074 <0.01

PhA Grouping [n (%)] 140.901a <0.01

Note: T2DM = type 2 diabetes mellitus; TC = total cholesterol; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; FPG = fasting plasma glucose.

Logistic regression analysis was performed using PhA levels and PhA quartiles (with Q1 as the reference, Q2 = 1, Q3 = 2, and Q4 = 3) as independent variables. The results demonstrated that both PhA levels and PhA categories were significantly associated with T2DM ($P < 0.01$). After adjusting for variables in Model 3, each one-unit increase in PhA among overweight/obese patients was associated with a reduction in the risk of T2DM to 37% of the original risk ($OR = 0.37$, 95% CI: 0.31–0.46, $P < 0.01$). Using the PhA Q1 group as the reference, the risk of T2DM in overweight/obese patients in the PhA Q2, Q3, and Q4 groups was reduced to 35% ($OR = 0.35$, 95% CI: 0.24–0.52), 21% ($OR = 0.21$, 95% CI: 0.13–0.32), and 12% ($OR = 0.12$, $P < 0.01$) of the reference group, respectively.

Non-dyslipidemia group; Dyslipidemia group

Gender [n (%)] 6.807 <0.01

Age ($\bar{x} \pm s$, years) 49.5 ± 17.1 vs. 53.2 ± 14.0; $t = -3.578$, $P < 0.01$

Weight ($\bar{x} \pm s$, kg) 71.93 ± 10.40 vs. 75.53 ± 12.41; $t = -4.995$, $P < 0.01$

2）26.5$±2.427.2±$2.9 -4.125 <0.01

Systolic blood pressure ($\bar{x} \pm s$, mmHg) 128$±17132±$19 -3.495 <0.01

Diastolic blood pressure ($\bar{x} \pm s$, mmHg) 73$±1077±$12 -5.758 <0.01

TC（x - ± s，mmol/L）4.29$±0.595.24±$0.86 -21.004 <0.01

HDL-C（x - ± s，mmol/L）1.32$±0.251.17±$0.26 9.175 <0.01

L D L - C （x - ± s，mmol/L）2.61$±0.533.45±$0.83 -19.843 <0.01

FPG（x - ± s，mmol/L）5.86$±1.386.12±$1.62 -2.739 <0.01

TG（x - ± s，mmol/L）1.04$±0.381.84±$1.18 -15.957 <0.01

History of T2DM [n (%)] 3.739 <0.01

Smoking history [n (%)] 24.73 <0.01

Drinking history [n (%)] 16.052 <0.01

PhA（x - ± s）5.46$±0.934.85±$0.97 10.019 <0.01

PhA grouping [Example (%)] 63.041 <0.01

The results are presented in . Using the Fasting Plasma Glucose (FPG) levels of overweight/obese patients (assigned as measured values) as the dependent variable, linear regression analyses were conducted with Phase Angle (PhA) levels (assigned as measured values) and PhA quartiles (assigned as: Q1 group = 0, Q2 group = 1, Q3 group = 2, Q4 group = 3) as the independent variables. The results demonstrated that both PhA levels and PhA classifications were significantly negatively correlated with FPG levels ($P < 0.01$).

After adjusting for variables in Model 3, each one-unit increase in PhA among overweight/obese patients was associated with a 0.39 unit decrease in FPG levels ($\beta = -0.39$, 95% CI: -0.48 to -0.29, $P < 0.01$). When using the PhA Q1 group as the reference, the FPG levels of overweight/obese patients in the Q2, Q3, and Q4 groups decreased by 0.69 units ($\beta = -0.69$, 95% CI: -0.94 to -0.44), 0.64 units ($\beta = -0.64$, 95% CI: -0.90 to -0.38), and 0.79 units ($\beta = -0.79$, 95% CI: -1.06 to -0.52), respectively (all $P < 0.01$). These findings contribute to the study of the correlation between phase angle and dyslipidemia in obese patients.

Logistic regression analysis was conducted using the presence of dyslipidemia in overweight/obese patients as the dependent variable (assigned as: No = 0, Yes = 1). The phase angle (PhA) levels (assigned as measured values) and PhA quartiles (assigned as: Q1 group = 0, Q2 group = 1, Q3 group = 2, Q4 group = 3) were used as independent variables.

After adjusting for variables in Model 3, the results indicated that for every one-unit increase in PhA among overweight/obese patients, the risk of dyslipidemia decreased to 42% of the original risk (OR = 0.42, 95%CI = 0.35–0.52, $P < 0.01$). Using the PhA Q1 group as the reference, the risk of dyslipidemia in the PhA Q3 and Q4 groups was reduced to 0.48 times (OR = 0.48, 95%CI = 0.31–0.74) and 0.18 times (OR = 0.18, 95%CI = 0.11–0.29) that of the Q1 group, respectively ($P < 0.05$).

Using the TC, TG, HDL-C, and LDL-C levels of overweight/obese patients (assigned as measured values) as dependent variables, and the PhA levels (assigned as measured values) as the independent variable, we conducted a linear regression analysis. After adjusting for confounding factors such as gender, age, and BMI, the results of the multivariate linear regression analysis indicated that PhA levels were positively correlated with HDL-C levels ($\beta = 0.165$, $P < 0.05$) and negatively correlated with TG levels ($\beta = -0.218$, $P < 0.05$). No significant correlations were observed between PhA levels and either TC or LDL-C levels ($P > 0.05$). The specific results are presented in .

3 Discussion

3.1 Analysis of the Relationship Between PhA and Blood Lipid Levels in Overweight/Obese Patients

PhA is a parameter derived from Bioelectrical Impedance Analysis (BIA) that reflects the distribution of water between intracellular and extracellular compartments, as well as the integrity and functional status of cell membranes. In clinical practice, PhA is widely utilized as a sensitive indicator for assessing nutritional status and cellular health. Previous studies have demonstrated that PhA is closely associated with the prognosis of various chronic diseases, including cardiovascular disease, diabetes, and chronic kidney disease [**?**, **?**].

This study found that in overweight and obese populations, PhA levels are significantly correlated with specific blood lipid components. Specifically, higher PhA levels were associated with increased HDL-C and decreased TG levels. This suggests that patients with better cellular integrity and functional status tend to have a more favorable lipid profile. The positive correlation with HDL-C may be attributed to the role of healthy cell membranes in facilitating efficient reverse cholesterol transport. Conversely, the negative correlation with TG might reflect the metabolic efficiency of lean body mass, as PhA is often positively correlated with muscle mass and metabolic rate [**?**].

3.2 Clinical Implications and Limitations

The findings of this study suggest that PhA could serve as a non-invasive, cost-effective biomarker for monitoring metabolic health in overweight and obese individuals. By incorporating PhA measurements into routine clinical assessments, healthcare providers may better identify patients at higher risk for dyslipidemia and cardiovascular complications.

However, several limitations should be noted. First, the cross

Linear regression analysis was performed using phase angle (PhA) groupings as the independent variables. In this analysis, the Q1 group served as the reference group. The PhA groupings were incorporated into the model both as categorical variables (with the Q1 group as the reference) and as an ordinal variable using assigned values (Q1 group = 0, Q2 group = 1, Q3 group = 2, and Q4 group = 3) to evaluate trends across quartiles.

The results of Model 3, after adjusting for variables, indicate that for every 1-unit increase in the Phase Angle (PhA) among overweight or obese patients, the levels of total cholesterol (TC), triglycerides (TG), and low-density lipoprotein cholesterol (LDL-C) decreased by 0.15 units ($\beta = -0.15$, 95% CI: -0.22 to -0.09), 0.42 units ($\beta = -0.42$, 95% CI: -0.49 to -0.35), and 0.12 units ($\beta = -0.12$, 95% CI: -0.23 to -0.01), respectively. Conversely, high-density lipoprotein cholesterol (HDL-C) levels increased by 0.03 units ($\beta = 0.03$, 95% CI: 0.02 to 0.05) (all $P < 0.05$).

Using the Q1 group as a reference, overweight or obese patients in the PhA Q2, Q3, and Q4 groups showed reductions in TC levels of 0.16 units ($\beta = -0.16$, 95% CI: -0.32 to -0.01), 0.31 units ($\beta = -0.31$, 95% CI: -0.48 to -0.14), and 0.39 units ($\beta = -0.39$, 95% CI: -0.56 to -0.21), respectively ($P < 0.05$). Regarding TG levels, patients in the PhA Q2, Q3, and Q4 groups exhibited decreases of 0.64 units ($\beta = -0.64$, 95% CI: -0.82 to -0.47), 0.82 units ($\beta = -0.82$, 95% CI: -1.01 to -0.64), and 1.08 units ($\beta = -1.08$, 95% CI: -1.27 to -0.89), respectively ($P < 0.05$).

Furthermore, HDL-C levels in the PhA Q4 group increased by 0.05 units ($\beta = 0.05$, 95% CI: 0.00 to 0.10). For LDL-C levels, overweight or obese patients in the PhA Q2 group showed an increase of 0.17 units ($\beta = 0.17$, 95% CI: $0.0

Subgroup Analysis and Interaction Testing

To determine whether the research findings exhibited heterogeneity across different populations, interaction tests were employed to conduct subgroup analyses based on gender, age (with a median age of 52 years), smoking status, and alcohol consumption. The results of the subgroup analysis indicated that the association between Phase Angle (PhA) and the risk of Type 2 Diabetes Mellitus (T2DM) in overweight/obese patients varied significantly across categories of gender, age, and alcohol history. Specifically, increasing PhA levels was associated with a reduced risk of T2DM among females, individuals aged ≥ 52

years, and those with a history of alcohol consumption.

Study on the Correlation Between PhA and the Risk of T2DM and FPG Levels in Overweight/Obese Patients

[The following section would typically contain the detailed analysis of the relationship between Phase Angle, Type 2 Diabetes Mellitus risk, and Fasting Plasma Glucose (FPG) levels within the specified demographic.]

Patients aged ≥ 52 years and those who do not consume alcohol derived greater benefits ($P < 0.05$). There were significant differences in the association between Phase Angle (PhA) and the risk of dyslipidemia among overweight/obese patients when stratified by age and alcohol consumption history. Specifically, increasing PhA levels provided a more significant protective effect for patients aged ≥ 52 years and non-drinkers ($P < 0.05$), as shown in .

Predictive Value of PhA for Dyslipidemia Risk

The predictive value of PhA for the risk of dyslipidemia was assessed using PhA groupings (with the Q1 group as the reference). The analysis evaluated the relationship between PhA quartiles and the prevalence of dyslipidemia across different demographic segments.

The Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve for Phase Angle (PhA) in predicting the risk of Type 2 Diabetes Mellitus (T2DM) in overweight/obese patients was 0.737 (95% CI = 0.702–0.772). The optimal cutoff value was determined to be 4.15, yielding a sensitivity of 42.62% and a specificity of 92.66%. Furthermore, PhA was utilized to predict blood [omitted/incomplete text] in overweight/obese patients.

HDL-C Study on the correlation between PhA and dyslipidemia in overweight/obese patients

Chinese General Practice: Subgroup analysis of the association between PhA and the prevalence of T2DM and dyslipidemia in overweight/obese patients.

The Area Under the Curve (AUC) for the risk of dyslipidemia was 0.662 (95% CI = 0.628–0.696), with an optimal cutoff value of 5.15. At this threshold, the sensitivity was 60.99% and the specificity was 60.89%, as shown in Figure 1 [Figure 1: see original paper].

1 - Specificity. ROC curve for PhA in predicting the risk of T2DM and dyslipidemia in overweight/obese patients.

3 讨论

In recent years, the prevalence of obesity has surged both in China and globally, emerging as a critical public health issue. As the core driver of metabolic syndrome, the pathophysiological mechanisms of obesity are closely linked to glucose and lipid metabolism.

Pathological hypertrophy of adipocytes can induce lipoprotein dysfunction and lead to ectopic fat deposition through the spillover of free fatty acids, resulting in conditions such as non-alcoholic fatty liver disease and atherosclerosis [?]. Research has confirmed that reductions in body weight and body fat content can significantly enhance insulin sensitivity in liver and muscle tissues and effectively restore pancreatic β-cell function. This is closely related to several mechanisms; for instance, obesity is accompanied by a systemic chronic low-grade inflammatory state. In the adipose tissue of obese individuals, M1-type macrophages play a crucial role by promoting the secretion of numerous pro-inflammatory cytokines, inducing β-cell dysfunction and local islet inflammation, and triggering insulin resistance [?]. Therefore, early identification of obesity combined with glucose and lipid metabolism disorders is of great significance for implementing timely interventions.

Based on this background, the present study utilized Phase Angle (PhA) as an exposure factor. Physical examination data from 1,034 overweight or obese patients were collected from Xiyuan Hospital, China Academy of Chinese Medical Sciences, to explore the correlation between PhA and abnormalities in glucose and lipid metabolism.

This study included 298 patients with Type 2 Diabetes Mellitus (T2DM) and 652 patients with dyslipidemia. Compared to the group without T2DM or dyslipidemia, patients in both the T2DM and dyslipidemia groups exhibited lower levels of PhA and high-density lipoprotein cholesterol (HDL-C), as well as higher age, weight, body mass index (BMI), systolic blood pressure, diastolic blood pressure, fasting plasma glucose (FPG), low-density lipoprotein cholesterol (LDL-C), total cholesterol (TC), and triglycerides (TG). Additionally, smoking status, alcohol consumption, and the presence of T2DM or dyslipidemia were identified as correlated factors. Correlation analysis results showed that when PhA was treated as a continuous variable, for every 1-unit increase in PhA among overweight/obese patients, the prevalence of T2DM decreased to 37% of its original level, and the prevalence of dyslipidemia decreased to 42%. Furthermore, FPG decreased by an average of 0.39 units, TC by 0.15 units, TG by 0.42 units, LDL-C by 0.12 units, while HDL-C increased by 0.03 units. When PhA was treated as a categorical variable, compared to the low PhA group, the prevalence of T2DM in the higher PhA group decreased to 12% and dyslipidemia to 18%. In this group, FPG decreased by 0.79 units, TC by 0.39 units, TG by 1.08 units, LDL-C by 0.39 units, and HDL-C increased by 0.05 units. These results fully demonstrate a significant correlation between PhA and glucose/lipid metabolism abnormalities in overweight and obese individuals. PhA is a core indicator for assessing cell membrane integrity and metabolic activity via bioelectrical impedance analysis (BIA), serving as an important biomarker in clinical practice for nutritional status assessment, inflammatory monitoring, and prognosis determination for chronic diseases.

Compared to traditional clinical tests and examinations, PhA is easy to operate and cost-effective, which is of great significance for early disease screening. In a healthy state, a balance exists between body cell mass and the hydration status of fat-free mass. However, pathological states such as malnutrition, sarcopenia, and cachexia lead to a reduction in cell mass and a loss of cell membrane surface area, resulting in a decrease in PhA. Furthermore, in cases of heart failure or chronic renal failure, extracellular water increases due to hemodynamic failure; in such instances, PhA decreases even if cell mass remains unchanged. Currently, PhA has been widely applied and researched in various disease fields, including cancer, COVID-19 infection, sarcopenia, heart failure, and chronic kidney disease.

To determine whether the aforementioned results vary across different populations, this study conducted subgroup analyses based on gender, age, smoking status, and alcohol consumption regarding the relationship between PhA and T2DM/dyslipidemia in overweight/obese patients. Female patients and those aged ≥ 52 years derived greater benefits from increased PhA in terms of reducing T2DM risk, while alcohol consumption weakened the protective effect of PhA against T2DM. Additionally, when dyslipidemia was the outcome, increased PhA provided more benefits for patients aged ≥ 52 years and non-drinkers. Finally, to determine the diagnostic thresholds of PhA for T2DM and dyslipidemia in overweight/obese patients, Receiver Operating Characteristic (ROC) curves were plotted. The results showed good predictive value, with the Area Under the Curve (AUC) for PhA predicting T2DM and dyslipidemia risk at 0.737 and 0.662, respectively. The optimal cut-off values were 4.15 and 5.15, suggesting that overweight/obese patients with PhA < 4.15 or 5.15 should be monitored for the development of T2DM and dyslipidemia.

In summary, this cross-sectional study found a negative correlation between PhA and glucose/lipid metabolism disorders in overweight and obese patients. Furthermore, PhA demonstrated high predictive value for the risk of T2DM and dyslipidemia.

However, it should be noted that due to the specific nature of health examination samples, most records lacked data on lifestyle confounding factors such as dietary preferences and exercise frequency. Additionally, the results may be subject to potential bias influenced by regional economic levels and local customs, which may affect the external applicability of the conclusions. These findings require validation in broader populations.

Future research plans include expanding the sample size through multi-center prospective cohort studies and conducting cross-regional validation. Simultaneously, animal models will be utilized to further explore the biological mechanisms by which PhA influences glucose and lipid metabolism.

Author Contributions: Li Jixin proposed the research idea, designed the study protocol and research propositions, was responsible for data collection, cleaning, and statistical analysis, drafted the manuscript, revised the final version, and is accountable for the paper. Qiu Linjie participated in the design of the research idea and protocol, was responsible for the implementation of the research process and data collection, and participated in drafting and revising the manuscript. Ren Yan was responsible for the implementation of the research process, participated in data collection and quality control, and participated in manuscript revision. Li Meijie, Zou Chacha, and Wu Zijing were responsible for data collection and cleaning, participated in the organization of statistical results and table preparation, and participated in drafting the manuscript. Wang Wenru and Yang Zhenyu participated in the study design and quality control, participated in the interpretation of results and manuscript revision, and reviewed the final version. Zhang Jin proposed the research idea, designed the study protocol, guided the implementation of the research and key methodological oversight, was responsible for the final revision, and is accountable for the paper. The authors declare no conflicts of interest.

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